Postharvest Handling

A Systems Approach

Third Edition

Edited by

Wojciech J. Florkowski, Robert L. Shewfelt,
Bernhard Brueckner and Stanley E. Prussia

Postharvest Handling

This page intentionally left blank

Postharvest Handling
A Systems Approach

Third Edition

Edited by

Wojciech J. Florkowski
University of Georgia, Griffin, GA, USA

Robert L. Shewfelt
University of Georgia, Athens, GA, USA

Bernhard Brueckner
Institute for Vegetable and Ornamental Crops (IGZ), Germany

Stanley E. Prussia
University of Georgia, Griffin, GA, USA

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Academic Press is an imprint of Elsevier

Academic Press is an imprint of Elsevier
525 B Street, Suite 1800, San Diego, CA 92101-4495, USA
32 Jamestown Road, London NW1 7BY, UK
225 Wyman Street, Waltham, MA 02451, USA

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-408137-6

For information on all Academic Press publications
visit our website at http://elsevierdirect.com

Printed and bound in the United States of America

14 15 16 17 18 10 9 8 7 6 5 4 3 2 1

Dedication

The third edition of this book is dedicated
in memory of Dr. Tommy Nakayama, Food Science and Technology
in honor of Dr. Brahm Verma, Biological and Agricultural Engineering
in memory of Dr. Joseph C. Purcell, Agricultural and Applied Economics,
of the University of Georgia Experiment Station, Griffin, Georgia, USA
and
in honor of Dr. Jürgen Weichmann of the Technical University
Munich, Germany.

Tommy Nakayama and Brahm Verma had the vision to develop a collaborative research project between food science and engineering and hired a scientist and an engineer to turn the vision into a reality.
Joseph C. Purcell encouraged the economists he hired to be actively involved in extending economic knowledge to ongoing projects in production and postharvest research.
Jürgen Weichmann constantly inspired his team of young scientists to uncover physiological plant processes, essential to improve postharvest technology.
Without their vision and confidence in us, this book would not have been written.

This page intentionally left blank

Contents

This page intentionally left blank

Preface

This book is the 3rd revised edition of the book titled “Postharvest Handling: A Systems Approach” published originally in 1993. The application of systems thinking and the systems approach to postharvest handling of fresh fruits and vegetables generates a continued interest and stimulates interdisciplinary research on the topic. Since the publication of the 2nd edition, the systems approach has been proposed for the study of food and development policy.

The systems approach offers a technique needed to address the increasing complexities of modern world problems, and is a tacit admission of inadequate solutions of real world problems through the application of a strictly disciplinary approach. The disciplinary approach will remain important, but the practical use of such solutions calls for placing them in the context of the actual situation and accounting for direct and increasingly important indirect effects on other players in the fresh fruit and vegetable industry.

Since the 2nd edition of the book, the world consumption of fresh fruits and vegetables has increased. The international trade in fresh fruit has been growing quite rapidly, increasing the importance of rules, regulations, temperature regimes and legal responsibilities because the value of the shipped fresh produce is high. The variety of issues in terms of postharvest handling, packing, transporting, tracing the path of fresh produce, retailing and addressing sustainability has increased as the population of consumers expands worldwide and becomes increasingly diversified in terms of their ability to purchase and their preferences.

The systems approach remains relevant to fresh fruit and vegetable supply value chains for delivering the quality desired by consumers. As in the previous editions, the team of authors made their contributions to the current version. We continue to struggle with the shaping of a common vision of the industry, while sharing the recognition of the systems approach as the single vision driving our individual efforts. We intend to apply this approach while being open to new perspectives as the world around the fruit and vegetable industry changes. In recent years, progress has been uneven across various disciplines engaged in the delivery of quality fresh produce to consumers. That uneven progress is reflected in the content of the current edition in comparison to the 2nd edition.

The daily consumption of fresh fruit and vegetables continues to fall short of the recommended level in many countries of the world. We note in the current edition that the source of variation in consumption is not limited to disposable income, but it is influenced by a number of factors. Household fresh fruit consumption differs from vegetable consumption and poses a challenge to suppliers and postharvest researchers. Consumers remain the key to the sustained economic success of the fresh fruit and vegetable industry and will remain the focus of the industry.

Consumer and household diversification offers earlier absent opportunities for trade and marketing requiring specific handling procedures, selection of distribution channels, focus on quality, but also poses new challenges in terms of protecting quality in shipping and finding solutions for trade disputes. These new developments expand rather than limit the application of the systems approach, and this revised and updated book emphasizes this message to audiences around the world; from players in the private and public sector to students and researchers in academic and government institutions.

List of Contributors

Nigel H. Banks
Postharvest.Co Limited, New Zealand

Frank Bollen
Zespri International Ltd, Mt Maunganui, New Zealand

Claudio Bonghi
DAFNAE, University of Padova, Italy

Jacobus J. Bouwer
Koos Bouwer Consulting, Welgemoed, Cape Town, South Africa

Bernhard Brueckner
Leibniz-Institute for Vegetable and Ornamental Crops (IGZ), Grossbeeren, Germany

Inge Bulens
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Ray Collins
School of Food and Agricultural Sciences, University of Queensland, Australia

Carlos H. Crisosto
Department of Plant Sciences, University of California, Davis, CA, USA

Josse De Baerdemaeker
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Bart De Ketelaere
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Malcolm C. Dodd
Department of Horticultural Science, Stellenbosch University, Stellenbosch, South Africa

Jean-Pierre Emond
Electro-Optical Systems Laboratory, Georgia Tech Research Institute, Atlanta, GA, USA

Elazar Fallik
ARO – The Volcani Center, Department of Postharvest Science of Fresh Produce, Bet Dagan, Israel

Wojciech J. Florkowski
Department of Agricultural and Applied Economics, The University of Georgia, Griffin, GA, USA

Emanuela Fontana
Emanuelafontana.com Consulting, Vinovo (Torino), Italy

Shengfei Fu
Department of Agricultural and Applied Economics, The University of Georgia, Athens, GA, USA

Maarten L.A.T.M. Hertog
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Anna M. Klepacka
Faculty of Production Engineering, Warsaw University of Life Sciences-SGGW, Warsaw, Poland

Jeroen Lammertyn
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

George A. Manganaris
Department of Agricultural Sciences, Biotechnology & Food Science, Cyprus University of Technology, Lemesos, Cyprus

Ting Meng
Department of Agricultural and Applied Economics, The University of Georgia, Athens, GA, USA

Padmanand Madhavan Nambiar
Department of Agricultural and Applied Economics, The University of Georgia, Athens, GA, USA

Bart M. Nicolaï
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Silvana Nicola
Department of Agricultural, Forest and Food Sciences – AgriForFood, DISAFA, Università di Torino, Grugliasco (Torino), Italy

Sompoch Noichinda
Division of Agro-Industrial Technology, Faculty of Applied Science, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

Cristian M. Ortiz
LIPA: Laboratorio de Investigación en Productos Agroindustriales Universidad Nacional de La Plata, Argentina y Centro de Investigación y Desarrollo en Criotecnología de Alimentos, CIDCA (CONICET-UNLP), La Plata, Argentina

Stanley E. Prussia
University of Georgia, College of Engineering, Griffin, GA, USA

Wouter Saeys
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Daniel B. Sarpong
University of Ghana-Legon, Ghana

Rob E. Schouten
Group HPC: Horticultural Production Chains, Wageningen University and Research, Wageningen, The Netherlands

Sholomo Sela
Postharvest Science of Fresh Produce, Agricultural Research Organization, The Volcani Center, Israel

Ghanna Sheremenko
Department of Agricultural and Applied Economics, The University of Georgia, Athens, GA, USA

Robert L. Shewfelt
Food Science and Technology, University of Georgia, Athens, GA, USA

Anna L. Snowdon
University of Cambridge, Wolfson College, Cambridge, UK

Gabriel O. Sozzi
Consejo Nacional de Investigaciones Científicas y Técnicas, Ciudad de Buenos Aires, Argentina

Sara A. Sparks
Thermo Pac, Stone Mountain, Georgia

Leopold (Pol) M.M. Tijskens
Group HPC: Horticultural Production Chains, Wageningen University and Research, Wageningen, The Netherlands

Pietro Tonutti
Institute of Life Science, Scuola Superiore Sant'Anna, Pisa, Italy

Pieter Verboven
Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

Ariel R. Vincente
LIPA: Laboratorio de Investigación en Productos Agroindustriales Universidad Nacional de La Plata, Argentina y Centro de Investigación y Desarrollo en Criotecnología de Alimentos, CIDCA (CONICET-UNLP), La Plata, Argentina

Kerry B. Walsh
Plant Sciences Group, Central Queensland University, Rockhampton, Queensland, Australia

Wendy V. Wismer
Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada

Chalermchai Wongs-Aree
Postharvest Technology Program, School of Bioresources and Technology, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

CHAPTER

Postharvest Systems – New Contexts, New Imperatives

1

Nigel H. Banks
Postharvest.Co Limited, www.postharvest.co

Because Mandalay mango bliss is a secret you have yet to taste
Because cassava is the staple food of fungi at the factory gate
Because the cries of a thousand million hungry need to find an ear
Because my world warms on the fumes of fretting fruit
Because green potatoes are bitter as death
Because a grower yearns to dispatch Heaven to Tokyo
Because the gourmet in Tokyo imagines still so much more
Because one in three food darts never hits the board
Because her lettuce waits and wilts patiently in the cold and dark
We are postharvesters with purpose and time is almost out ....

The world has changed

The last edition of this volume was published just four years ago. Since that time, a series of well-researched articles have reached very similar, very disturbing conclusions that dramatically reframe the challenges for those designing, developing and innovating postharvest systems (Buzby and Hyman, 2012; FAO, 2013; Gooch et al., 2010; Gustavsson et al., 2011; Institution of Mechanical Engineers, 2013; Lipinski et al., 2013; Parfitt et al., 2010; Value Chain Management Center, 2012; Vermeulen et al., 2012; World Bank, 2011). In 2009, a reasonable and responsible stretch goal might have been for all supply systems to focus on achieving "managed scarcity" of greatly enhanced value versions of the products they conveyed. Systems focused in this way looked likely to secure improved products for consumers and enhanced returns for growers, delivering a better world for both. Now, the larger systems view informed by these recent studies makes it clear that the challenges we face are much more profound and intractable.

Despite the ever-increasing sophistication and integration of some parts of the food supply system, overall levels of postharvest food wastage are of the order of 30% (Gustavsson et al., 2011). When assessed on a calorific basis, losses of the cereals figure most prominently, at 53% of the total wastage (Lipinski et al., 2013).

Postharvest Handling.

In contrast, when assessed by the same team from the point of view of loss of fresh weight, the high water content of fruits and vegetables means that they make up a stunning 64% of total food wastage. When we array all of this information up with the fact that agriculture is responsible for about a quarter of all greenhouse gas emissions (Vermeulen et al., 2012), we can see that postharvest inefficiency is single-handedly contributing perhaps even a double digit percentage of the greenhouse gas emissions that are widely believed to threaten both global ecology and economy.

On top of this, our world is:

- home to nearly a billion hungry people (Brown, 2011);
- needing to produce about 60% more food by 2050 to adequately support the projected increase in human population by that time (Lipinski et al., 2013);
- swept up in global system changes that threaten the sustainability of, let alone dramatic enhancements to, food production (Vermeulen et al., 2012).

Brown (2009) has suggested that unless the world actively cuts greenhouse gas emissions by 80% by 2020 — surely all but impossible at this juncture — increasing instability of climate will threaten food production systems in many parts of the world. At present, significant controversy still surrounds such propositions (Nongovernmental International Panel on Climate Change, 2013). Indeed, opinion is sufficiently divergent for it to have been proposed that useful increases in crop yields that may accompany further CO_2 enrichment of the global atmosphere could offset threats to food production capacity from global warming (Center for the Study of Carbon Dioxide and Global Change, 2013). At the same time, the growing volume of indicators of the instability in global climate (Intergovernment Panel on Climate Change, 2013) give real cause for concern that reliably feeding the burgeoning global human population could become a steepening challenge over the coming decades.

II Perspectives in a postharvest system

Unless participants in a postharvest system are communicating openly with each other, they are quite likely to start out with very different perspectives on what product features make for success:

- growers: high yields of highly valuable product;
- packhouse: consistently high external quality, well-storing product that is cheap to sort, grade, pack and store;
- distribution center manager: consistently high external quality product that has low levels of losses through the distribution phase and nil recalls;
- consumer: safe and nutritious product that eats as well as it looks;
- marketer: consistently superior quality product that is valued by consumers, is produced without glut by growers to achieve "managed scarcity" and achieves consistently high prices.

These perspectives can be consistent but at the same time, repeated sorting of product through the first three of these phases does not necessarily deliver product that automatically delivers on the promise sought by the consumer. Leadership at the level of the whole supply system is required for that to occur – a leadership that can often be found in a branded product because of the care invested by all system participants in maintaining the reputation of the brand.

III Concepts in postharvest systems

The term "postharvest" relates to the phase of a food supply system that connects the moment of harvest with the moment of consumption. A system is usually thought of as a set of things that work together as part of a mechanism that forms an integrated whole and is itself part of a network of other systems (Anon, 2013; Figure 1.1). A postharvest system is, therefore, a purposeful collection of participants, facilities, technologies and processes that deliver harvested products to their consumers. The systems view of postharvest handling was pioneered by the team at Georgia (Prussia et al., 1986; Prussia and Mosqueda, 2006). Now, nearly 30 years on, the discipline has matured and provides a sound platform for innovation in postharvest systems.

In the initial stages of establishing a new production and postharvest system, participants usually seek to define elements of "best practice" that will deliver a consistently high quality product. Best practice comprises a method or technique that consistently delivers superior results compared to those achieved by other

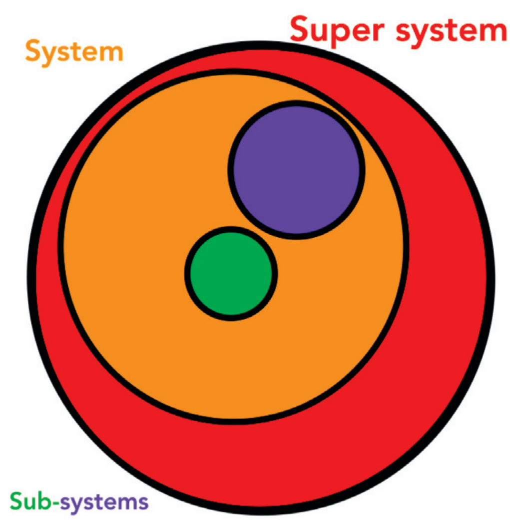

FIGURE 1.1

Conceptual relationships between a system, its sub-systems and its super-system.

means (http://en.wikipedia.org/wiki/Best_practice). A defined best practice is used as a benchmark of the way that things should be done.

A collection of such best practice processes forms the basis of a marketing and quality-assurance system (Figure 1.2) that enables standardization of the ways that a postharvest system is able to deliver product of desired quality to market (Carriquiry and Babcock, 2007). At the same time, best practice can evolve for the better through innovation – making changes to the standard way of doing something with the goal of making improvements. Combining operational excellence to achieve successful implementation of today's best practice together with the flexibility and conceptual insights to be able to continually innovate effectively, all in the context of robust market demand, are the hallmarks of successful new horticultural enterprises (Hewett, 2012).

The process of innovation connects physical systems with the conceptual models that describe our beliefs about the way that they work. Through innovation, a marketing and quality-assurance system becomes able to adjust itself on the basis of reflection – it becomes a "learning system" (Wysocki et al., 2006). Learnings develop through repeated, overlapping cycles in which participants:

- observe behaviors in the current system;
- analyze information gathered about these behaviors in relation to goals;
- integrate these new understandings into an overall conceptual model of system behavior;

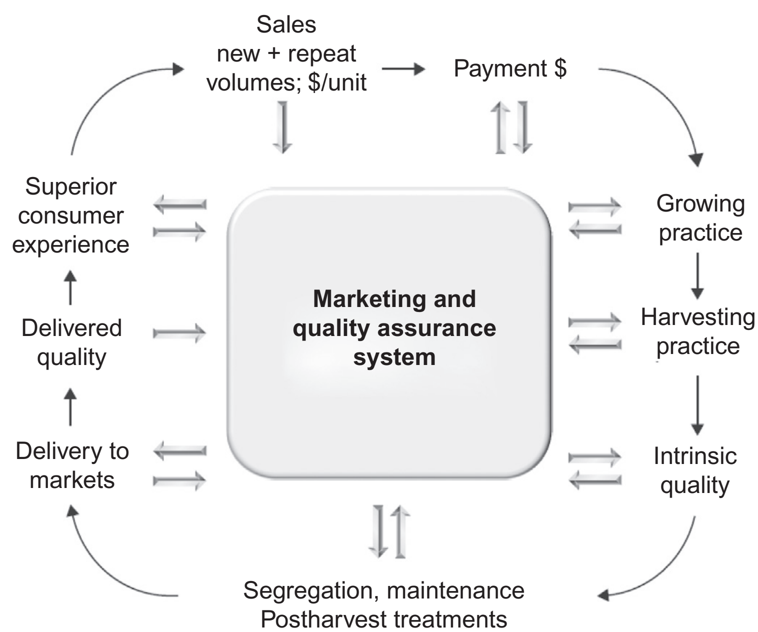

FIGURE 1.2

Flows of resources (outer flows: product, physical, financial) and information (inner flows) in the marketing and quality assurance system of a fresh produce supply system.

- design mechanisms and processes intended to improve upon the current system;
- apply these new approaches back into the system.

By repeated application of this learning cycle, innovation develops as the accumulation of changes that enhance overall system performance (Figure 1.3). An iterative process is also encouraged in the Soft Systems Methodology pioneered by Checkland (1999) for improving Human Activity Systems.

In his classic exposition of systems concepts, Senge (1990 and 2006) and Senge et al. (1994) outlined how a virtuous or self-reinforcing cycle develops when feedback from a process reinforces the forward rate of that same process (Figure 1.4). Postharvest systems develop a virtuous cycle when consumers are enabled to reward growers for delivering superior product.

Effective marketing and quality-assurance systems that create this responsiveness require that participants right through the system (growers, marketers, consumers, technologists and quality, operations and logistics managers) work in a coordinated way to:

- identify what makes a great eating experience;
- devise a measurement and rewards system for the key attributes of product that delivers a great eating experience;

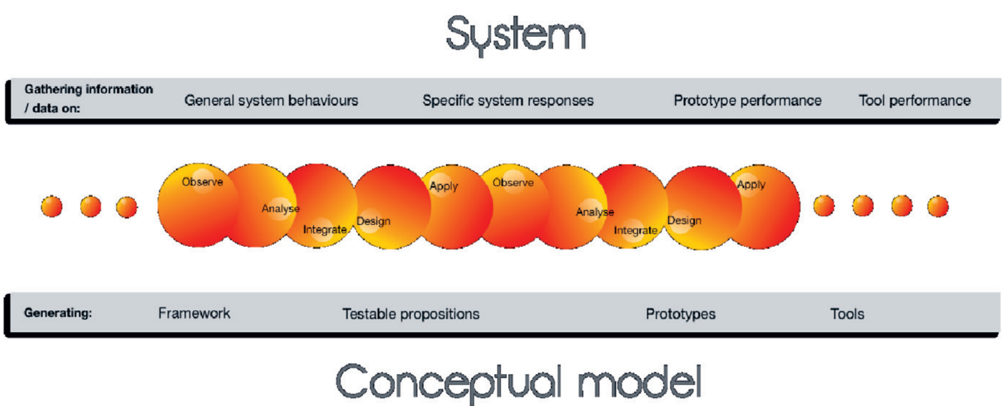

FIGURE 1.3

Innovation in postharvest systems.

© Postharvest.Co 2013.

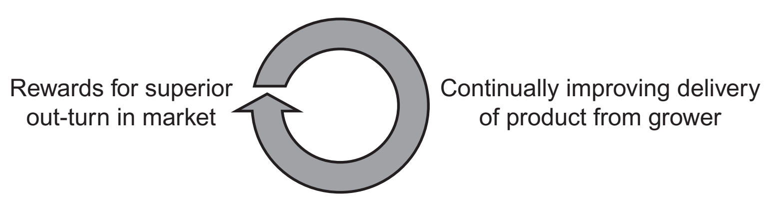

FIGURE 1.4

Virtuous cycle that supports continually improving quality of product delivered to market.

- develop ways to grow and deliver superior product;
- achieve and maintain high transparency concerning value, so that fairness can be seen to be dominant and trust emerges (Cadilhon et al., 2007; van der Vorst et al., 2007).

Once the postharvest system has these features, it is then equipped to develop the positive-feedback loop that comprises the virtuous cycle that can deliver extraordinary returns (Figure 1.4). The presence of a brand can further strengthen development of a virtuous cycle. For all participants in the supply system, a brand can function as a "virtual telescope" that connects them to other parts of the system, providing simplified information about a shared perspective on what is important to all who identify with the brand, supporting rapid decision making on values-based issues and building reputation throughout the supply chain (Florkowski, 2000).

For consumers, a brand helps them make purchasing choices in the context of an overload of information as they make fresh fruit purchases (Figure 1.5). Developing the trust that is important to the emergence of a virtuous cycle in a postharvest system has become easier since the advent of e-commerce, which makes transparent ethical business practice so critical in contemporary business practice (Fritz et al., 2007).

Whilst opportunities like these would in themselves provide a reasonable level of stretch for most postharvest systems, particularly those focused on developing high value trade for developing countries (Hewett, 2012), the publications of the last few years on the state of the world and its food production systems make clear that postharvesters need to tackle still more audacious goals.

Food wastage (see also Chapter 3) refers to any food lost by deterioration or waste and encompasses both food loss and food waste (Figure 1.6).

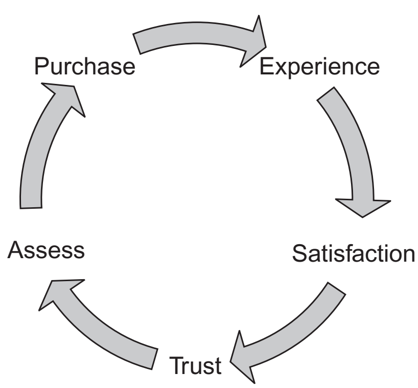

FIGURE 1.5

Learning with a brand: with each cycle of purchase and consumption, the consumer's level of trust in the brand promise is modified according to experience.

Simplified from: Andani and MacFie (2000).

FIGURE 1.6

Summaries of the new definitions of food losses and food waste published recently by FAO (2013).

Apart from the impact of natural disasters, FAO (2013) reports that food losses are largely caused by inefficiencies in food supply chains:

- poor infrastructure and logistics;
- lack of technologies, skills, knowledge and management;
- lack of access to markets.

In comparison, food waste occurs when products are:

- kept beyond their expiry dates or left to spoil;
- in oversupply;
- not interesting to consumers, either for purchase or for eating.

IV New goals for postharvest systems

In the past, innovation in postharvest systems – developing of branded points of difference and improved and safer eating experiences – has legitimately been focused upon improving the positioning of individual supply systems in relation to their competitors. This approach has required its own fair share of leadership: system participants have needed to adopt a “whole of supply system” perspective that enables them all to thrive together as a unit, rather than having each competing with neighbors in the flow of supply for what are perceived as scarce resources flowing through the system.

The abundance mentality (Covey, 1989) required to address the new goals for postharvest systems will demand a clear and re-defined sense of purpose — one based upon global good and a vision for outcomes that are only going to be available options for us for a limited period. In addition to addressing innovation that delivers continual evolution in individual postharvest systems and the quality of product that each delivers, globally responsive and responsible postharvest systems now also need to achieve innovation that retains more of the food produced by growers and facilitates more consumers eating a greater proportion of delivered food. In short, the improved systems will:

- lose less food;
- waste less food;
- distribute food more equitably.

Together, these innovations will reduce projected further increases in the burden of greenhouse gas emissions upon the global ecology.

This book outlines the principles and technologies by which health-giving fresh produce is currently delivered into the homes of people around the world. It also contains information upon which you will build your vision for the role you can play in innovating the world's postharvest systems. As you embark upon the adventure of digesting the diverse and amazing contents of this valuable volume, be prepared to consider how what you learn will enable you to inject leadership into the postharvest systems that you participate in — every month's delay now seriously erodes options for the future of your systems, the fate of a billion hungry people and the global ecology upon which we all depend — totally.

Bibliography

Andani, Z., MacFie, H.J.H., 2000. Consumer preference. In: Shewfelt, R.L., Bruckner, B. (Eds.), Fruit and Vegetable Quality. Technomic, Lancaster, PA, USA, pp. 158—177.

Anon, 2013. System. From; Dictionary/thesaurus, The Free Dictionary. <http://www.the-freedictionary.com/system> (accessed 24.10.13)

Brown, L.R., 2009. Plan B: Mobilizing to save civilization. <http://www.earth-policy.org/books/pb4> (accessed 11.01.14).

Brown, L.R., 2011. World on the Edge — How to Prevent Environmental and Economic Collapse. W.W. Norton & Company, New York, 327 pp.

Buzby, J.C., Hyman, J., 2012. Total and per capita value of food loss in the United States. Food Policy 37, 561—570.

Cadilhon, J.J., Fearne, A.P., Giac Tam, P.T., Moustier, P., Poole, N.D., 2007. Business-to-business relationships in parallel vegetable supply chains of Ho Chi Minh City (Viet Nam): reaching for better performance. In: Batt, P.J., Cadhilon, J.J. (Eds.), Proceedings of the International Symposium on Fresh Produce Supply Chain Management. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Publication 2007/21.

Carriquiry, M., Babcock, B.A., 2007. Reputations, market structure, and the choice of quality assurance systems in the food industry. Am. J. Agric. Econ. 89, 12–23.

Center for the Study of Carbon Dioxide and Global Change, 2013. CO_2 Science – Agriculture (Species – Wheat) – Summary (sic), 1 p. <http://www.co2science.org/subject/a/summaries/agriculturewheat.php> (accessed 8.11.2013).

Checkland, P., 1999. Systems Thinking, Systems Practice. John Wiley & Sons, Chichester, UK, 330 pp.

Covey, S.R., 1989. The Seven Habits of Highly Effective People. Free Press, 380 pp.

FAO, 2013. Food wastage footprint – impacts on natural resources, Summary Report, 2013, 61 pp. <http://www.fao.org/docrep/018/i3347e/i3347e.pdf>.

Florkowski, W.J., 2000. Economics of quality. In: Shewfelt, R.L., Bruckner, B. (Eds.), Fruit and Vegetable Quality. Technomic, Lancaster, PA, USA, pp. 227–245.

Fritz, M., Hausen, T., Schiefer, G., 2007. Trust and e-commerce in the agrifood industry: configuration of a trust environment for e-commerce activities. In: Theuvsen, L., Spiller, A., Peupert, M., Jahn, G. (Eds.), Quality Management in Food Chains. Wageningen Academic Publishers, The Netherlands, pp. 463–474.

Gooch, M., Felfel, A., Marenick, N., 2010. Food waste in Canada – Opportunities to increase the competitiveness of Canada's agri-food sector, while simultaneously improving the environment. Value Chain Management Centre, George Morris Centre, 16 pp. <http://vcm-international.com/wp-content/uploads/2013/04/Food-Waste-in-Canada-112410.pdf> (accessed 24.10.13).

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A., 2011. Global food losses and food waste – extent, causes and prevention. FAO, Rome, 29 pp. <http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf> (sic).

Hewett, E.W., 2012. High-value horticulture in developing countries: barriers and opportunities. CAB Review 16, 2012–No. 054.

Institution of Mechanical Engineers, 2013. Global food – waste not, want not, 31 pp. <http://www.imeche.org/docs/default-source/reports/Global_Food_Report.pdf> (accessed 8.11.13).

Intergovernment Panel on Climate Change, 2013. Summary for policymakers. Fifth Assessment Report, Working Group 1, 36 pp. <http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf> (accessed 08.11.13).

Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Searchinger, T., 2013. Reducing Food Loss and Waste. Working paper, Instalment 2 of: "Creating a sustainable future". World Resources Institute, Washington, D.C., <http://www.wri.org/publication/creating-sustainable-food-future-installment-two> (sic).

Nongovernmental International Panel on Climate Change, 2013. Climate change reconsidered II: physical science – executive summary, 5 pp. <http://heartland.org/media-library/pdfs/CCR-II/Executive-Summary.pdf> (accessed 08.11.13).

Parfitt, J., Barthel, M., Macnaughton, S., 2010. Food waste within food supply chains: quantification and potential for change to 2050. Philos. Trans. R. Soc. B 365, 3065–3081.

Prussia, S.E., Jordan, J.L., Shewfelt, R.L., Beverly, R.B., 1986. A systems approach for interdisciplinary postharvest research on horticulture crops. Georgia Agricultural Experimental Station Research Report No. 514. Athens, GA, USA.

Prussia, S.E., Mosqueda, M.R.P., 2006. Systems thinking for food supply chains: fresh produce applications. Proceedings of the Fourth International Conference on Managing Quality in Chains. Purves A.C., McGlasson W.B., Kanlayanarat, S. (Eds.) Acta Horticulturae, 712, 91–104.

Senge, P.M., 1990. The Fifth Discipline. The Art and Practice of the Learning Organisation. Random House, London, UK (445 pp in the 2006 edition).

Senge, P.M., Kleiner, A., Roberts, C., Ross, R.B., Smith, B.J., 1994. The Fifth Discipline FieldBook: Strategies and Tools for Building a Learning Organization. Random House, New York, 593 pp.

Value Chain Management Center, 2012. Cut waste, grow profit — How to reduce and manage food waste, leading to increased profitability and environmental sustainability, Value Chain Management Centre, George Morris Centre, 25 pp. <http://vcm-international.com/wp-content/uploads/2013/05/Cut-Waste-Grow-Profit-FINAL-DOCUMENT-Oct-3-121.pdf> (accessed 24.10.13).

van der Vorst, J.G.A.J., da Silva, C., Trienekens, J.H., 2007. Agro-industrial supply chain management: concepts and applications. Agriculture Management, Marketing and Finance Occasional Paper 17. FAO, Rome, Italy.

Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I., 2012. Climate change and food systems. Annu. Rev. Environ. Resour. 37, 195—222.

World Bank, 2011. Missing food: the case of postharvest grain losses in Sub-Saharan Africa. Report No. 60371-AFR, 96 pp. <http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10_web.pdf> (accessed 11.01.14).

Wysocki, A.F., Peterson, H.C., Harsh, S.B., 2006. Quantifying strategic choice along the vertical coordination continuum. Implications for agri-food chain performance. In: Ondersteijn, C.J.M., Wijnands, J.H.M., Huirne, R.B.M., van Kooten, O. (Eds.), Quantifying the Agri-Food Supply Chain. Springer, The Netherlands, pp. 173—188.

CHAPTER

Challenges in Handling Fresh Fruits and Vegetables

2

Robert L. Shewfelt[a], Stanley E. Prussia[a] and Sara A. Sparks[b]

[a]University of Georgia, Athens GA, [b]Product Development, Thermo Pac, Stone Mountain GA

I Introduction

Despite campaigns to consume more fresh fruits and vegetables, American consumers have shown little or no change in per capita consumption of fresh fruits (Figure 2.1) or vegetables (Figure 2.2) since 2000 (USDA ERS, 2012, 2013). Health concerns are the driving force for recommending increased fruit and vegetables in the dietary guidelines (USDA/HHS, 2005). Fruits and vegetables are low in calories and fats and are rich sources of nutrients, including dietary fiber, vitamins, and minerals. Unfortunately, American consumers are not making major shifts in their diets to fresh produce, and their selection is limited to a few popular fruits and vegetables (USDA ERS, 2012, 2013). They are consuming more fruits and vegetables in foodservice outlets (42% of the total), but retail markets still claim the biggest segment of the business (57%) with direct sales accounting for less than 2% (Cook, 2011).

Fresh fruits and vegetables displayed on supermarket shelves are unlike a fresh tomato grown in a backyard garden, picked at the peak of flavor, and eaten minutes after harvest. Before appearing in the supermarket display, a fruit or vegetable has taken a long and sometimes circuitous journey. Part of each shipment becomes unacceptable and is discarded at culling points within the system because of over-ripening and the development of physiological disorders, handling damage, visible decay, or other causes. Some of these losses are diverted to secondary markets. Estimates of postharvest losses in the United States of fresh fruits are 30% and vegetables are 32% when including waste by consumers (Buzby and Hyman, 2012). Losses in developing countries can exceed 50% from harvest to consumption (Wilson, 2013).

Since fresh produce is living, respiring tissue, physiological processes occurring between harvest and consumption can result in the loss of quality characteristics. In some cases, quality degradation leads to a discarded product, whereas in others it reduces consumer acceptability. Such losses are minimized by proper and efficient handling of the fruit or vegetable on the journey from farm to market. More subtle

Postharvest Handling.

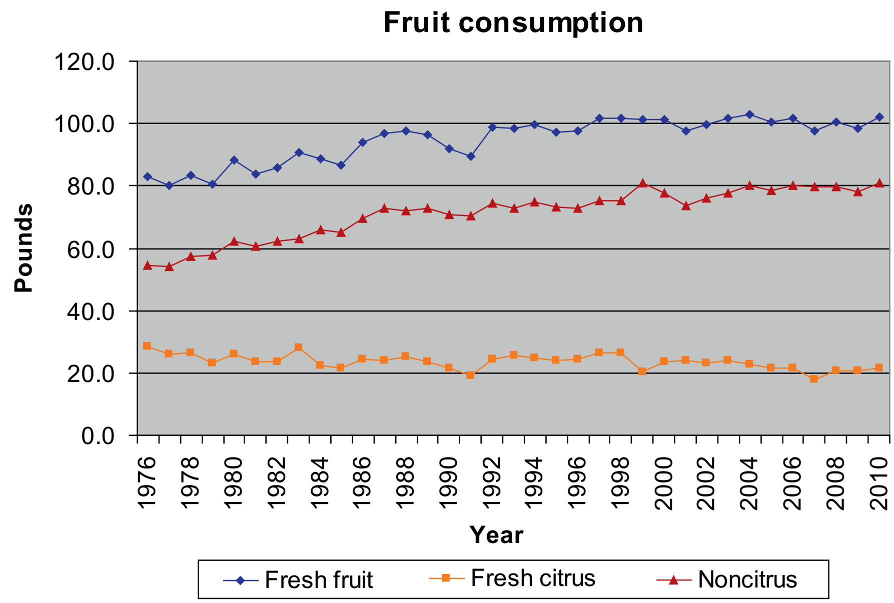

FIGURE 2.1

Changes in per capita use of citrus (■), noncitrus (▲) and total fresh fruit (♦) 1976–2010.

Adapted from Table A1 of USDA ERS (2012).

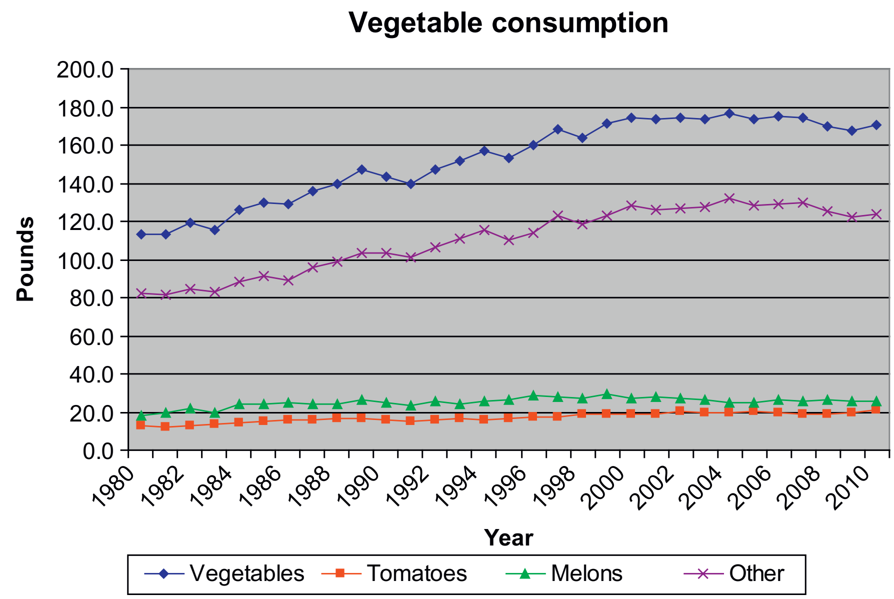

FIGURE 2.2

Changes in consumption of tomatoes (■), melons (▲), other vegetables (X) and total fresh vegetables (♦) 1980–2010.

Adapted from Table 2 of USDA ERS (2013).

losses of quality result from production, harvesting, and handling strategies that emphasize appearance at the expense of flavor and nutritional quality.

This edition of the book provides a rationale for the continued pursuit of a better understanding of postharvest handling, in order to reduce the losses of fresh fruits and vegetables from farm to consumer, as well as to improve quality and shelf life of these items when they reach the consumer. To achieve this goal, two disciplines have developed. Postharvest physiology seeks to understand the basic physiological changes and underlying mechanisms that occur in a detached plant organ during handling and storage. Postharvest technology seeks to understand the handling and storage conditions that lead to extended shelf life and better quality of harvested produce. This chapter:

- outlines current approaches to postharvest handling,
- describes progress toward a more integrated approach to postharvest research,
- emphasizes the importance of a systems approach, and
- illustrates continuing challenges in postharvest handling amenable to systems solutions.

II Handling of fruits and vegetables from farm to consumer

Scientific research is usually directed at narrowly defined problems using hypothesis testing or empirical observation to draw conclusions. Efficient handling and distribution of fresh fruits and vegetables is the direct result of the current understanding of postharvest physiology and the development of new technologies from narrowly focused studies. The first edition of this book (Shewfelt and Prussia, 1993) encouraged the development of a broader-based program. Before studying the handling system, we suggested that the component handling steps must be understood.

A Production phase operations

Although the emphasis of this book is postharvest handling, conditions in the field before harvest influence quality and shelf life after harvest. Genetic potential, growing conditions and cultural practices all influence quality at harvest as well as shipping and storage stability. Droby et al. (2009) call for a paradigm shift to a systems approach in production agriculture. The relationship between preharvest factors and postharvest quality is complex and not well understood. For example, Lee and Kader (2000) conclude that the vitamin C content of fruit and vegetable crops is affected by cultural factors, genotype and weather conditions. Woolf and Ferguson (2000) emphasize the critical role that preharvest temperature plays in the postharvest quality of fruits, such as avocado. Johnson and Hofman (2009) add pests and diseases during production to those factors affecting mango quality during postharvest storage. Prusky (2011) identifies climate, cultivation practices, mechanical damage, soil type and water supply as important factors affecting postharvest quality of flowers, fruits and vegetables.

Overuse of growth regulators during the growing phase of table grapes led to increased levels of gray mold and fine cracking during cold storage (Zoffoli et al., 2008). Application of auxin to zucchini plants increased fruit size but also increased their susceptibility to chilling injury (Martínez et al., 2012). Preharvest application of selected fungicides inhibited ripening, and thus postharvest quality of tomatoes (Domínguez et al., 2012). A low chemical production system improved quality of one cultivar of bananas but not of another when compared with a conventional production system (Ambuko et al., 2013). Increases in the levels of boron, calcium and potassium led to a firmer mango with higher soluble solids and improved color of the ripe fruit (Singh et al., 2013a).

Plant breeders must satisfy many requirements in the breeding and selection of commercial cultivars. Most importantly, a cultivar must produce high yields under a wide range of growing conditions. More emphasis is being placed on greater resistance to stress, disease and insects because of increasing consumer concern about the safety of agricultural chemicals. Uniformity of maturity at harvest permits the use of once-over harvest techniques. Resistance to mechanical damage during harvesting or subsequent handling operations improves shipping and storage stability. Flavor and nutrient composition are important to the consumer, but maintenance of acceptable appearance and firmness or turgor is more important to other buyers within the handling system. Achieving all these desirable characteristics in a single genotype is a difficult task; thus, a cultivar is usually judged by its most limiting characteristic.

Most commercial cultivars are selected primarily on the basis of potential yield over a range of growing conditions with the idea of maintaining an acceptable level of shipping quality. Biotechnological techniques such as cell culture and genetic engineering greatly accelerate the breeding and selection process. Cell culture techniques have the potential to provide a means of screening large numbers of genotypes for specific traits, but the journey from culture tube to stable, commercial cultivar is a long and difficult one. Advances in genetics and genetic engineering offer potential for improved quality, with major advances being made recently with melon (Cohen et al., 2012) and tomato (Mathieu et al., 2009).

Growing conditions play an important role in the postharvest performance of harvested crops. Preharvest stress conditions can affect the flavor, microbial quality and composition of a fruit or vegetable. Cultural practices are chosen for other reasons including maximizing yield, minimizing visual damage and improving efficiency of farm operations. Row spacing and training regimes facilitate field operations such as harvest or the application of agricultural chemicals. Growth regulators promote common growth patterns of crops, resulting in greater uniformity of maturity at harvest. The pressure to reduce the use of agricultural chemicals has resulted in the development of a strategy of Integrated Pest Management (IPM), which seeks to apply chemicals only when required to prevent economic damage

(Palumbo and Castle, 2009). IPM helps reduce pesticide use, but requires close monitoring and a good understanding of the biology of the crop and the pests.

B Harvest

By definition, postharvest handling begins at harvest. Numerous reviews emphasize the importance of the maturity of the crop at harvest for subsequent postharvest quality and shelf life (Nuñez-Palenius et al., 2008; Pohlan et al., 2008; Johnson and Hofman, 2009; Michailides and Manganaris, 2009; Singh and Khan, 2010; Pareek et al., 2011). Determination of the harvest date is based on yield, visual appearance, anticipated prices, estimated culling losses to achieve shipping quality and field conditions. Harvesting is accomplished by hand, by mechanically assisted picking devices or by mechanical harvesters. Robotics offers the long-term potential of combining the efficiency of machines with the selectivity of humans. Factors during harvesting operations that can influence postharvest quality include the degree of severity of mechanical damage induced by machine or human, the accuracy of selecting acceptable rather than unacceptable fruit, the time of day of harvest and the pulp temperature at harvest (Michailides and Manganaris, 2009; Prusky, 2011).

C Packing

Placement of the harvested crop into shipping containers is one of many activities described as packing operations. Packing may occur directly in the field or in specially designed facilities called packinghouses. Most packing operations include a means of removing foreign objects, sorting to remove substandard items, sorting into selected size categories, inspecting samples to ensure that the fruit or vegetable lot meets a specified standard of quality and packing into a shipping container. Some commodities are washed to remove soil and decrease the microbial load. Many commodities are precooled to remove field heat and slow physiological processes (Johnson and Hofman, 2009). Some special functions, such as the removal of trichomes (fuzz) from peaches, are also part of packing operations (Crisosto and Valero, 2008). Automation is now used in packing operations for apples, eggplants, leeks, oranges, pears and peaches (Kondo, 2010). Each operation is designed to achieve a product of uniform quality, but each handling step provides the opportunity to induce damage or disease.

D Transportation

The wide availability of fresh fruits and vegetables year-round, and the availability of items for sale where they cannot be grown is a triumph of modern transportation systems. The primary transportation step carries the crop from the growing region to the selling region. This trip may be cross-continent by truck or rail, overseas by ship or plane, or across the county line in a pickup truck. Minimizing mechanical damage, maintaining proper temperatures and ensuring commodity compatibility are the most important considerations in transportation operations. Mechanical damage occurs during loading, unloading and stacking operations, or from shock and vibration during transport (Aba et al., 2012). Shipment of a load at or near its optimal temperature is affected by the initial temperature, refrigeration capacity, condition of refrigeration equipment and degree of airflow around the product. Construction of the shipping container, proper alignment of the vent holes in the containers and use of approved and appropriate stacking patterns ensures adequate airflow. Attention must also be given to commodity compatibility within a load. Ethylene-sensitive commodities such as lettuce should not be shipped with ethylene generators such as apples (Ashraf et al., 2012).

Other transportation steps are also important in quality maintenance, for example, from field to packing facility and from wholesale distribution point to retail outlet. The principles that apply to long-distance shipments, also apply to short-distance ones, but handling practices tend to receive less attention when the shipping distance is short. Fields and rural roads are usually bumpier than highways; thus, vehicles hauling the harvested crop from field to packinghouse are generally not as capable of preventing shock and vibration damage as are tractor-trailer rigs. The delay of cooling of a crop is affected by the time required to load a vehicle in the field, the distance from field to packinghouse, the speed of the vehicle, and the number of vehicles waiting to be unloaded at the packinghouse. The trip from wholesale warehouse to retail outlet brings together a wide range of commodities arranged by store. Mechanical damage results from the shifting of loads in transport or crushing of cartons due to unconventional stacking of containers of differing sizes, shapes and strengths. Quality losses also can result from inadequate temperature control or product incompatibility. Even the most careful attention to proper stacking methods and proper temperature management can be defeated at the loading dock by rough handling or long delays in unrefrigerated conditions.

Local purchasing options are now being emphasized to improve the flavor and nutritional quality of fresh produce and do less damage to the environment (Wilson, 2013). The emphasis is on the reduction of food miles – the miles a food product travels from harvest to market (Mitra et al., 2011). As food miles decrease, the time between harvest and consumption should decrease, leading to less loss of vitamins and lower fossil fuel consumption. Local produce is more likely to be harvested at peak maturity, resulting in better flavor and higher vitamin content than when harvested in a less mature state (Chapter 11). The concept of food miles, however, is over-simplistic and may not accurately reflect the impact on quality or on carbon consumption. Fruits and vegetables picked at peak maturity also deteriorate more rapidly, particularly when not stored under optimal conditions, as is typical of local handling systems (Lee and Kader, 2000). In addition, the fuel efficiency of vehicles carrying smaller loads of produce to markets, and special trips in consumer's private vehicles to buy a single item or to shop at multiple markets for different items rather than one-stop shopping are likely to decrease the benefit of local products in terms of lower carbon dioxide emissions. Overseas shipment by ship and transport by rail are more energy-efficient than truck transport. Farming systems in Europe and North America are frequently more carbon-intensive than those in other growing locations, so even long shipments may represent a smaller carbon footprint than those grown locally (Saunders et al., 2006).

E Storage

Within the handling system, fruits and vegetables are placed in storage for a period of time ranging from few hours up to several months, depending on the commodity and storage conditions. Storage of a commodity serves as a means of extending the season, delaying marketing until prices rise, providing a reserve for more uniform retail distribution or reducing the frequency of purchase by the consumer or food service establishment. The commodity must have sufficient shelf life to remain acceptable from harvest to consumption.

The shelf life of a fruit or vegetable during storage is dependent on its initial quality, its storage stability, the external conditions and the handling methods. Shelf life can be extended by maintaining a commodity at its optimal temperature, relative humidity (RH) and environmental conditions, as well as by the use of chemical preservatives or gamma irradiation treatment (Lee and Kader, 2000). An extensive list of optimal storage temperatures and RHs with anticipated shelf life is available (Gross et al., 2004). Controlled atmosphere storage is a commercially effective means of extending the season of apples and many other crops (Thompson, 2010). Atmosphere modification within wholesale or retail packages is a further extension of this technology. Modification of the atmosphere is achieved by setting initial conditions and using absorbent compounds within the packaging to limit carbon dioxide (CO_2) and ethylene (C_2H_4) concentrations (Martínez-Romero et al., 2007). The use of gamma irradiation extends the shelf life of some commodities (Prakash et al., 2000; Arvanitoyannis et al., 2009). The application of 1-methylcylclopropene (1-MCP) can delay ripening by slowing respiration and volatile compound generation (De Martino et al., 2007).

Physiological disorders that reduce the acceptability of susceptible commodities can develop during storage. Chilling injury, i.e., damage incurred at low temperatures above the freezing point, leads to a wide range of quality defects (Butz et al., 2005; Singh and Singh, 2012). Crops also may be sensitive to high levels of CO_2 or C_2H_4, low levels of O_2, water stress due to high transpiration, high temperatures and irradiation (Kays and Paull, 2004).

F Retail distribution

The ultimate destination of most fresh fruits and vegetables is the retail market, where a consumer makes the final decision to accept or reject an individual item or packaged product. Retail distribution is the most visible of all handling steps, and frequently the least controlled. Merchandising displays are designed to enhance quick, impulsive purchases, not necessarily to maintain quality. Conditions within the outlet (temperature, RH, lighting), close display of incompatible commodities, length of exposure to conditions or incompatible commodities and the degree and severity of handling by store personnel or consumers all affect quality and acceptability. Addition of ice to lower temperatures and maintain high RH and timed water misting are examples of techniques used to maintain quality. The most effective way to prevent quality losses at retail, however, is a rapid turnover of stock on the shelves. Because it is the only part of the process most consumers see, retail distribution provides an excellent opportunity to communicate with the consumer.

III Toward a more integrated approach to handling

As a result of physiological and technological studies, guidelines for the efficient management of fresh fruits and vegetables are now available for each handling step described earlier. Although these guidelines are not always followed, postharvest technologists do have the knowledge of ways handle these produce items properly at each step. The basic premise of the first edition (Shewfelt and Prussia, 1993), however, was that many handlers of produce within the postharvest system do not have a good understanding of the interaction between these handling steps. Optimization of each handling step does not necessarily result in the best handling system. In extreme cases, an emphasis on individual handling steps results in poorer final quality. Questions raised in the first edition of the book about the inadequacy of conventional approaches are now being addressed by systems approaches.

In the first edition, the need for greater integration between preharvest factors and postharvest quality, effects of storage at nonoptimal temperature and the economic rewards of adopting new technology were emphasized. Recent studies (Zoffoli et al., 2008; Domínguez et al., 2012; Martínez et al., 2012; Ambuko et al., 2013; Singh et al., 2013a) and reviews (Johnson and Hofman, 2009; Michailides and Manganaris, 2009; Prusky, 2011) have emphasized the importance of preharvest factors and maturity on quality during postharvest handling and storage as described earlier in this chapter. The two other areas of questions that we posed have not been adequately addressed in the literature. Most studies still seek to determine optimal storage temperature (Singh and Khan, 2010; Johnston and Brookfield, 2012; Martínez et al., 2012) despite the exposure of items to temperatures that are not optimal in various handling steps (Toivonen and Lu, 2007). Large commercial firms who own all or most of the operations in the handling system and those who are a major buyer in a market can set quality standards and insist that specific technologies are adopted. In smaller handling systems, however, the incentives for an operator to adopt a specific technology may not be obvious (Hodges et al., 2011).

To answer these and other questions that require an understanding of the interaction of various handling steps, a greater integration of specialized expertise and research perspectives is still needed. We continue to advocate a greater emphasis on integrated studies between:

- postharvest technologists and postharvest physiologists,
- crop production (horticulture, entomology, pathology) and utilization (economics, engineering, food science) disciplines,
- researchers in universities, governmental agencies and commercial establishments,
- field and quality assurance departments within food processing companies, and
- business schools and businesses.

Such studies require a better definition of commercially relevant goals (economics, quality, shelf life) within the confines of environmental and economic constraints. An appeal to develop a common language for postharvest-handling studies by Shewfelt and Tijskens (2000) has been largely ignored. Also overlooked were recommendations by Prussia and Mosqueda (2006) to use systems thinking methodologies for integrating researchers with businesses, as were opportunities described by Collins (2010) for using the concept of the virtuous value cycle that allows individual firms to identify their potential as value chain partners, or groups of collaborating firms to evaluate their performance as a value chain. A basic premise of this chapter is that successful interaction of "basic" and "applied" research is synergistic. Technological problems require immediate attention, which stimulates basic inquiry into underlying physiological mechanisms. New basic knowledge suggests, in turn, new approaches and solutions to old problems.

With an improved knowledge of interactions between handling steps and a clearer understanding of the ultimate goals, vertically integrated handling systems within the supply chain can be developed that incorporate answers to the questions posed earlier (Figure 2.3). Traditional postharvest studies alone are not capable of answering these questions. The adoption of a systems approach can provide a context for future advances in postharvest science and its commercial application.

IV Challenges amenable to systems solutions

Research with fruits and vegetables (Prussia, 2000; Crisosto et al., 2006; Michailides and Manganaris, 2009; Kader, 2010; Kubota, 2012) reveals several critical problems that require systems studies in order to provide meaningful solutions. Particular

FIGURE 2.3

The integration of handling steps from farm to retail is the key to quality.

attention is required to identify conditions encountered in postharvest handling that affect consumer acceptability as well as preharvest factors that influence postharvest quality. Research challenges that are particularly amenable to systems solutions include stress physiology, quality management, marketing and food safety. It is also important that we recognize the benefits of appropriate technology for constrained handling systems and working at the interfaces of postharvest handling with the crop production and consumer handling systems.

A Stress physiology

An "aberrant change in physiological processes brought about by one or a combination of environmental biological factors" is known as the stress response (Hale and Orcutt, 1987). Almost any handling technique used to keep harvested crops fresh for an extended period of time causes some stress to that tissue. Temperature extremes, desiccation, microbial invasion, gaseous atmosphere, light and mechanical handling can all induce stress in harvested fruits or vegetables. Certain fruits and vegetables are more susceptible to disorders such as chilling, freezing and CO_2 injury than others. One complicating factor is that damage, such as bruising or chilling injury, may be incurred at one point in the system but not become evident until a later point. Whoever "owns" the item when damage becomes evident usually “pays”, rather than the “owner” when the damage was incurred. Many factors are implicated in the syndromes which are associated with stress response, but the physiological mechanisms of these responses remain elusive (Singh and Khan, 2010). Advances in molecular biology promise to provide techniques that will help unravel the physiological basis of quality degradation (Toivonen, 2006; Inaba, 2007; Johnston and Brookfield, 2012; Singh et al., 2013b).

B Quality management

Quality Assurance is an integral part of most manufacturing industries, including food processing. There has been less motivation to develop quality management programs for fresh produce than for other food items, but widely publicized food-poisoning outbreaks involving fresh produce (Hanning et al., 2009; Mota et al., 2009; Ma et al., 2010; Palma et al., 2010; Kozak et al., 2013) have led to increased scrutiny of fresh items. The primary differences between fresh and processed foods that affect quality management factors include the following:

- fresh fruits and vegetables are maintained in recognizable form whereas processed products are modified;
- variability in response to storage conditions among different items in the same lot is much greater in fresh fruits and vegetables than in processed products; and
- the relationship between physiological processes and food quality has not been defined clearly in many fresh fruits and vegetables.

The fruit and vegetable processing industry is able to avoid these problems by (1) treating the crop as raw material, thus mixing lots of varying composition to produce a product that meets uniform product specifications, and (2) inactivating physiological processes during food processing operations. Several articles have provided frameworks for the quality management of fresh produce (Brueckner, 2006; Fouayzi et al., 2006; Beuchat, 2007) including the implementation of HACCP plans (Tapia et al., 2009). A survey of the use of quality management techniques has been described by Kuepper and Batt (2012).

C Marketing

Fresh produce is a major profit center for supermarket food chains. Fierce competition among chains is changing the merchandising of fresh items. Brands are used in the marketing schemes of shippers directed at wholesale distributors, but whether brands will have an impact at retail distribution is still uncertain, with some studies suggesting that product quality is more important than branding (Bertazzoli et al., 2005) while others indicate that brand is an important factor in a purchase decision (Behe, 2006; Ekelund et al., 2007).

Display of consumer information, including nutritional composition, handling and preparation suggestions and point of origin are part of the merchandising process in many outlets. Retail distribution is arguably the most important step of the entire postharvest system for determining consumer acceptability, yet this step may be the least understood in physiological and technological terms.

D Food safety

The growing demand for fresh fruits and vegetables by health-conscious consumers also results in an increased concern about food safety. Media attention to the use of agricultural chemicals to maintain the "cosmetic" quality of fresh produce has heightened this concern. It is not clear how much pesticide use can be reduced without losing some visual quality of fresh fruits and vegetables, nor is it clear how reduced visual quality would affect consumption (Palumbo and Castle, 2009; Probst et al., 2010). Safety must become the responsibility of all handlers through the system, as contaminated items that are allowed to pass through an early step can lead to the spread of contamination later in their journey from farm to consumer.

It is becoming more apparent that the true safety dangers of fresh produce come from pathogenic microorganisms and not from pesticides (van Boxstael et al., 2013). Microbial food safety, largely ignored when the first edition of this book was published, is now considered the greatest challenge in the distribution of fresh items (Francis et al., 2012; Jacxsens et al., 2012; Soon et al., 2013; van Boxstael et al., 2013; Warriner and Namvar, 2013). Preharvest contamination from manure, sludge and runoff water is a major factor in outbreaks (Beuchat, 2006), but evidence is not conclusive regarding whether organic produce presents a greater risk of foodborne outbreaks (Magkos et al., 2006; Mukherjee et al., 2006; Bohaychuk et al., 2009; Maffei et al., 2013) and may be dependent on grower practices (Plotto and Narciso, 2006). Better control of irrigation water has been suggested as a means of decreasing changes of food-associated outbreaks from human pathogens (Plauborg et al., 2010; Gullino and Caprioli, 2013) or heavy metals (Avci, 2013). Sanitizers in the packinghouse can be effective for some items, but they should not be seen as a substitute for good sanitation practices within the handling system (Alvarado-Casillas et al., 2007). Refrigeration temperatures, once thought to guarantee the safety of fresh fruits and vegetables, do not protect fresh produce from psychrotropic pathogens such as *Listeria* (Koo, 2011; Francis et al., 2012). Edible coatings can contain inhibitors of microbial growth on fresh and fresh-cut fruits and vegetables (Lin and Zhao, 2007). Modified atmosphere packaging is effective in extending shelf life, but microbial growth must be carefully monitored, as the modified atmospheres can favor pathogen growth while inhibiting spoilage microbes (Caleb et al., 2013).

By definition, fresh and fresh-cut fruits and vegetables do not go through a heat process to reduce pathogen load. A major area of research involves methods of decontaminating fresh produce (Koo, 2011; Foong-Cunningham et al., 2012; Goodburn and Wallace, 2013). Although chlorine is widely used as a sanitizer, alternative solutions have been proposed such as irradiation (Olaimat and Holley, 2012; Follett and Wall, 2013), organic acids (Ganesh et al., 2012) and ozone (Rosenblum et al., 2012). Simple washing techniques tend to be ineffective and can lead to cross-contamination from a highly contaminated batch to one that is reasonably free of pathogens (Warriner and Namvar, 2013). A portable instrument using hyperspectral imaging to detect ATP bioluminescence has been designed for determining the effectiveness of sanitation procedures in produce packinghouses and processing plants (Wiederoder et al., 2013).

E Constrained handling systems

The challenges facing handlers of fresh fruits and vegetables in countries that lack infrastructure and advanced postharvest technology are different from those who do have these advantages. Most postharvest research has been directed at complex systems which provide fresh fruits and vegetables to mass markets. Thus, different circumstances require different solutions. When transferring technology from one country to another, a systems approach requires a basic understanding of the handling system and existing infrastructure (Kader, 2010; Sparks, 2013). In sub-Saharan Africa postharvest losses are caused on the farm due to inappropriate cultivar selection or harvesting method (World Bank, 2010) and in transit due to poor packaging, poor temperature management, rough handling and unpaved roads (Kitinoja et al., 2011). Lack of adequate cooling facilities leads to a greater need to move the product to market more rapidly, but produce harvested when too ripe or soft results in rapid moisture loss or decay (Kitinoja and Kader, 2002). In general, many postharvest handlers in these countries have little or no training in appropriate techniques (Kitinoja et al., 2011), and many well-meaning outsiders do not have an appreciation of the handling system (Paarlberg, 2010).

Reduction of postharvest losses can be achieved by selecting cultivars that have good nutritional quality and last longer after harvest, and also by integrating crop management techniques (Kitinoja et al., 2011). Plastic bins or buckets are preferable to woven baskets or wooden containers as the plastic is easier to clean and sanitize and also provides more protection from mechanical damage (Aba et al., 2012). Some ventilation in the container is needed to prevent the build-up of heat. Extended postharvest life can also be achieved by harvesting at cooler times of the day and constructing low-cost equipment using moistened charcoal to provide evaporative cooling. Construction of a simple packing area from wooden poles and plastic sheeting with a thatched roof provides shade that lowers product temperature, and such a central workplace can reduce the number of times an item is handled (Kitinoja and Kader, 2002). Selection of fruits and vegetables at proper maturity at harvest, gentler handling and ethylene management can also reduce losses (Saeed and Khan, 2010). Transport to market requires attention such as the use of straw or woven mats on a truck bed, transport speeds that take into consideration the grade and quality of the road and appropriate air pressure in the tires to minimize vibration (Kitinoja and Kader, 2002).

Globally, over half of the food supply is produced through the efforts of non-mechanized human labor. Investments in training and low-cost improvements in simple handling systems can provide dividends in reducing losses and increasing grower income (Kitinoja and Kader, 2002). Such improvements can eventually impact poverty, health and food security (Goletti and Wolff, 1999; Hodges et al., 2011).

F Working at the interfaces of the postharvest system

When we initiated research into the application of the systems approach to the handling of fresh fruits and vegetables, we tended to study the postharvest system in isolation and ignored what happened before harvest (production) or after retail sale (home storage and consumption). We soon learned the limitations of this perspective. Much of the variation observed during postharvest storage was attributed to preharvest factors as described previously in the chapter. In addition, the key to increasing the amount of an item consumed and the economic value of the item lies in understanding consumer desires. Progress in quality improvement of fresh fruits and vegetables will be made possible by working at the interfaces of the system (Figure 2.4) and providing:

- a clearer specification of quality and value of an item from the consumer perspective;
- an ability to understand preharvest factors that contribute to sample variability and predetermine storage stability; and
- a means to predict mathematically the period of optimum marketability under a specified set of handling conditions.

The remainder of this book places postharvest handling in a systems context. In the original edition of this book (Shewfelt and Prussia, 1993) we proposed a systems approach as a new paradigm for postharvest research. A series of international conferences based on this concept have been held in Potsdam, Germany

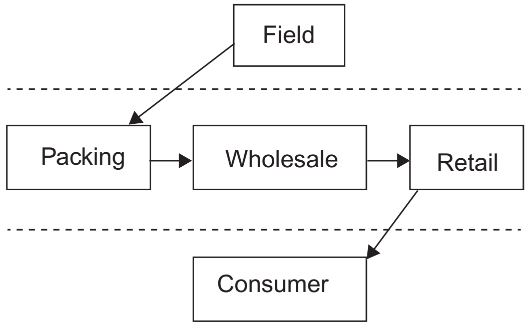

FIGURE 2.4

A generalized postharvest handling system and its interfaces with production systems and the consumer.

(Shewfelt and Brueckner, 2000), Griffin, Georgia, USA (Florkowski et al., 2000), Wageningen, The Netherlands (Tijskens and Vollebregt, 2003), Bangkok, Thailand (Purvis et al., 2006), Napier, New Zealand (Johnston, et al., 2010) and Cranfield, United Kingdom (Terry, 2013).

Bibliography

Aba, I.P., Gana, Y.M., Ogbonnaya, C., Morenikeji, O.O., 2012. Simulated transport damage study on fresh tomato (*Lycopersicon esculentum*) fruits. Agric. Eng. Int. 14, 119–129.

Alvarado-Casillas, S., Ibarra-Sanchez, S., Rodruguez-Garcia, O., Martinez-Gonzales, N., Castillo, A., 2007. Comparison of rinsing and sanitizing procedures for reducing bacterial pathogens on fresh cantaloupes and bell peppers. J. Food Prot. 70, 655–660.

Ambuko, J., Sekozawa, Y., Sugaya, S., Gemma, H., 2013. A comparative evaluation of postharvest quality attributes of two banana (*Musa* spp) varieties as affected by preharvest production conditions. J. Agric. Sci. 5, 170–178.

Ashraf, N., Sharma, M.K., Bhat, M.Y., 2012. A review on new techniques for enhancing storage life of temperate fresh fruits. Environ. & Ecol. 30, 1267–1271.

Arvanitoyannis, I., Stratakos, A.C., Tsarouhas, P., 2009. Irradiation applications in vegetables and fruits: A review. Critic. Rev. Food Sci. & Nutr. 49, 427–462.

Avci, H., 2013. Heavy metals in vegetables irrigated with wastewaters in Gaziantep, Turkey: a review of causes and potential for human health risks. Fresenius Environ. Bull. 22, 146–151.

Behe, B.K., 2006. Conjoint analysis reveals consumers prefer long, thin asparagus spears. HortScience 41, 1259–1262.

Bertazzoli, A., Buccioli, N., Nocella, G., 2005. Consumers' perception and evaluation of fresh cut buying attributes: a survey on the Italian market. J. Food Prod. Mark. 11, 35–55.

Beuchat, L.R., 2006. Vectors and conditions for preharvest contamination of fruits and vegetables with pathogens capable of causing enteric diseases. Brit. Food J. 108, 38–53.

Beuchat, L.R., 2007. Managing food safety risks in the fresh-cut industry. Acta Hortic. 746, 103–114.

Bohaychuk, V.M., King, R.K., Rieve, R., Romero Barrios, P., Gensler, G.E., Bradbury, R. W., et al., 2009. A microbiological survey of selected Alberta-grown fresh produce from farmers' markets in Alberta, Canada. J. Food Prot. 72, 415–420.

Brueckner, B., 2006. Addressing consumer notions and individuality. Acta Hortic. 712, 121–130.

Butz, P., Hofmann, C., Tauscher, B., 2005. Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. J. Food Sci. 70, R131–R141.

Buzby, J.C., Hyman, J., 2012. Total and per capita value of food loss in the United States. Food Policy 37, 561–570.

Caleb, O.J., Mahajan, P.V., Al-Said, F.A.J., Opara, U.L., 2013. Modified atmosphere packaging technology of fresh and fresh-cut produce and the microbial consequences – a review. Food and Bioprocess Technol. 6, 303–329.

Cohen, S., Tzuri, G., Harel-Beja, R., Itkin, M., Portnoy, V., Sa'ar, U., et al., 2012. Co-mapping studies of QTLs for fruit acidity and candidate genes of organic acid metabolism and proton transport in sweet melon (*Cucumis melo* L.). Theor. Appl. Genet. 125, 343–353.

Collins, R., 2010. Postharvest science and value chain management: Using the virtuous value cycle to define common ground. Acta Hortic. 880, 67–74.

Cook, R.L. (2011). Fundamental forces affecting U.S. fresh produce growers and marketers. Choices, the Agric. Appl. Econ. Assoc. 26 (4). <http://agecon.ucdavis.edu/people/faculty/roberta-cook/docs/Articles/ChoicesProduceArticleCookJan2012.pdf> (accessed 21.1.14).

Crisosto, C.H., Crisosto, G.M., Echeverria, G., Puy, J., 2006. Segregation of peach and nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic characteristics. Postharvest Biol. Technol. 29, 10–19.

Crisosto, C.H., Valero, D., 2008. Harvesting and postharvest handling of peaches for the fresh market. In: Layne, D., Bassi, D. (Eds.), The Peach: Botany, Production and Uses. CABI, Wallingford UK, pp. 575–596.

De Martino, Giovanni, Mencarelli, F., Golding, J.B., 2007. Preliminary investigation into the uneven ripening of banana (*Musa* sp.) peel. New Zealand J. Crop. Hortic. Sci 35, 193–199.

Domínguez, I., Ferreres, F., del Riquelme, F.P., Font, R., Gil, M.I., 2012. Influence of preharvest application of fungicides on the postharvest quality of tomato (*Solanum lycopersicum* L.). Postharvest Biol. Technol. 72, 1–10.

Droby, S., Wisniewski, M., Macarisin, D., Wilson, C., 2009. Twenty years of postharvest biocontrol research: Is it time for a new paradigm? Postharvest Biol. Technol. 52, 137–145.

Ekelund, L., Fernqvist, F., Tjärnemo, H., 2007. Consumer preferences for domestic and organically labelled vegetables in Sweden. Acta Agric. Scand. 4, 229–236.

Florkowski, W.J., Prussia, S.E., Shewfelt, R.L. (2000). Integrated View of Fruit & Vegetable Quality: International Multidisciplinary Conference. Technomic Pub. Co., Lancaster PA.

Follett, P.A., Wall, M.M., 2013. Phytosanitary irradiation for export of fresh produce: Commercial adoption in Hawaii and current issues. J. Radioanalyt. Nucl. Chem. 296, 517–522.

Foong-Cunningham, S., Verkaar, E.L.C., Swanson, K., 2012. Microbial decontamination of fresh produce. In: Dermirci, A., Ngadi, M.O. (Eds.), Microbial Decontamination in the Food Industry: Novel Methods and Applications. Woodhead Publishing Ltd, Cambridge UK, pp. 1–29.

Fouayzi, H., Caswell, J.A., Hooker, N.H., 2006. Motivations of fresh-cut produce firms to implement quality management systems. Rev. Agric. Econ. 28, 132–146.

Francis, G.A., Gallone, A., Nychas, G.J., Sofos, J.N., Colelli, G., Amodio, M.L., et al., 2012. Factors affecting quality and safety of fresh-cut produce. Critic. Rev. Food Sci. Nutr. 52, 595–610.

Ganesh, V., Hettiarachchy, N.S., Griffis, C.L., Martin, E.M., Ricke, S.C., 2012. Electrostatic spraying of food-grade organic and inorganic acids and plant extracts to decontaminate *Escherichia coli* O157:H7 on spinach and iceberg lettuce. J. Food Sci. 77, M391–M396.

Goletti, F., Wolff, C., 1999. The impact of postharvest research. MSS Discussion Paper No. 29. International Food Policy Research Institute, Washington D.C.

Goodburn, C., Wallace, C.A., 2013. The microbiological efficacy of decontamination methodologies for fresh produce: A review. Food Control 32, 418−427.

Gross, K.C., Wang, C.Y., Saltviet, M., 2004. The commercial storage of fruits, vegetables, and florist and nursery socks. USDA Agriculture Handbook No. 66. U.S. Govt. Printing Office, Washington, DC.

Gullino, M.L., Caprioli, A., 2013. Human pathogens, how to reduce contamination of vegetables. Inform. Agrar. 69, 56−59.

Hale, M.G., Orcutt, D.M., 1987. The Physiology of Plants under Stress. John Wiley & Sons, New York.

Hanning, I.B., Nutt, J.D., Ricke, S.C., 2009. Salmonellosis outbreaks in the United States due to fresh produce: sources and potential intervention measures. Foodborne Pathog. Dis. 6, 635−648.

Hodges, R.J., Buzby, J.C., Bennett, B., 2011. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. J. Agric. Sci. 149 (Suppl. 1), 37−45.

Inaba, A., 2007. Studies on the internal feedback regulation of ethylene biosynthesis and signal transduction during fruit ripening, and the improvement of quality. J. Japan Soc. Hortic. Sci 76, 1−12.

Jacxsens, L., Uyttendaele, M., Holvoet, K., Kierezieva, K., Luning, P., 2012. The impact of climate change and globalisation on the safety of fresh produce. Int. Food Hyg. 23, 26−27.

Johnson, G.I., Hofman, P.J., 2009. Postharvest technology and quarantine treatments. In: Litz, R.E. (Ed.), The Mango: Botany, Production and Uses, second ed. CABI, Wallingford UK, pp. 529−605.

Johnston, J.W., Brookfield, P., 2012. Delivering postharvest handling protocols for apples and pears faster: integrating "omics" and physiology approaches. Acta Hortic. 945, 23−28.

Johnston, J.W., Gunson, F.A., Hewett, E.W., 2010. Proceedings of the Vth International Symposium on Managing Quality in Chains. Acta Hortic. 880.

Kader, A.A., 2010. Handling of horticultural perishables in developing vs. developed countries. Acta Hortic. 877, 121−126.

Kays, S.J., Paull, R.E., 2004. Postharvest Biology. Exon Press, Athens GA.

Kitinoja, L., Saran, S., Roy, S.K., Kader, A.A., 2011. Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy. J. Sci. Food Agric. 91, 597−603.

Kitinoja, L., Kader, A.A., 2002. Small-scale Postharvest Handling Practices: A Manual for Horticultural Crops, Forth ed. University of California, Davis.

Kondo, N., 2010. Automation on fruit and vegetable grading system and food traceability. Trends. Food Sci. & Technol. 21, 145−152.

Koo, J.E., 2011. Microbial safety of fresh and processed vegetables. In: Sinha, N.K., Hui, Y.H. (Eds.), Handbook of Vegetables and Vegetable Processing. Wiley−Blackwell, Ames IA USA, pp. 483−503.

Kozak, G.K., MacDonald, D., Landry, L., Farber, J.M., 2013. Foodborne outbreaks in Canada linked to produce: 2001 through 2009. J. Food Prot. 76, 173−183.

Kubota, C., 2012. Environmental control technologies to improve greenhouse product quality. Acta Hortic. 952, 843−851.

Kuepper, G., Batt, P.J., 2012. The adoption of quality management systems in the fresh produce industry in Western Australia. Acta Hortic. 936, 27−34.

Lee, S.K., Kader, A.A., 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol. 20, 207–220.

Lin, D., Zhao, Y.Y., 2007. Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables. Comp. Rev. Food Sci. Food Saf. 6, 60–75.

Ma, L., Zhang, G.D., Gerner-Smidt, P., Tauxe, R.V., Doyle, M.P., 2010. Survival and growth of *Salmonella* in salsa and related ingredients. J. Food Prot. 73, 434–444.

Maffei, D.F., Silveira, N.F., Catanozi, M., 2013. Microbiological quality of organic and conventional vegetables sold in Brazil. Food Control 29, 226–230.

Magkos, F., Arvanti, F., Zampelas, A., 2006. Organic food: Buying more safety or just peace of mind? A critical review of the literature. Crit. Rev. Food Sci. Nutr. 46, 23–56.

Martínez, C., Manzano, S., Megías, Z., Rubio, A., Valenzuela, J.L., Jamilena, M., et al., 2012. Effects of auxin-induced parthenocarpy on ethylene production and postharvest quality attributes of zucchini fruit. Acta Hortic. 934, 1319–1325.

Martínez-Romero, D., Bailén, G., Serrano, M., Guillén, F., Valverde, J.M., Zapata, P., et al., 2007. Tools to maintain postharvest fruit and vegetable quality through the inhibition of ethylene action: a review. Critic. Rev. Food Sci. Nutr. 47, 543–560.

Mathieu, S., Cin, V.D., Fei, Z., Li, H., Bliss, P., Taylor, M.G., et al., 2009. Flavour compounds in tomato fruits: identification of loci and potential pathways affecting volatile composition. J. Exp. Bot. 60, 325–337.

Michailides, T.J., Manganaris, G.A., 2009. Harvesting and handling effects on postharvest decay. Stewart Postharvest Rev. 5 (2), article 3.

Mitra, S.K., Chakraborty, I., Pathak, P.K., 2011. Postharvest technology of tropical export produce: recent developments and challenges of a future free-trade world market. Acta Hortic. 906, 114–123.

Mota, A., Tarwater, P.M., Cháidez, C., Mena, K.D., Soto-Beltran, M., 2009. Risk assessment of *Cryptosporidium* and *Giardia* in water irrigating fresh produce in Mexico. J. Food Prot. 72, 2184–2188.

Mukherjee, A., Speh, D., Jones, A.T., Buesing, K.M., Diez-Gonzalez, F., 2006. Longitudinal microbiological survey of fresh produce grown by farmers in the upper midwest. J. Food Prot. 69, 1928–1936.

Nuñez-Palenius, H.G., Gomez-Lim, M., Ochoa-Alejo, N., Grumet, R., Lester, G., Cantliffe, D.J., 2008. Melon fruits: genetic diversity, physiology, and biotechnology features. Critic. Rev. Biotechnol. 28, 13–55.

Olaimat, A.N., Holley, R.A., 2012. Factors influencing the microbial safety of fresh produce: a review. Food Microbiol. 32, 1–19.

Paarlberg, R., 2010. Food Politics: What Everyone Needs to Know. Oxford University Press, Oxford.

Palma, M.A., Paggi, M., Knutson, R.D., Ribera, L.A., Bessler, D., 2010. Potential impacts of foodborne illness incidences on market movements and prices of fresh produce in the US J. Agric. Appl. Econ. 42, 731–741.

Palumbo, J.C., Castle, S.J., 2009. IPM for fresh-market lettuce production in the desert southwest: the produce paradox. Pest Manag. Sci. 85, 1311–1320.

Pareek, S., Yahia, E.M., Pareek, O.P., Kaushik, R.A., 2011. Review: Postharvest physiology and technology of Annona fruits. Food Res. Int. 44, 1741–1751.

Plauborg, F., Andersen, M.N., Liu, F., Ensink, J., Ragab, R., 2010. Safe and high quality food production using low quality waters and improved irrigation systems and management: SAFIR. Agric. Water Manag. 98, 377−384.

Plotto, A., Narciso, J.A., 2006. Guidelines and acceptable postharvest practices for organically grown produce. Hort Science 41, 287−291.

Pohlan, J., Vanderlinden, E.J.M., Janssens, M.J.J., 2008. Harvest maturity, harvesting and field handling of rambutan. Stewart Postharvest Rev. 4 (2), article11.

Prakash, A., Guner, A.R., Caporaso, F., Foley, D.M., 2000. Effects of low-dose gamma irradiation on the shelf life and quality characteristics of cut romaine lettuce packaged under modified atmosphere. J. Food Sci. 65, 549−553.

Probst, L., Aigelsperger, L., Hauser, M., 2010. Consumer attitudes towards vegetable attributes: potential buyers of pesticide-free vegetables in Accra and Kumasi, Ghana. Ecol. Food Nutr. 49, 228−245.

Prusky, D., 2011. Reduction of the incidence of postharvest quality losses, and future prospects. Food Secur. 3, 463−474.

Prussia, S.E., 2000. Soft systems methodologies for modeling postharvest chains. Acta Hortic. 536, 653−660.

Prussia, S.E., Mosqueda, M.R.P., 2006. Systems thinking for food supply chains: fresh produce applications. Acta Hortic. 712, 91−104.

Purvis, A.C., McGlasson, W.B., Kanlayanarat, S., 2006. Proceedings of the Fourth International Conference on Quality in Chains: The integrated view on fruits and vegetables quality, Acta Hortic. 712.

Rosenblum, J., Ge, C., Bohrerova, Z., Yousef, A., Lee, J., 2012. Ozonation as a clean technology for fresh produce industry and environment: sanitizer efficiency and wastewater quality. J. Appl. Microbiol. 113, 837−845.

Saeed, A., Khan, S.N., 2010. Post harvest losses of tomato in markets of district Lahore. Mycopathologia 8, 97−99.

Saunders, C., Barber, A., Taylor, G., 2006. Food miles − Comparative energy/ emissions performance of New Zealand's agriculture industry. Lincoln University Research Report No. 285.

Shewfelt, R.L., Brueckner, B., 2000. Fruit and Vegetable Quality: An Integrated View. Technomic Publishing Co, Lancaster PA, USA.

Shewfelt, R.L., Prussia, S.E., 1993. Postharvest Handling: A Systems Approach. Academic Press, New York.

Shewfelt, R.L., Tijskens, L.M.M., 2000. A more integrated view. In: Shewfelt, R.L., Brueckner, B. (Eds.), Fruit and Vegetable Quality: An Integrated View. Technomic Publishing Co, Lancaster PA, USA, pp. 296−306.

Singh, D.K., Ram, R.B., Yadava, L.P., 2013a. Preharvest treatment of Ca, K, and B reduces softening of tissue in 'Dashehari' mango. Int. J. Fruit Sci. 13, 299−311.

Singh, S.P., Singh, Z., 2012. Role of membrane lipid peroxidation, enzymatic and non-enzymatic antioxidative systems in the development of chilling injury in Japanese plums. J. Amer. Soc. Hortic. Sci. 137, 473−481.

Singh, Z., Khan, A.S., 2010. Physiology of plum fruit ripening. Stewart Postharvest Rev. 6 (2), article 3.

Singh, Z., Singh, R.K., Sane, V.A., Nath, P., 2013b. Mango − postharvest biology and biotechnology. Critic. Rev. Plant Sci. 32, 217−236.

Soon, J.M., Davies, W.P., Chadd, S.A., Baines, R.N., 2013. Field application of farm-food safety risk assessment (FRAMp) tool for small and medium fresh produce farms. Food Chem. 136, 1603–1609.

Sparks, S.A., 2013. Postharvest Handling Systems For Fresh Fruits And Vegetables In Sub-Saharan Africa And Potential Enhancement By The Aid For Trade Initiative. M.S. Thesis. University of Georgia.

Tapia, M.S., Gómez-López, V.M., Olaizola, C., 2009. HACCP implementation in the production of fresh-cut fruits and vegetables. Stewart Postharvest Rev. 5, article 6.

Terry, L.A., 2013. Convener of Managing Quality in Chains VI conference. Cranfield, UK, September 2–5.

Thompson, A.K., 2010. Controlled Atmosphere Storage of Fruits and Vegetables, second ed. CABI, Wallingford, UK.

Tijskens, L.M.M., Vollebregt, H.M., 2003. Proceedings of the International Conference on Quality in Chains. An Integrated View on Fruit and Vegetable Quality. Acta Hortic. 604.

Toivonen, P.M.A., 2006. Fresh-cut apples: Challenges and opportunities for multidisciplinary research. Can. J. Plant Sci. 86, 1361–1368.

Toivonen, P.M.A., Lu, C., 2007. An integrated technology including 1-MCP to ensure quality retention and control of microbiology in fresh and fresh-cut fruit products at non-ideal storage temperatures. Acta Hortic. 746, 223–228.

USDA ERS., 2012. Table A1. In Fruits and Tree Nuts Situation and Outlook Yearbook. <http://usda.mannlib.cornell.edu/MannUsda/viewStaticPage.do?url = http://usda01.library.cornell.edu/usda/ers/./89022/2011/index.html> (accessed 21.10.14).

USDA ERS., 2013. Table 2. In Vegetables and Pulses Yearbook. <http://www.ers.usda.gov/datafiles/Vegetable_and_Pulses_Yearbook_Tables/General/YRBK2013_Section%201_General.pdf> (accessed 21.10.14).

USDA/HHS, 2005. Dietary Guidelines for Americans. 2005. U.S. Govt. Printing Office, Washington, D.C.

van Boxstael, S., Habib, I., Jacxsens, L., de Vocht, M., Baert, L., van de Perre, E., et al., 2013. Food safety issues in fresh produce: Bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. Food Control 32, 190–197.

Warriner, K., Namvar, A., 2013. Recent advances in fresh produce post-harvest decontamination technologies to enhance microbiological safety. Stewart Postharvest Rev. 9 (1), Article 3.

Wiederoder, M.S., Liu, N., Lefcourt, A.M., Kim, M.S., Lo, Y.M., 2013. Use of a portable hyperspectral imaging system for monitoring the efficacy of sanitation procedures in produce processing plants. J. Food Eng. 117, 217–226.

Wilson, C.L., 2013. Establishment of a world food preservation center. Agric. and Food Secur. 2 (1) <http://www.agricultureandfoodsecurity.com/content/2/1/1>. (accessed 21.10.14).

Woolf, A.B., Ferguson, I.B., 2000. Postharvest responses to high fruit temperatures in the field. Postharvest Biol. Technol. 21, 7–20.

World Bank, 2010. Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa. The World Bank, Washington, DC.

Zoffoli, J.P., Latorre, B.A., Naranjo, P., 2008. Preharvest applications of growth regulators and their effect on postharvest quality of table grapes during cold storage. Postharvest Biol. Technol. 51, 183–192.

CHAPTER

3 Consumer Eating Habits and Perceptions of Fresh Produce Quality

Wendy V. Wismer

Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada

I Introduction

Over the past 10 years, consumers have been exposed to evolving and often conflicting information about quality dimensions of fresh fruits and vegetables. Health-enhancing and disease-preventing properties of fruits and vegetables are widely promoted, consumers are encouraged to buy organic and locally sourced produce and non-seasonal produce items are increasingly available to expand consumer food choice. In contrast, consumer concerns about product quality in this commodity group have emanated from recalls of microbiologically contaminated fresh produce and subsequent outbreaks of foodborne illness, food fraud (e.g., product substitution, eco-labeled products) (see also Chapter 8) and economically motivated adulteration of processed fruits and vegetables. Public health professionals and policy makers continue to elucidate barriers to the consumption of fresh fruits and vegetables with increased emphasis on the importance of childhood exposure to these products and maintained recognition of psycho-social determinants (factors related to the interrelationship between an individual and the surrounding environment) as constraints to their purchase. For consumers, these issues add complexity to longstanding concerns of inconsistent eating quality of fresh fruits and vegetables.

Consumers of manufactured food products such as ready-to-eat breakfast cereals enjoy the same product quality with each and every eating event. Consumers of fresh fruits and vegetables, however, may experience greatly variable product quality when eating a single type of produce (Abbott, 1999). In addition to biological variation within the same harvested lot, post-harvest technological and supply variables add to the variation in quality the consumer experiences when eating a single horticultural commodity (Harker et al., 2002b). Consumers may recognise and accept variable postharvest quality in fruit, and balance tangible quality attributes (e.g., taste and texture) with perceived product benefits such as healthfulness (Harker et al., 2002b). This multidimensional perspective of quality highlights the

Postharvest Handling.

potential difference in the perception of quality between consumers and those who evaluate the postharvest attributes of fresh produce and the complexity of the consumer quality evaluation of fresh fruits and vegetables (Harker et al., 2008; Klee, 2010; Tesfaye et al., 2013).

An understanding of consumer perceptions of quality is well known as a key to market expansion and to promote consumption (Oude Ophuis and Van Trijp, 1995). Harker et al. (2003) suggest that knowledge of factors affecting consumer perceived apple quality rather than management of apple price and supply will encourage industry growth through increased consumption. More recently, Tesfaye et al. (2013) argue that successful plant breeding for flavor improvement will only be realized when breeding programs begin with the consumers' perspective of flavor quality.

This chapter describes current consumption patterns of fresh produce around the globe, and describes the tangible and intangible product dimensions which influence consumer perceptions of fresh fruits and vegetables.

II Current fresh produce eating habits

A Global availability and consumption

The total global production of 30 commonly produced and consumed fruits (e.g., melons, lemons and limes, pineapples) and vegetables (e.g., corn, spinach, eggplant) tracked by the FAO increased from 1980 to 2004, international trade in some fresh fruits and vegetables increased during this time, and an oversupply of some fresh produce items occurred as organically grown products emerged on the market (FAO/WHO, 2005). However, estimates of supply of fresh fruits and vegetables vary greatly by country due to factors such as geographic area of production and retail price (OECD/European Union, 2010). Availability is suggested to be below recommended levels in both developing and developed countries (FAO/WHO, 2005). Although the supply of fruits and vegetables available for consumption in the EU increased from 1980 to 2010 (OECD/European Union, 2010), a review by the European Food Information Council (2012) indicates localized availability and accessibility issues (e.g., poor fruit quality and limited selection in shops) restrict consumption (see also Chapter 7 for additional examples and discussion). Reduced availability and consumption of staple fruits and vegetables and their products has changed diet patterns globally; increased dietary fat intake and energy density have occurred at the expense of decreased total carbohydrate and fiber, with reduced protein intake in developing countries (FAO/WHO, 2005).

B Consumption trends in North America

Per capita consumption of fresh fruits and vegetables declined in the United States in the decade from 2003 to 2013 (Karst, 2013a) (see Chapter 2, Figures 2.1 and 2.2).

Availability of all fresh fruits (domestic and imported) was stable during that time, while fresh vegetable availability was reduced. After adjusting for losses (waste and loss from grower to consumer), the 2011 per capita availability of fruits was 47.8 pounds and of fresh vegetables was 87.7 pounds, respectively (Karst, 2013b). Some apparent decline in produce consumption may be due to the consumption of exotic fruits and vegetables not tracked by government agencies (Karst, 2013b), and fear that fresh produce will perish and money will be wasted on its purchase (Welker, ND). However, more prominent factors are suggested to be lower incomes, perceived product price increases and competition from processed foods (Karst, 2013b). Only about 25% of Americans are achieving the USDA recommended "5 a day" consumption of fruits and vegetables (see Chapter 7 for additional fresh produce consumption promotion programs). Adults consume fruit about 1.1 times per day and vegetables about 1.6 times per day; consumption is highest in California and Oregon (CDC, 2013).

Similarly, only 26% of all Canadians and fewer than 20% of teens and younger men consumed the minimum number of servings for their age−gender group recommended by Canada's Food Guide (Black and Billette, 2013). Statistics Canada reported that 40.6% of Canadians over the age of 12 years self-reported consumption of five or more fruits and vegetables per day, a figure unchanged from 2011, but down from the 45.6% reported in 2009 (Statistics Canada, 2013).

Based on dietary data from the Mexican National Health and Nutrition Survey (2006), it was concluded that less than 30% of the Mexican population had adequate fruit and vegetable consumption, and fewer vegetables were consumed compared to fruits (Ramírez-Silva et al., 2009). Average total daily fruit and vegetable intakes ranged from 88.7 g in preschool-age to 122.6 g in adults. Intakes were lowest in the north of the country and among those with the lowest well-being.

As described above, the global availability and consumption of fruits and vegetables is viewed as declining or as increasing only slightly, and 20−50% of the world's population consumes the WHO-recommended 400 g per day (FAO, 2006). The inability to consume sufficient fresh produce on a daily basis to maintain a healthy diet and prevent major diseases such as cardiovascular disease and some cancers is of concern to the WHO, whose mandate is to improve global public health (FAO, 2006). "Low fruit and vegetable intake" is ranked by WHO as 6^{th} out of 20 risk factors for global human mortality (FAO, 2006). To promote the consumption of fruits and vegetables the WHO has liaised with a variety of programs, both national (e.g., "Go for 2&5®" in Australia; "5 al día" in Chile) and regional (i.e., IFAVA, International Fruit and Vegetables Alliance; EPBH, European Partnerships for Fruits, Vegetables and Better Health). The WHO/FAO "Fruit and Vegetables for Health" workshop report (FAO/WHO, 2005) identified a variety of initiatives to increase the production and consumption of fruits and vegetables, and encouraged individual nations to address barriers to consumption specific to their inhabitants. Personal and situational variables that influence fresh produce consumption, including accessibility, price, income, gender and age are discussed further in this chapter in Section V.

A challenge to interpretations and global comparisons of national fruit and vegetable consumption data are the varying definitions of fruits and vegetables and the methods used to measure intake (EUFIC, 2012). Usual intake may be determined by national appearance and disappearance figures for fruit and vegetable commodities, or be generated by consumers through food diaries and dietary recalls or as self-reported daily intake in number of servings. Additionally, some consumption statistics do not account for fruit and vegetable waste between the grocery store and the dining table, as well as subsequent household waste (WHO, 2003). An FAO report on global food losses and food waste (Gustavsson et al., 2011) identified losses of about 20% of initial production due to products not meeting postharvest grading requirements in Europe, North America, Oceania and Latin America. In these same geographic regions consumers discarded 30% (by weight) of their fruit and vegetable purchases. In a study of deterioration and disposal of fruit in New Zealand homes, 28% of consumers indicated that they disposed of fruit in the home every week when it lost its optimum freshness (Campbell et al., 2009).

During preparation, fruits and vegetables are trimmed of inedible or undesirable portions, and the resulting edible portion is a percentage of the weight of the "as purchased" product, that can range from 66% for leaf lettuce to 99% for tomatoes (Molt, 2001). Food remaining on a plate to be discarded after a meal is measured as "plate waste" (Engstrom and Carlsson-Kanyama, 2004), a measure that gives insight into the desirability of served foods (Connors and Rozell, 2004). Plate waste assessments often indicate that fruits and vegetables are not consumed to the same extent as other foods served. Engstrom and Carlsson-Kanyama (2004) observed that plate waste was the largest contributor to food waste in institutions and restaurants in Stockholm, Sweden, and on average constituted 11–13% of the amount of food served. In restaurants, vegetables represented the majority of plate waste. A plate waste assessment of meals served in an acute care hospital in North Texas revealed that all vegetables served to adult patients were consumed at less than the desirable benchmark value of intake, while fruit consumption exceed the benchmark value (Connors and Rozell, 2004). Plate waste of sixth-graders ($n = 743$) in a School Lunch Program in Kentucky was approximately 30% for vegetables and 36–52% for fruits (Marlette et al., 2005). Plate waste was influenced by the food preparation method (i.e., apple sauce was preferred to whole apples), and in particular, fruit waste was increased by the availability of competitive food items in the school, which were often high in fat and/or sugar. Vegetables were served at dinner meals by 96.5% of parents of 231 pre-school children in a study in Houston, Texas, however, the average serving was 0.77 of a recommended serving, and 30% was identified as plate waste (Nicklas et al., 2012).

Although comparison of fruit and vegetable consumption on a global scale illustrates a diversity of regional eating habits and geographic factors (climate and arable land usage) related to availability, it is apparent the fruit and vegetable consumption is at best steady in some countries, but is more frequently described as declining. A multitude of reasons for this decline have been suggested, and provide the background for the complex analysis of consumer eating habits of fresh fruits and vegetables.

There are a multitude of paradigms and models by which food choice and eating variables can be related. For the purposes of this chapter, the paradigm of consumer-perceived quality is a useful method for grouping these variables, because quality is a core concept of consumer satisfaction (Oude Ophuis and Van Trijp, 1995). Quality in the eyes of the consumer should be the focus for advancing the horticultural industry (Harker et al., 2003; Klee, 2010; Lan Chen and Opara, 2013; Poole et al., 2007; Tesfaye et al., 2013).

III How do consumers define quality?

Steenkamp (1990) suggested that successful industries generate products of a quality that is "dependant on the perceptions, needs and goals of the consumer" rather than objective quality (see also Chapter 8) that is based on an innate measurable and predetermined standard. Oude Ophuis and van Trijp (1995) apply the principle of consumer-perceived quality to successful consumer-driven food product development. They describe quality as a "multi-faceted concept" for which consumers use both quality attributes and quality cues to form their assessment of perceived quality. Quality cues are observable product characteristics that can be intrinsic (e.g., appearance, color, shape, size, structure) or extrinsic (e.g., price, brand, nutritional information, production information, country of origin). Quality attributes are abstract, and can be based on experience (e.g., taste, freshness, convenience) or perceived benefits (e.g., healthfulness, naturalness, animal and/or environmental friendliness). Perceived benefit quality attributes are known as credence quality attributes, as the benefits cannot be experienced directly and information or judgment by others forms the basis of the perceived benefits. Together these dimensions of quality, the intrinsic and extrinsic quality cues and the experience and credence quality attributes, are integrated to develop a picture for the consumer of perceived quality.

The horticultural industry has traditionally assessed produce quality using intrinsic quality cues such as appearance and texture assessment by instrumental methods (Lan Chen and Opara, 2013), promotion of fresh produce extrinsic quality cues such as nutritional and production information, brand name and price are relatively recent activities. Consumer-perceived quality consists of numerous quality dimensions that differ in importance among individuals, thus it follows that there is no single universal definition of quality for any product, food or non-food. However, groups of individuals with similar values and characteristics represent consumer segments with similar expectations of fruit and vegetable quality. These consumer segments, or niche markets, represent both challenges and opportunities for the horticultural industry of matching products with consumers. A variety of techniques from the discipline of sensory and consumer science (see also Chapter 4) have been used to match the product quality cues (i.e., appearance) and experiential attributes (i.e., taste) to the preferences of target markets, such as the selection of markets for kiwifruit (Jaeger et al., 2003b), pears (Gamble et al., 2006; Jaeger et al., 2003a) and raspberry consumer segmentation (Villamor et al., 2013). For any consumer segment, the combined knowledge of their intrinsic quality cue information and their perceived quality attributes optimizes the ability of product developers and marketers to match consumer segments to products (Lundahl, 2006).

IV Consumer perceptions of fresh produce quality

External sensory attributes of fresh produce, such as appearance, color, shape, size and hand-evaluated texture are intrinsic quality cues evaluated by the consumer prior to consumption, while flavor (taste and aroma) and oral texture are experience quality attributes evaluated at the time of consumption. Although the composite evaluation of sensory attributes generates an overall opinion of the sensory qualities of the produce, this perception is not generated at a single point in time, and is continuously modified with every consumption experience (see also Chapter 4).

In addition, the sensory attributes of fresh fruit and vegetables are variable, reflecting the diversity inherent in a biological commodity, exacerbated by a variety of postharvest handling protocols. For example, the inherent biological diversity is illustrated by Dever et al. (1995), who noted that different sensory characteristics could occur in two sides of a single apple (blush versus non-blush) and from the top to the bottom of an apple. A variety of accounts of the influence of postharvest handling protocols on produce sensory attributes exist in the literature. Crisosto et al. (2002) substituted SO_2 with a range of CO_2 and O_2 concentrations in early and late-harvested "Redglobe" grapes. Atmospheres above 10 kPa CO_2 combined with 3, 6 or 12 kPa O_2 effectively limited botrytis decay during 12 weeks' cold storage, but accelerated stem browning and "off-flavor" development. The "flavor-life" of stored produce is known to be shorter than visually assessed "storage life", due to the development of off-flavors (Mayuoni-Kirshinbaum et al., 2013). Visually descriptive sensory profiles generated from the trained sensory panel attributes of stored "Wonderful" pomegranates display reduced desirable flavors ("sweet", "red wine" and "pomegranate") and increased undesirable flavors ("off flavor" and "over riping, old flavor") from harvest to 20 weeks of storage at 7°C (Mayuoni-Kirshinbaum et al., 2013). The sensory quality of "Clemenules" mandarins decreased due to the reduction of mandarin-like flavor and development of off-flavor when fruit were held for 12 days at 1.5°C as a quarantine treatment for Mediterranean fruit fly (Palou et al., 2008). In these examples, undesirable sensory attributes such as off-flavors are given consideration as a component of fruit quality.

A Intrinsic quality cues – the influence of appearance

Appearance is the first sensory attribute evaluated by consumers. "The eyes are the gatekeeper to the mouth", and if the appearance of a product is not liked, then the product is not further evaluated. Appearance is a major factor in the quality assessment of fruits and vegetables (von Alvesleben and Meier, 1990; Abbott, 1999; Barrett et al., 2010) and is an important determinant in the purchase of fruits and vegetables in the grocery store (Gamble et al., 2006; Barrett et al., 2010). In a study of consumer-perceived quality of tomatoes, appearance was observed to provide credence attribute cues for "healthiness" (van den Heuvel et al., 2007).

Color is an influential quality factor; consumers have expectations of overall quality based on color, such as color cues for banana ripeness (Barrett et al., 2010). Horticultural products bred for novel colors have recently developed consumer appeal. Potato breeding programs have sourced heirloom potato varieties for their unusual color patterns to breed specialty varieties (Brown et al., 2012). Some plant pigments generate expectations of health benefits, such as anthocyanin pigmented produce (e.g., corn), desired for their purple color and antioxidant health benefits (Li et al., 2011; Lago et al., 2013).

At times, color expectations of quality may not be valid because, for example, some orange (*Citrus* spp.) cultivars are at their optimum when they are green, not orange as most consumers perceive (Kays, 1999). Stommel et al. (2005) presented tomato samples to consumers under white light and then under red light to mask sample color differences. It was observed that consumers favored the more highly pigmented fruit and perceived a greater intensity of tomato quality attributes such as tomato-like flavor, juiciness and overall eating quality. While the appearance factors of shape and form are considered to be generally of minor influence in the consumer evaluation of quality, size is an important quality determinant related to end use (Jaeger et al., 2011).

Cliff et al. (2002) demonstrated that digital imagery could be used successfully to control the visual attributes of apples to determine consumer liking for apple appearance factors, such as color, shape, type and background color. Digitally modified photographic images were presented to consumers in New Zealand, and in British Columbia and Nova Scotia in Canada. Red-colored apples were generally preferred by consumers in all locations, while preferences for blush and stripes were geographically linked. The authors suggest that the evaluation of digital images by consumers in different markets can help breeders and marketing agents direct produce with the appropriate external quality cues to selected markets.

B Experiential quality attributes – taste, texture and perceptions of freshness

Taste, texture and freshness are attributes evaluated by consumers as the product is consumed. Consumers may be intending to consume fruit because of its beneficial health consequences, but taste and texture are fundamental qualities that must be satisfied for continued consumption (Harker et al., 2003; Barrett et al., 2010). The memory of the experiential quality attributes influences future assessments of quality, and consumers have been observed to remember day to day differences in apple firmness as small as 5N (Harker et al., 2002b) (see also Chapter 14).

The taste or flavor attributes of horticultural products are frequently evaluated as a measure of consumer acceptance as new varieties are developed for the marketplace. The identification of flavor targets for fruit breeding for specific markets has generated commercial success for kiwifruit by matching fruit to markets with different taste preferences (Wismer et al., 2005). Klee (2010) suggests that "consumers have noticed a significant drop-off in flavor quality over the recent decades. . ." and tomato and strawberry fruit flavors are frequently unacceptable to consumers (Tesfaye et al., 2013). Breeding for flavor has been neglected in favor of firmness, postharvest shelf life (Klee, 2010), disease resistance, production efficacy and visual appearance (Tesfaye et al., 2013) (see also Chapter 14). Improved flavor of fruit and vegetables would make them more attractive alternatives to less healthy snack alternatives (Klee, 2010). Some consumers are willing to pay more for flavorful produce (Klee, 2010). Heirloom and organic produce are purported to have superior taste to their conventionally produced counterparts and are favored by some consumers due to this perception (Hughner et al., 2007; Barrett et al., 2012).

Texture is an important attribute of fresh fruit and vegetables; many of these products are desired for their crispy or crunchy characteristics, but others are appreciated for their juicy, soft and easy to chew and swallow characteristics (Roininen et al., 2004). Consumers have specific expectations of texture (Barrett et al., 2012), and texture defects often result in the rejection of a fresh product (Harker et al., 2003). Instrumental measurements of fruit and vegetable texture are common and desirable in industry and research because they reduce variation in measurement (relative to human texture assessments) and provide a measure of output that is interpretable (Abbott, 1999). In some instances, such as the evaluation of apple texture, penetrometer measurements can be reliably used to predict the sensory perception of apple texture (Harker et al., 2002a). Instrumental evaluations provide practical targets for rapid and large-volume assessments and generate data of a quality that can be mathematically related to pre- and postharvest treatment factors. However, instrumental evaluations do not capture the multi-attribute profile of textural qualities consumers expect of fresh produce, nor can such evaluations be related easily to other quality attributes or emotive quality dimensions.

Consumers who regularly purchase specific apple cultivars have a firm expectation of its quality and sensory attributes (Harker et al., 2003), although they are accepting of variations in quality, e.g., firm textures in apples (Harker et al., 2002b). Roininen et al. (2004) completed individual semi-structured interviews with young adults (25−40 years old) and the elderly (60 plus years old) in Finland and the United Kingdom to elicit perceptions of the consequences of positive and negative textural properties of fruits and vegetables. Age groups in both countries indicated that seeds, peel and hard and fibrous textures were qualities of fruit that made them troublesome to eat, while vegetable attributes that were troublesome were "hard" and "contained peel". Fruits and vegetables were preferred if they required no preparation, were ready-to-eat or not too difficult to eat. It was suggested that fruits and vegetables that were pre-processed to alleviate the negative attributes would likely promote the consumption of these products.

Freshness is an important quality criterion for the acceptance of fruit and vegetables (Peneau et al., 2006, 2007, 2009). Kays (1999) described freshness, cleanliness and maturity (see also Chapter 15) as part of the appearance factor of "condition", a "somewhat nebulous quality consideration" that embodies many properties, including the general physical condition of the product. A set of attributes were used to evaluate European consumer perceptions of the freshness of strawberries, carrots and apples (Peneau et al., 2006, 2007). Appearance attributes dominated the assessment of strawberries, and both texture and appearance attributes were used for carrots. Many of the attributes were negative (i.e., should not be present in a fresh product), which suggested that observed sensory properties are used to evaluate the physiological aging of horticultural products to generate an assessment of product freshness (Peneau et al., 2007). More recently, freshness was described by Swiss consumers as a collective concept that embodied "a level of closeness to the original product" as determined by time, distance and processing (Peneau et al., 2009).

Postharvest technologies aimed at extending the shelf life of fresh fruits and vegetables may support consumer-perceived freshness and influence the likelihood of their purchase and increase consumption opportunities. Modified atmosphere packaging, irradiation techniques (Oms-Oliu, 2012), heat treatments (Sivakumar, 2013) and ozone-based treatments (Miller et al., 2013) to extend shelf life and resistance to handling damage during transportation and sale are useful in this regard. New packaging technologies, including edible coatings on fresh-cut fruits (Olivas and Barbosa-Canovas, 2006) and nanotechnology-generated inedible coatings (Duran and Marcato, 2013), may both prolong freshness and enhance convenience (see also Chapter 10).

Treatment of produce with 1-methylcyclopropene (1-MCP) is used to improve the storage potential and maintain the quality of some fruits and vegetables, however its effects on quality are variable (Watkins, 2008), and quality concerns exist such as reduced fruit production of characteristic flavor volatiles (Marin et al., 2009), higher acidity and increased firmness (Almeida and Gomes, 2009). As with any postharvest treatment, it is necessary to perform consumer evaluations of product quality. Marin et al. (2009) observed that although apple consumers ($n = 600$) could differentiate between 1-MCP-treated and untreated "Gala" apples, they preferred them equally and purchase intent was similar. However, a subset of regular consumers of "Gala", "Red Delicious" and "Fuji" apples preferred untreated fruit to 1-MCP-treated fruit, a discrimination that may have been the result of their familiarity with the flavor of these apples. Consumers differentiated between 1-MCP-treated and untreated "Hayward" kiwifruit on the basis of their sensory properties (Almeida and Gomes, 2009). Conditioning of stored treated fruit for five days at a higher temperature (23°C) than untreated fruit (0°C) resulted in an inability of consumers to detect a sensory-based difference between the two treatments, suggesting that storage regimes must be modified to optimize consumer-perceived quality of 1-MCP-treated produce.

C Credence quality attributes

Consumer demand for niche products, such as organic and locally grown, has grown rapidly over the past two decades (Moser et al., 2011). A variety of motivations to purchase these products exist, such as environmental concerns, nutrition and health (see also Chapter 5), support for small farms, family farms and farm workers and concerns about animal welfare. For the consumer, these product attributes are nearly impossible to confirm at any stage of consumption, and as their existence must be taken in faith, they are defined as credence attributes (Moser et al., 2011). Constantly evolving credence attributes are increasingly important in the determination of consumer-perceived quality (van den Heuvel et al., 2007).

Moser et al. (2011) summarized the findings of 40 studies designed to assess credence attributes of fresh fruits and vegetables to determine the attributes most relevant and decisive to consumer purchase and willingness to pay for them. They concluded that personal health and experiential eating quality were the strongest purchase determinants. Credence attributes such as environmental welfare were of regional importance (e.g., "strong" determinants in the United States and Canada, and "somewhat" determinant in Europe). The authors also concluded that "local" produce was more desired than "organic".

The ethical foods category encompasses fair trade, local and natural foods, and is dominated by the organic food sector (Sloan, 2011). Interest in reduced food miles and locally grown produce satisfies the credence attribute of reduced environmental damage (Harper and Makatouni, 2002). Local products are increasingly relevant to consumers, which may be attributed to greater confidence in the local label versus third-party certification of other ethical products (Moser et al., 2011). The knowledge of how a product is made and seeing people involved in its production is described as being a motivator for purchases of local products at farmers' markets and supermarkets (Sloan, 2011). Heirloom fruits and vegetables are specialty crops usually sold locally that appeal to consumers who value quality, flavor and heritage (Anonymous, 2013) as well as the benefits of increased variety in the diet and maintenance of genetic diversity (for more about genetics, see Chapter 20).

As described above, Moser et al. (2011) concluded that personal health was a strong determinant in the purchase of ethical food products. Interest in personal health also motivates the consumption of produce with phytochemical names recognized by consumers, such as polyphenols and flavonoids. Anthocyanins, resveratrol and carotenoids are less familiar but will be part of the next promotional wave by fruit and vegetable producers and processors (Sloan, 2011). The long-term health benefits of phytochemical ingestion, and fruit and vegetable consumption in general, is established in the scientific community, but consumers view this as credence attribute as health benefits are not realized in the short-term.

Ozcaglar-Toulouse et al. (2006) caution that ethical consumers in a niche market cannot be considered a homogeneous group; within a niche consumers must be further segmented (Bezençon and Blili, 2011). In addition, the improved effectiveness of marketing organic foods to consumers based on perceived health benefits rather than environmental concerns, both credence attributes, suggests that motivations and the consumers themselves who purchase these products have changed since the emergence of the ethical consumerism movement (Sloan, 2011). To differentiate sustainable consumer market segments, a combination of personality characteristics, food-related lifestyles and behavior can be used (Verain et al., 2012).

V Personal and situational variables that influence fresh produce eating habits

A Accessibility, price and income

Local access to fruits and vegetables, their price, and household income have been studied as variables influencing consumer eating habits for fresh produce, particularly among socio-economically disadvantaged groups, who are frequently cited as being less likely to purchase and consume fruits and vegetables (Jack et al., 2013; Nicklett and Kadell, 2013; see also Chapter 7).

In a study of environmental factors in a disadvantaged area of Brisbane, Australia, price, availability and variety were not associated with reduced opportunities to purchase fresh produce (Winkler et al., 2006). A mail survey of residents of a poor community in the United Kingdom (Pearson et al., 2005) concluded that age and gender were consumption determinants, while fruit and vegetable price, socio-economic deprivation and limited local grocery store access were not. Similarly, a study of residents in New York City neighborhoods determined that socio-economic status, particularly education, was a predictor of fruit and vegetable intake, while access determined by zip-code level disparities in availability was not (Jack et al., 2013). In contrast, 68 low-income residents of North Carolina identified six perceived barriers to fruit and vegetable consumption in qualitative interviews; cost, transportation, poor quality of available produce, limited variety, changing food environments and societal norms (Haynes-Maslow et al., 2013). It is not known why studies with similar aims reveal dissimilar barriers to fruit and vegetable consumption among economically disadvantaged participants, however sample size, geographic location of the participants and the characteristics of non-participants in each study may limit the generalizability of study findings (Haynes-Maslow et al., 2013).

A decade ago, in both Canada and the United States, high-income households increased their spending on fruits and vegetables when faced with theoretical additional income, while low-income households allocated additional income to meat, clothing or housing (Kirkpatrick and Tarasuk, 2003; Blisard et al., 2004). Recent observations reveal that as household income increases, more money is spent on food in general, including unhealthy products (defined as energy-dense nutrient-poor foods) (An, 2013). Healthy products (fruits and vegetables, fish, seafood and non-white bread) are less responsive to price change than unhealthy products such as cakes and cookies (Okrent and Alston, 2012). Consumer spending on food now includes a significant portion as "food away from home", and there are many substitution and complementary relationships for food products within and between the healthy and unhealthy food groups. This makes it difficult to accurately predict the effect of potential subsidies and taxes applied to some foods on the purchase and intake of other foods. Thus government initiatives to increase fruit and vegetable consumption will not reflect actual consumer behavior in the complex food market if consumption predictions are based on the traditional price elasticities of small groups of products (Okrent and Alston, 2012).

Economic models have been used successfully to determine the value of consumer-perceived quality attributes for specific fruits. Harker et al. (2003) reviewed consumer behavior aspects of price versus quality in the apple market and described several studies that use the experimental technique of conjoint analysis to observe consumer trade-offs of price and quality attributes. The contingent valuation literature includes a variety of studies that use the willingness-to-pay (WTP) approach (choice experiments) to model the probable increase in WTP as a function of consumer demographics, attitudes and values and liking for sensory attributes, all of which form the basis of quality perceptions. Gallardo (2011) suggests that this approach benefits fruit producers, retailers and marketers as it describes how consumers value novel products and fruit from alternative postharvest storage methods. This technique has been used to determine consumer WTP for optimal "Anjou" pear quality (Gallardo et al., 2011) and value-added blueberry products (Hu et al., 2009). Lund et al. (2006) used an experimental market setting to explore WTP and Willingness To Accept (WTA) apples of two different ages and qualities. New Zealand "Granny Smith" apples stored in a controlled atmosphere (CA) for 20 weeks were presented to consumers as "old" apples and Washington apples harvested six months after the New Zealand apples (never CA stored) were presented as "new" apples. "New" apples were initially preferred by consumers; however, preference decreased after tasting revealed a soft texture to the "new" apples. The revealed sensory qualities diminished the value of the apples for some participants, but not for others, who perceived stored apples ("old") to be less healthy than "new" apples. The perceived monetary value of the apples was influenced by both sensory aspects and emotional perceptions of freshness.

B Age and gender

Fresh fruit and vegetable consumption statistics have been generated in a number of developed countries in order to describe the relationship between age, gender and fruit and vegetable consumption, while research studies have been performed to explore and model the relationship among these factors. As described in Section II, differences in fruit and vegetable recommendations and data collection and documentation methods can make direct cross-country comparisons of consumption statistics difficult. However, there are some international commonalities in studies from developed economies: females are more likely to consume a greater number of daily fruit and vegetable servings than men (Alkerwi et al., 2012; de Abreu et al., 2013), while the greatest compliance in meeting the recommended intake is often seen among children and seniors (Nicklett and Kadell, 2013). It has been suggested that because children are more likely to consume juice than any other age group, they more easily meet fruit and vegetable recommendations (Black and Billette, 2013).

Perceptions of fruits and vegetables differ among children and adults (Krolner et al., 2011). Factors associated with their consumption have been studied generally for the purpose of understanding current consumption habits and increasing consumption through the influence of favorable factors.

Factors affecting childhood consumption

Food consumption and eating habits develop in the formative years of childhood. A number of theories have been proposed to describe behavior formation and continuation. Ecological models expand the theoretical perspective by considering direct environment-individual interactions, and may offer an explanation for consumption habits.

In their review of quantitative studies of the determinants of fruit and vegetable consumption among children and adolescents, Rasmussen et al. (2006) concluded that high consumption was associated with the female gender, low age, high socio-economic status, personal preference for fruits and vegetables and family-related factors of high parental intake, shared meals and high availability in the home. In their subsequent review of qualitative studies that captured the views and experiences of young participants, these authors summarized nine potential determinants of fruit and vegetable intake. Among these were the tradeoff of time and being healthy (fruits and vegetables were perceived to be less convenient to carry, prepare and eat than easily accessible pre-packaged foods), situational norms among peers that determined the appropriateness of the eating occasion of fruits and vegetables, limited availability of fresh products at school, and the cost and inconsistent taste of fruits and vegetables (Krolner et al., 2011).

The environment that is established and maintained by parents, childcare providers, and schools influences childhood fruit and vegetable consumption, and a combination of interventions by all of these groups is more effective at increasing fruit and vegetable consumption than the efforts of one group alone (Blanchette and Brug, 2005). The home environment and family support exert a strong influence on childhood fruit and vegetable consumption, including parental intake, availability and accessibility through fruit bowls, and regularly consumed family meals (Rasmussen et al., 2006; Krolner et al., 2011; Pedersen et al., 2012; Di Noia and Byrd-Bredbenner, 2013; van Ansem et al., 2013). Preparation by parents of fruits and vegetables as ready to go snacks is recommended to reduce children's perceived time-cost barrier to consumption (Krolner et al., 2011). Eating occasions at school may be enhanced if a variety of high-quality fresh produce is offered in school cafeterias and time is provided for fruit breaks (Krolner et al., 2011). Encouraging children to choose from among a selection of fruits and vegetables has been demonstrated to increase intake (Rohlfs Domínguez et al., 2013), and reduced access to less healthy rival snack food choices is often suggested to encourage fruit and vegetable consumption as snacks (Krolner et al., 2011).

Factors affecting adult consumption

Although childhood and adolescent patterns of fruit and vegetable consumption persist into adulthood (Lien et al., 2001; Pedersen et al., 2013), the overall factors which contribute to adult consumption differ from those of childhood consumption. Positive attitudes towards healthy eating behaviors generally result in greater fruit and vegetable consumption rates (Hearty et al., 2007) and also influence the likelihood of behavior change in the future.

The impact of some socio-economic variables (availability, price) on fruit and vegetable consumption remains controversial, as discussed in Section VA, while the impact of others is clear based on studies in developed economies. Being married is associated with increased fruit and vegetable consumption (Donkin et al., 1998; Billson et al., 1999). Male adults are less likely than females to meet recommended intakes of fruit and vegetables (Taylor et al., 2013). Taylor et al. (2013) reviewed nine intervention studies aimed at increasing fruit and vegetable intakes among males. They suggested that the main barriers to healthy dietary behaviors were perceived lack of time and a lack of willpower and motivation, and concluded that effective interventions for males must be "clear, concise and achievable", contain comical messages, and practical advice.

Older adults tend to eat more grains, fruit and vegetables than younger adults, although several studies suggest that less than 50% of older adults consume the recommended number of daily servings (Nicklett and Kadell, 2013). Disabled or mobility-impaired older adults face the greatest challenges to fresh fruit and vegetable intake due to health problems, social isolation and transportation challenges.

The psycho-social determinants of fruits and vegetable consumption elicited from Dutch adults using focus groups were determined to be satisfaction (with an emphasis on taste), perceived health consequences, social influences, skills and barriers, habit and lack of awareness of health benefits from recommended intakes (Brug et al., 1995). A review of psychosocial constructs from 35 studies revealed similar determinants (Shaikh et al., 2008). The motivation for these studies is ultimately improved population health through nutrition education regarding fruit and vegetable consumption. However, the beliefs about fruits and vegetables generate a picture of the quality expectations and quality perceptions of these products in the population surveyed. Information such as this can be used by the horticultural industry to describe perceptions of fresh produce quality within a population. Fruit and vegetable breeding, placement and promotion can then be targeted to meet quality perceptions.

VI Concluding comments

Descriptions and evaluations of consumer eating habits of fruit and vegetables appear in academic studies, trade publications and mass media with increasing frequency in response to the mounting evidence that the consumption of fresh fruits and vegetables is beneficial for maintaining health and preventing a variety of diseases. To date, fruit and vegetable consumption has been associated with decreased risk of diabetes, cardiovascular disease and some cancers, and associated with beneficial relationships with Chronic Obstructive Pulmonary Disease, eye health, asthma, bone health, weight management and neurodegenerative diseases of aging (Boeing et al., 2012; Willett and Stampfer, 2013). Nutrition is considered to be one of the few modifiable lifestyle factors predicting health in old age (Nicklett and Kadell, 2013).

Despite the establishment of increasing evidence of the link between increased fruit and vegetable consumption and health benefits, many consumers are not motivated to increase their consumption of fresh produce and to meet the minimum suggested daily serving recommendations for fruits and vegetables. However, health is only one motivator of fruit and vegetable consumption, and an emphasis on making health choices serves as a “disciplinary stick” and neglects “the pleasure of healthy eating” (Poole et al., 2007). It was previously observed that higher incomes allowed consumers to purchase a greater number of healthy products, including fruits and vegetables. However, this relationship no longer holds true (Okrent and Alston, 2012).

The determinants of consumer eating habits of fruits and vegetables describe the environmental and psychosocial factors that contribute to their consumption. Price, income and availability, gender and age and motivations of ethical consumerism are all part of the complex of determinants of eating behaviors and perceptions of quality that determine individual eating habits. Studies of determinants of fruit and vegetable consumption of both adults and children often yield conflicting results, and overall summaries of these studies reveal complex maps of factors that influence the decision-making process to eat these products. Perhaps because of this complexity of factors, promotional campaigns to increase fruit and vegetable consumption have not always met with their anticipated success. However, interventions appear to result in some degree of improved consumption, and further studies of psychosocial determinants of fruit and vegetable consumption linked to the design of promotional activities may result in enhanced fruit and vegetable consumption.

The horticultural industry can maximize benefit from both increased knowledge of consumer eating habits and the predicted increased demand for fresh fruits and vegetables, using the consumer-perceived quality paradigm to develop, target and promote products to consumers. The market-driven and consumer-oriented approach to quality (Oude Ophuis and Van Trijp, 1995) contains the elements of intrinsic and extrinsic quality cues, experience quality attributes and credence quality attributes. This paradigm of quality has the advantage of tangibly relating quality attributes to physical product parameters, such as sensory attributes, and to consumer trends such as the desire for organic, heirloom and locally grown produce, which are motivated by personal values. The horticultural industry must evaluate produce quality with consideration to consumer food use rather than industry-related quality attributes that frame fruits and vegetables as objects of trade. Advances in postharvest technologies must continue to be evaluated using the consumer-oriented approach to quality, as advances are of limited commercial value unless they result in products with attributes desired by the consumer. Additionally, product-specific information about fruits, such as variety specific information, can help consumers with their purchase decisions. As Oude Ophius and Van Trijp (1995) suggest, anyone who wants to make and sell food products should understand consumer perceived quality.

Descriptions of global consumer eating habits of fresh fruit and vegetables, health benefits associated with fruit and vegetable consumption, and the multitude of fruit and vegetable promotion campaigns confirm that increased fruit and vegetable consumption is both a public health issue and an opportunity for the fresh fruit and vegetable industry. However, the complexity of the determinants of eating habits and multitude of factors involved in the evaluation of consumer-perceived quality of fruits and vegetables present a challenge to this expansion. Continued monitoring of fresh fruit and vegetable intake and further studies to elucidate determinants of eating habits and increase understanding of consumer perceived quality, coupled with awareness, appreciation and monitoring of these factors by the fresh fruit and vegetable industry are key to overcoming this challenge. An understanding of consumer-perceived quality of fresh produce and management of postharvest systems to support consumer expectations will provide the horticultural industry with an opportunity for growth.

Bibliography

Abbott, J.A., 1999. Quality measurement of fruits and vegetables. Postharvest Biol. Technol. 15, 207–225.

Alkerwi, A., Sauvageot, N., Nau, A., et al., 2012. Population compliance with national dietary recommendations and its determinants: findings from the ORISCAV-LUX study. Br. J. Nutr. 108, 2083–2092.

Almeida, D.P.F., Gomes, M.H., 2009. Uncoupling the sensory effects of 1-Methylcyclopropen and ripening stage on ‘Hayward’ kiwifruit. HortScience 44, 1936–1940.

An, R., 2013. Effectiveness of subsidies in promoting healthy food purchases and consumption: a review of field experiments. Public Health Nutr. 16, 1215–1228.

Anonymous, 2013. Heirloom Vegetables. Cooperative Education Service – College of Agriculture, University of Kentucky, Available on-line at: <www.uky.edu/Ag/NewCrops/introsheets/heirloom.pdf> (accessed 26.08.13).

Barrett, C.E., Zhao, X., Sims, C.A., Brecht, J.K., Dreyer, E.Q., Gao, Z., 2012. Fruit composition and sensory attributes of organic heirloom tomatoes as affected by grafting. HortTechnology 22, 804–809.

Barrett, D.M., Beaulieu, J.C., Shewfelt, R., 2010. Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. Crit. Rev. Food Sci. Nutr. 50, 369–389.

Bezençon, V., Blili, S., 2011. Segmenting the market through the determinants of involvement: the case of fair trade. Psychol. Mark. 28, 682–708.

Billson, H., Pryer, J.A., Nichols, R., 1999. Variation in fruit and vegetable consumption among adults in Britain. An analysis from the dietary and nutritional survey of British adults. Eur. J. Clin. Nutr. 53, 946–952.

Black, J.L., Billette, J.M., 2013. Do Canadians meet Canada's Food Guide's recommendations for fruits and vegetables? Appl. Physiol. Nutr. Metab. 38, 234–242.

Blanchette, L., Brug, J., 2005. Determinants of fruit and vegetable consumption among 6–12-year-old children and effective interventions to increase consumption. J. Hum. Nutr. Diet. 18, 431–443.

Blisard, N., Stewart, H., Jolliffe, D., 2004. Low-income households' expenditures on fruits and vegetables. USDA/ERS Agricultural Economics Report No. 838, US Gov't Printing Office, Washington, DC 833, 1–26.

Boeing, H., Bechthold, A., Bub, A., et al., 2012. Critical review: vegetables and fruit in the prevention of chronic diseases. Eur. J. Nutr. 51, 637–663.

Brown, C., Vales, I., Yilma, S., et al., 2012. 'AmaRosa', a red skinned, red fleshed fingerling with high phytonutrient value. Am. J. Potato Res. 89, 249–254.

Brug, J., Lechner, L., De Vries, H., 1995. Psychosocial determinants of fruit and vegetable consumption. Appetite 25, 285–296.

Campbell, R.L., Smith, B.G., Jaeger, S.R., Harker, F.R., 2009. Deterioration and disposal of fruit in the home: consumer interviews and fruit quality assessments. J. Sci. Food Agric. 89, 24–32.

CDC, 2013. State Indicator Report on Fruits and Vegetables 2013, Centers for Disease Control and Prevention, U.S. Department of Health and Human Services, Atlanta, GA.

Cliff, M., Sanford, K., Wismer, W., Hampson, C., 2002. Use of digital images for evaluation of factors responsible for visual preference of apples by consumers. HortScience 37, 1127–1131.

Connors, P.L., Rozell, S.B., 2004. Using a visual plate waste study to nonitor menu performance. J. Am. Diet. Assoc. 104, 94–96.

Crisosto, C.H., Garner, D., Crisosto, G., 2002. Carbon dioxide-enriched atmospheres during cold storage limit losses from Botrytis but accelerate rachis browning of 'Redglobe' table grapes. Postharvest Biol. Technol. 26, 181–189.

de Abreu, D., Guessous, I., Vaucher, J., et al., 2013. Low compliance with dietary recommendations for food intake among adults. Clin. Nutr. 32, 783–788.

Dever, M.C., Cliff, M.A., Hall, J.W., 1995. Analysis of variation and multivariate relationships among analytical and sensory characteristics in whole apple evaluation. J. Sci. Food Agric. 69, 329–338.

Di Noia, J., Byrd-Bredbenner, C., 2013. Adolescent fruit and vegetable intake: influence of family support and moderation by home availability of relationships with afrocentric values and taste preferences. J. Acad. Nutr. Diet. 113, 803–808.

Donkin, A.J., Johnson, A.E., Morgan, K., Neale, R.J., Page, R.M., Silburn, R.L., 1998. Gender and living alone as determinants of fruit and vegetable consumption among the elderly living at home in urban Nottingham. Appetite 30, 39–51.

Duran, N., Marcato, P.D., 2013. Nanobiotechnology perspectives. Role of nanotechnology in the food industry: a review. Int. J. Food Sci. Nutr. Technol. 48, 1127–1134.

Engstrom, R., Carlsson-Kanyama, A., 2004. Food losses in food service institutions Examples from Sweden. Food Policy 29, 203–213.

European Food Information Council (EUFIC), 2012. Fruit and vegetable consumption in Europe – do Europeans get enough? EUFIC Rev., 1–7.

FAO, 2006. Spotlight: More fruit and vegetables. Issues in World Agriculture, 20 September 2013. Available on-line at: <http://www.fao.org/ag/magazine/0606sp2.htm>. (accessed 26.08.13).

FAO/WHO, 2005. Fruit and Vegetables for Health. Report of the Joint WHO/FAO Workshop on Fruit and Vegetables for Health Kobe, Japan, 1–3 September 2004 ISBN: 92 4 159281 8, 1–39.

Gallardo, R.K., 2011. Choice experiments' findings: a tool for fruit agribusiness managers' decision making. Int. Food Agribusiness Manage. Rev. 14, 95–110.

Gallardo, R.K., Kupferman, E., Colonna, A., 2011. Willingness to pay for optimal 'Anjou' pear quality. HortScience 46, 452–456.

Gamble, J., Jaeger, S., Harker, R., 2006. Preferences in pear appearance and response to novelty among Australian and New Zealand consumers. Postharvest Biol. Technol. 41, 38–47.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A., 2011. Global Food Losses and Food Waste. Food and Agriculture Organization of the United Nations, Rome, 30 pp.

Harker, F.R., Gunson, F.A., Jaeger, S.R., 2003. The case for fruit quality: an interpretive review of consumer attitudes, and preferences for apples. Postharvest Biol. Technol. 28, 333–347.

Harker, F.R., Maindonald, J., Murray, S.H., Gunson, F.A., Hallett, I.C., Walker, S.B., 2002a. Sensory interpretation of instrumental measurements 1: texture of apple fruit. Postharvest Biol. Technol. 24, 225–239.

Harker, F.R., Kupferman, E.M., Marin, A.B., Gunson, F.A., Triggs, C.M., 2008. Eating quality standards for apples based on consumer preferences. Postharvest Biol. Technol. 50, 70–78.

Harker, R.F., Gunson, A.F., Brookfield, P.L., White, A., 2002b. An apple a day: the influence of memory on consumer judgment of quality. Food Qual. Preference 13, 173–179.

Harper, G.C., Makatouni, A., 2002. Consumer perception of organic food production and farm animal welfare. Br. Food J. 104, 287–299.

Haynes-Maslow, L., Parsons, S.E., Wheeler, S.B., Leone, L.A., 2013. A qualitative study of perceived barriers to fruit and vegetable consumption among low-income populations, North Carolina, 2011. Preventing Chronic Disease 10:120206. doi: http://dx.doi.org/10.5888/pcd10.120206.

Hearty, A.P., McCarthy, S.N., Kearney, J.M., Gibney, M.J., 2007. Relationship between attitudes towards healthy eating and dietary behaviour, lifestyle and demographic factors in a represenative sample of Irish adults. Appetite 48, 1–11.

Hu, W., Woods, T., Bastin, S., 2009. Consumer acceptance and willingness to pay for blueberry products with nonconventional attributes. J. Agric. Appl. Econ. 41, 47–60.

Hughner, R.S., McDonagh, P., Prothero, A., Shultz II, C.J., Stanton, J., 2007. Who are organic food consumers? A compilation and review of why people purchase organic food. J. Consum. Behav. 6, 94−110.

Jack, D., Neckerman, K., Schwartz-Soicher, O., et al., 2013. Socio-economic status, neighbourhood food environments and consumption of fruits and vegetables in New York City. Public Health Nutr. 16, 1197−1205.

Jaeger, S.R., Lund, C.M., Lau, K., Harker, F.R., 2003a. In search of the "ideal pear" (*Pyrus* spp.): results of a multidisciplinary exploration. J. Food Sci. 68, 1108−1117.

Jaeger, S.R., Rossiter, K.L., Wismer, W.V., Harker, F.R., 2003b. Consumer-driven product development in the kiwifruit industry. Food Qual. Preference 14, 187−198.

Jaeger, S.R., Harker, R., Triggs, C.M., et al., 2011. Determining consumer purchase intentions: the importance of dry matter, size, and price of kiwifruit. J. Food Sci. 76, S177−S184.

Karst, T., 2013a. Per-capita numbers reveal vegetable slide. The Packer. Available at <http://www.thepacker.com/fruit-vegetable-news/Per-capita-numbers-reveal-vegetable-slide-224445271.html> (accessed 20.09.13).

Karst, T., 2013b. Facing the facts: per capita consumption still declining. The Grower. Available at <http://www.thepacker.com/opinion/fresh-talk-blog/Facing-the-facts-Per-capita-consumption-still-declining-214550011.html> (accessed 20.09.13).

Kays, S.J., 1999. Preharvest factors affecting appearance. Postharvest Biol. Technol. 15, 233−247.

Kirkpatrick, S., Tarasuk, V., 2003. The relationship between low income and houehold food expenditure patterns in Canada. Public Health Nutr. 6, 589−598.

Klee, H.J., 2010. Improving the flavor of fresh fruits: genomics, biochemistry, and biotechnology. New Phytol. 187, 44−56.

Krolner, R., Rasmussen, M., Brug, J., Klepp, K.I., Wind, M., Due, P., 2011. Determinants of fruit and vegetable consumption among children and adolescents: a review of the literature. Part II: qualitative studies. Int. J. Behav. Nutr. Phys. Act. 8, 112-5868-8-112.

Lago, C., Landoni, M., Cassani, E., Doria, E., Nielsen, E., Pilu, R., 2013. Study and characterization of a novel functional food: purple popcorn. Mol. Breed. 31, 575−585.

Lan Chen, Opara, U.L., 2013. Texture measurement approaches in fresh and processed foods − a review. Food Res. Int. 51, 823−835.

Li, J., Walker, C.E., Faubion, J.M., 2011. Acidulant and oven type affect total anthocyanin content of blue corn cookies. J. Sci. Food Agric. 91, 38−43.

Lien, N., Lytle, L.A., Klepp, K.I., 2001. Stability in consumption of fruit, vegetables, and sugary foods in a cohort from age 14 to age 21. Prev. Med. 33, 217−226.

Lund, C.M., Jaeger, S.R., Amos, R.L., Brookfield, P., Harker, F.R., 2006. Tradeoffs between emotional and sensory perceptions of freshness influence the price consumers will pay for apples: results from an experimental market. Postharvest Biol. Technol. 41, 172−180.

Lundahl, D.S., 2006. A holistic approach to product development. Food Technol. 60, 28−33.

Marin, A.B., Colonna, A.E., Kudo, K., Kupferman, E.M., Mattheis, J.P., 2009. Measuring consumer response to 'Gala' apples treated with 1-Methylcyclorpopene (1-MCP). Postharvest Biol. Technol. 51, 73−79.

Marlette, M.A., Templeton, S.B., Panemangalore, M., 2005. Food type, food preperation, and competitive food purchases impact school lunch plate waste by sixth-grade students. J. Am. Diet. Assoc. 105, 1779−1782.

Mayuoni-Kirshinbaum, L., Daus, A., Porat, R., 2013. Changes in sensory quality and aroma volatile composition during prolonged storage of 'Wonderful' pomegranate fruit. Int. J. Food Sci. Technol. 48, 1569−1578.

Miller, F.A., Silva, C.L.M., Brandao, T.R.S., 2013. A review on ozone-based treatments for fruit and vegetables preservation. Food Eng. Rev. 5, 77−106.

Molt, M., 2001. Food For Fifty, 11th ed. Prentice Hall, Upper Saddle River, NJ.

Moser, R., Rafaelli, R., Thilmany-McFadden, D., 2011. Consumer preferences for fruit and vegetables with credence-based attributes: a review. Int. Food Agribusiness Manage. Rev. 14, 121−141.

Nicklas, T.A., O'Neil, C.E., Stuff, J.E., Hughes, S.O., Liu, Y., 2012. Characterizing dinner meals served and consumed by low-income preschool children. Child. Obes. 8, 561−571.

Nicklett, E.J., Kadell, A.R., 2013. Fruit and vegetable intake among older adults: a scoping review. Maturitas 75, 305−312.

OECD/European Union, 2010. Supply of Fruit and Vegetables for Consumption. Health at a Glance: Europe 2010. OECD Publishing, pp. 66−67.

Okrent, A., Alston, J.M., 2012. The demand for disaggregated food-away-from-home and food-at-home products in the United States. Available at <http://www.ers.usda.gov/publications/err-economic-research-report/err139.aspx#.Unfm-PmkpCY> (accessed 30.08.13).

Olivas, G.I., Barbosa-Canovas, G.V., 2006. Edible coatings for fresh fruit. Crit. Rev. Food Sci. Nutr. 45, 657−670.

Oms-Oliu, G., Odriozola-Serrano, I., Soliva-Fortuny, R., Elez-Martínez, P., Martín-Belloso, O., 2012. Stability of health-related compounds in plant foods through the application of non thermal processes. Trends Food Sci Tech 23, 111−123.

Oude Ophuis, P.A.M., Van Trijp, H., 1995. Perceived quality: a market driven and consumer oriented approach. Food Qual. Preference 6, 177−183.

Ozcaglar-Toulouse, N., Shiu, E., Shaw, D., 2006. In search of fair trade: Ethical consumer decision making in France. Int. J. Consum. Stud. 30, 502−514.

Palou, L., Jacas, J., Marcilla, A., Alonso, M., del Río, M.Á., 2008. Physico-chemical and sensory quality of 'Clemenules' mandarins and survival of the Mediterranean fruit fly as affected by complementary cold and carbon dioxide quarantine treatments. Postharvest Biol. Technol. 48, 443−450.

Pearson, T., Russell, J., Campbell, M.J., Barker, M.E., 2005. Do "food deserts" influence fruit and vegetable consumption? a cross-sectional study. Appetite 45, 195−197.

Pedersen, T.P., Holstein, B.E., Flachs, E.M., Rasmussen, M., 2013. Meal frequencies in early adolescence predict meal frequencies in late adolescence and early adulthood. BMC Public Health 13, 445. Available from: http://dx.doi.org/10.1186/1471-2458-13-445.

Pedersen, T.P., Meilstrup, C., Holstein, B.E., Rasmussen, M., 2012. Fruit and vegetable intake is associated with frequency of breakfast, lunch and evening meal: cross-sectional study of 11-, 13-, and 15-year-olds. Int. J. Behav. Nutr. Phys. Act. 9, 9. Available from: http://dx.doi.org/10.1186/1479-5868-9-9.

Peneau, S., Hoehn, E., Roth, H.R., Escher, F., Nuesli, J., 2006. Importance and consumer perception of freshness of apples. Food Qual. Preference 17, 9−19.

Péneau, S., Linke, A., Escher, F., Nuessli, J., 2009. Freshness of fruits and vegetables: consumer language and perception. Br. Food J. 111, 243–256.

Peneau, S., Brockhoff, P.B., Hoehn, E., Escher, F., Nuessli, J., 2007. Relating consumer evaluation of apple freshness to sensory and physico-chemical measurements. J. Sens. Stud. 22, 313–335.

Poole, N.D., Martinez, L.M.C., Gimenez, F.V., 2007. Quality perceptions under evolving information conditions: Implications for diet, health. Food Policy 32, 175–188.

Ramírez-Silva, I., Rivera, J.A., Ponce, X., Hernández-Ávila, M., 2009. Fruit and vegetable intake in the Mexican population: Results from the Mexican National Health and Nutrition Survey 2006. Salud Pública de México 51, 574–585.

Rasmussen, M., Krolner, R., Klepp, K., et al., 2006. Determinants of fruit and vegetable consumption among children and adolescents: a review of the literature. Part I: quantitative studies. Int. J. Behav. Nutr. Phys. Act. 3, 22. Available from: http://dx.doi.org/10.1186/1479-5868-3-22.

Rohlfs Domínguez, P., Gámiz, F., Gil, M., et al., 2013. Providing choice increases children's vegetable intake. Food Qual. Preference 30, 108–113.

Roininen, K., Fillion, L., Kilcast, D., Lähteenmäki, L., 2004. Exploring difficult textural properties of fruit and vegetables for the elderly in Finland and the United Kingdom. Food Qual. Preference 15, 517–530.

Shaikh, A.R., Yaroch, A.L., Nebeling, L., Yeh, M.C., Resnicow, K., 2008. Psychosocial predictors of fruit and vegetable consumption in adults a review of the literature. Am. J. Prev. Med. 34, 535–543.

Sivakumar, D., Fallik, E., 2013. Influence of heat treatments on quality retention of fresh and fresh-cut produce. Food Rev Int 29, 294–320.

Sloan, A.E., 2011. Navigating thenatural marketplace. Food Technol. 65, 24–33.

Statistics Canada., 2013. Fruit and vegetable consumption, 2012. Available at <http://www.statcan.gc.ca/pub/82-625-x/2013001/article/11837-eng.htm> (accessed 20.09.13).

Steenkamp, J.E.M., 1990. Conceptual model of the quality perception process. J. Bus. Res. 21, 309–333.

Stommel, J., Camp, M.J., Saftner, R.A., Abbott, J.A., 2005. Sensory and objective quality attributes of beta-carotene and lycopene-rich tomato fruit. J. Am. Soc. Hortic. Sci. 130, 244–251.

Taylor, P.J., Kolt, G.S., Vandelanotte, C., et al., 2013. A review of the nature and effectiveness of nutrition interventions in adult males – a guide for intervention strategies. Int. J. Behav. Nutr. Phys. Act. 10, 13. Available from: http://dx.doi.org/10.1186/1479-5868-10-13.

Tesfaye, L., Bink, M., Lans, I., Gremmen, B., Trijp, H., 2013. Bringing the voice of consumers into plant breeding with Bayesian modelling. Euphytica 189, 365–378.

van Ansem, W.J.C.v., Schrijvers, C.T.M., Rodenburg, G., van de Mheen, D., 2013. Is there an association between the home food environment, the local food shopping environment and children's fruit and vegetable intake? Results from the Dutch INPACT study. Public Health Nutr. 16, 1206–1214.

van den Heuvel, T., van Trijp, H., van Woerkum, C., Jan Renes, R., Gremmen, B., 2007. Linking product offering to consumer needs; inclusion of credence attributes and the influences of product features. Food Qual. Preference 18, 296–304.

Verain, M.C.D., Bartels, J., Dagevos, H., Sijtsema, S.J., Onwezen, M.C., Antonides, G., 2012. Segments of sustainable food consumers: a literature review. Int. J. Consum. Stud. 36, 123–132.

Villamor, R.R., Daniels, C.H., Moore, P.P., Ross, C.F., 2013. Preference mapping of frozen and fresh raspberries. J. Food Sci. 78, S911−S919.

von Alvesleben, R., Meier, T., 1990. The influence of origin and variety on consumer perception. Acta Hortic. 259, 151−161.

Watkins, C.B., 2008. Overview of 1-Methylcycloproopene trials and uses for edible horticultural crops. HortScience 43, 86−94.

Welker, E., ND. Barriers to fresh fruit and vegetable intake. Available at <http://gillingsproject.wordpress.com/barriers-to-fresh-fruit-and-vegetable-intake/> (accessed 20.09.13).

WHO, 2003. WHO Fruit and Vegetable Promotion Initiative − report of the meeting. Available at <http://www.who.int/dietphysicalactivity/fruit/en/> (accessed 24.08.13).

Willett, W.C., Stampfer, M.J., 2013. Current evidence on healthy eating. Annu Rev. Public Health 34, 77−95.

Winkler, E., Turrell, G., Patterson, C., 2006. Does living in a disadvantaged area entail limited opportunities to purchase fresh fruit and vegetables in terms of price, availability, and variety? Findings from the Brisbane Food Study. Health Place 12, 741−748.

Wismer, W.V., Harker, F.R., Gunson, F.A., Rossiter, K.L., Lau, K., Seal, A.G., Lowe, R.G., Beatson, R., 2005. Identifying flavour targets for fruit breeding: a kiwifruit example. Euphytica 141, 93−104.

CHAPTER

Testing and Measuring Consumer Acceptance

4

Bernhard Brueckner

Leibniz-Institute for Vegetable and Ornamental Crops (IGZ), Grossbeeren, Germany

Introduction

The view on fruit and vegetable quality has changed. What had been an alternative concept a few decades ago has become mainstream today. The agricultural production chain is more integrated across all stakeholders now, and the consumer has gained a central role: produce quality cannot be defined without information from and about the consumer. In the past, each member of the supply chain of fresh produce focused on attaining acceptance by following the links within the chain. In practice, it largely required maintenance of quality standards (see Chapters 8 and 9). The rationale was to have defined criteria, which could facilitate communication during shipment or distribution and, to some extent, allow comparison of different product shipments.

Thus, the quality of fresh horticultural produce was usually evaluated against standards for grading. These standards included product attributes which can be readily determined, and are related to color, appearance and absence of defects. In the past, breeders successfully developed cultivars with improved yields and attributes laid down in the specifications. Besides yield and grades, other targets were the hardiness and resistance of the plants, uniformity, extension of the season and in a few cases shelf life or suitability for processing. Consumers were thought to be satisfied with the grades, season extension and varied choices at prices they could afford. However, this proved not to be the whole truth (Köster and Mojet, 2012; see also Chapter 3). For instance, in the 1990s German consumers were dissatisfied with the poor flavor intensity of fresh tomatoes originating from The Netherlands. Subsequently, Dutch tomatoes experienced a sustained decline in sales of 30% in Germany (Behr and Illert, 2002). Due to efforts to improve the flavor through breeding, variety selection, cultural and postharvest techniques and consumer surveying, The Netherlands are now the largest exporter of fresh tomatoes in Europe (Gumbel, 2013). Much of the attractiveness to consumers of products of this origin was lost during those years, because of the characteristics of the fruit which were perceived through the senses of consumers. Flavor intensity is part of the consumption experience and thus, perceivable only after purchase. Other important drivers of acceptance among consumers include

Postharvest Handling.

intrinsic attributes, such as appearance, color, odor and texture. These can be more readily perceived, and help in the search for attractive products before the final selection and purchase. Both quality assessed from experience and quality used during the search can be evaluated by consumers directly by comparing their expectations with the information received from their sensorial perceptions (Grunert, 2005). Innovation in the food sector often relies on additional information (technical and emotional) provided with the product to assist consumer evaluation (Grunert, 2012).

II Experience and credence attributes

It is argued that the quality of a product is assessed by consumers very rarely using direct sensory impressions (Costell et al., 2010; Meiselman, 2013). And of course, there are other factors which cannot be ascertained even by experienced consumers. Most health-related properties and their effect on the human body cannot be experienced, felt or validated by a consumer. The quality of the production process – increasingly important and well-recognized by many consumers – is, in most cases, undetectable as an intrinsic property. Not only are consumers unable to detect differences between the use and non-use of genetically modified techniques (see also Chapter 20), regard or disregard for social or environmental standards, or whether the produce is conventionally or organically grown, even sophisticated instrumentation can hardly authenticate organically grown produce (Banasiak et al., 2004).

These credence attributes are important to many consumers, but they are unable to experience them and must rely on the statements of others (see also Chapter 3). Consumers, therefore, use cues which they recognize at and around the product, and infer the credence attributes from these (Grunert, 2012). All properties which can be observed may serve this purpose, e.g., appearance, color, size, visible structure, firmness to the touch and increasingly packaging and the information on it (Köster, 2009; Thomson, 2008). They may also be communicated at a retail outlet, or through media, including Internet pages or forums. In the case of fruit and vegetables, the place of origin is an important cue for inferring quality. This cue can be so strong that it surpasses actual sensory perception, for instance, in the case of nationally or organically produced tomatoes over imported ones, although all three may be intrinsically the same, but differently labeled (Ferquist and Ekelund, 2013). Important cues can also be brands or product concepts, although these are more often associated with processed products.

Not only prior to, but also after purchase, credence attributes will be perceived and may still influence the perceived quality of the product, which may fade with time. Especially in the case of repeated purchase and consumption, personal experience becomes more important than the indirectly assessed credence qualities. This gradual loss of quality dimensions may become a disadvantage, especially for products where a high proportion of extrinsic, credence quality is involved (e.g., functional foods).

The producer only partly controls the perception of credence attributes, as well as the perception of experience attributes. Situational variables change during transport, storage, preparation and consumption. Learning how to handle produce can result in consistency or improve the experience of quality and, therefore, information on maturity (see also Chapter 15), storage conditions and preparation methods is helpful to consumers.

A comprehensive discussion of the influences on consumer acceptance can be found in the book by Meiselman (2007), Chapter 1 of which contains a review of many models of food acceptance, with different emphases within the three classes of variables of eating research:

- food variables: palatability, appearance and flavor (Harper, 1981; Land, 1983; Cardello, 1996; Tuorila, 2007);
- people variables: responsiveness to food cues, restrained eating, expectations;
- human focused (Connors et al., 2001), human-product linked (Cardello, 1994; Krystallis, 2007); and
- environmental variables: physical, social context and economic factors (Marshall, 1995).

Influences on acceptance were discussed more recently (Meiselman, 2013) and are the subject of intensifying research.

III Acceptance

Depending on the inclusion of variables from one or more of the above classes (i.e., food, people or environment) acceptance can be understood in another way:

Focus on:	Food is Acceptable Only When:
Food variables	Attributes are acceptable
People variables	Attributes and food cues meet responsive minds and match expectations
Environmental variables	Product is attractive (people variable) and has favorable physical, social and an economic situation or circumstance

The separation of effects into three classes, of course, is a simplification of actual possibilities. Acceptance of attributes, for instance, depends not only on the attributes, but also on people factors. However, when consumers are considered as individuals (and between individual variance is avoided) the influence of product attributes triggers acceptance (compare: Chapter 15).

The classical definition (Amerine et al., 1965) reflects the two opposite scenarios: “actual utilization (purchase or eating)” by consumers and “experience or feature of experience, characterized by a positive attitude toward the food." The first states that for assessment of acceptance, knowledge of the product variables, personal variables, the situational variables and even the outcome of trade-offs between perceived quality and perceived price (Grunert, 2005) has been reached. The second refers to an experience, gained directly from the sensory interaction between consumer and product.

This interface is the central focus of sensory acceptance tests. The investigator is interested in "whether the consumer likes the product, prefers it over another product or finds the product acceptable based on its sensory characteristics" (Lawless and Heymann, 2010). Food acceptance is treated as a "perceptual/evaluative construct", a "phenomenological experience, best categorized as a feeling, emotion or mood with a defining pleasant or unpleasant character" (Cardello, 1996; Jeager et al., 2013). Cardello adds two ways to measure acceptance. Self- or verbal-reports are used where a phenomenological approach prevails, whereas choice and consumption are observed when the focus is on the consequences of acceptance. Data from observed behavior can be collected electronically or through personal observation. Self-reporting includes group or face-to-face interviews, telephone interviews with CATI (computer aided telephone interview) or without electronic support, paper and pencil method (self administered questionnaire), or mailed questionnaires (Busch-Stockfisch, 2013).

IV Qualitative tests

Qualitative tests often measure the subjective responses of a consumer sample to the sensory properties of a product. Consumers talk about their feelings in a small group setting or interview (Meilgaard et al., 2006). The initial response to a new concept, the general acceptance of a prototype or information on other obvious problems is obtained and allows for project readjustment. Because of the personal interaction, the consumer's terminology can be studied and consumer-oriented terms can be learned for use in questionnaires and advertisements. Another advantage is to learn about reasons for and practices of consumer behavior regarding product use, which could facilitate handling, etc. For fruit and vegetables, this is not only limited to innovation in package convenience, but also to new mix, size and properties of the produce for use in cooking.

Usually, an interviewer or moderator with skills in group dynamics, probing techniques, summarizing and reporting meets a group of 10−12 persons (focus group). Group members are selected on the basis of product usage and socio-demographics, and they participate in two or three sessions, each for one to two hours. The subject of interest is presented, and the discussion facilitates obtaining as much information as possible. If the group meets on a regular basis, for instance to use a product at home between sessions, it is called a focus panel. If additional (or sensitive) information is sought from each individual, one-on-one consumer interviews are appropriate. Such interviews may be conducted at the interviewer's site or in consumer's homes. In some cases, observation of the consumer's product preparation, etc., yields very different information from the consumer's verbal statements (Meilgaard et al., 2006).

V Quantitative tests

There are two approaches to quantitative consumer acceptance testing: tests that rely on choice or on rating. Relative preference is determined using the first method.

VI Testing preference

Preference, classically used for testing in the food industry, can be defined in three ways (Amerine et al., 1965):

1. expression of a higher degree of preference;
2. choice of one object over others; and
3. basis of choice, psychological continuum of affectivity (pleasantness/unpleasantness).

However, preference tests are usually designed to measure the appeal of one food or food product over another (Stone et al., 2012). The panelists receive two coded samples (usually simultaneously), and their task is to answer the question: "which sample do you prefer or like better?" (Meilgaard et al., 2006). The task is rather intuitive and can be performed easily even by semi- or illiterate consumers (Coetzee and Taylor, 1996).

It is usually recommended that the consumer must choose one product over the other (Stone et al., 2012). Such a choice helps the interpretation (because tests rely on a binominal distribution), and enables the use of all answers. If a preference decision is not given, the researcher has to decide either to ignore or to split those answers 50:50, or to split them in proportion to other answers. Another possibility for large consumer numbers (>100) is to calculate confidence intervals based on a multi-nominal distribution. With non-overlapping confidence intervals of respondents expressing a preference, and a small number of no preference answers, the significance level can be identified. Details of relevant procedures can be found in the literature (Lawless and Heymann, 2010; Moskowitz et al., 2012b).

Special cases of preference testing are repeated pair-wise preference tests and sequential preference ranking of a series of samples. The aim of both methods is to obtain information on the relative preference for an array of products. It is again an intuitive task for consumers to rank products according to their preference for visual, tactile and pronounced taste or flavor perception, but complex multi-flavor or taste samples can become stressful. A sequence of increased acceptance can be calculated not only from ranking, but also from the results of repeated pair-wise comparisons. In both cases, received data are ordinal and thus the absolute degree of liking and the relative distance of successive samples cannot be quantified. The reported liking is only relative between the samples and inherent to the presented set of samples.

Preference tests are less frequently used than measuring acceptance with fruit and vegetables. This is probably because the typical case is not comparing one cultivar, cultivation technique or maturity stage to another (see also Chapter 15), but comparing a range of influences on the resulting quality. In very few cases only a single property may be changed, but physiological processes lead to a multitude of altered texture, taste, aroma or flavor attributes. To be able to explain differences in acceptance, therefore, a larger data set which gives quantitative information on acceptance is necessary. There are cases where testing whether, for example, the use of a chemical or distinct postharvest alternatives have a positive or negative effect on preference. Here preference testing is most efficient (Harker et al., 2008).

VII Testing acceptance

Most hedonic testing of fruit and vegetables is done using acceptance tests. Here panelists work as a measuring instrument not to measure products, but to quantify their own affective reaction evoked by the sample. Except in preference testing, acceptance tests can be performed using only one sample, but usually 10 or 12 samples are tested. The samples are coded with a three- to four-digit number and are usually presented one after the other (monadic). The sequence of samples differs from panelist to panelist, because the constant position as an earlier or later presented sample will bias the results. The possible number of samples depends, as well as the type of samples and the composition of the panel, on the number and type of questions posed.

The central question is “how much do you like the product?” or “how acceptable is the product?” (Meilgaard et al., 2006). However, detailed information on the acceptance of several attributes is often required, and can be included in the protocol. Additional questions ask consumers how much they like the appearance, aroma, flavor, texture or after-taste, or even more specific attributes such as color, sweetness or crunchiness. Answers allow responses as to whether, for example, the sweetness is not liked because the product is too sweet or not sweet enough. Therefore, just-about-right questions (JAR) are used where respondents have to rate whether the level of the sensory attribute is “too low”, “just right” or “too high”. Although the rating is also done on a hedonic scale, it forces panelists to form a fairly analytical judgment and is found to influence results (Popper et al., 2004).

An even more analytical approach is required when, instead of hedonic questions, attribute intensity questions are included, but this is generally not recommended (Stone et al., 2012). Again the more integrative, hedonic and naïve (an approach not used by a specialist) approach is disturbed by a specific, analytical task. Another important reason for not recommending hedonic and analytic tasks to be combined in one test is the different selection criteria for participants in hedonic and analytic tests.

Panelists for acceptance tests are chosen to represent a target population. They are users of the product in question, but should be naïve users, not professionals in food issues. A discussion of the use of employees for in-company product testing can be found in Lawless and Heymann (2010). Other requirements are demographic characteristics, such as age or gender distribution, again with respect to the target population. In contrast, analytical testers are selected after successfully passing standardized tests for olfactory, taste and color sensibilities, as well as memory, verbal abilities and creativity. They do not need to be members of a target population (Stone et al., 2012; Lawless and Heymann, 2010).

VIII Scales

Information regarding scales is obtained from assigned words, numbers or scale positions marked by a panelist. There has been much discussion about the best scale (Moskowitz et al., 2012b; Cardello and Jaeger, 2010). Important points are the number and type of statements, the relative difference between single statements or a more-or-less unstructured line scale. Very often a nine-point hedonic scale is used. It consists of four, presumably equally spaced, categories for liking, a neutral point and four corresponding categories for disliking (e.g., dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like very much and like extremely).

This scale has been suggested by Peryam and Pilgrim (1957), and has been validated and successfully used (Stone et al., 2012). It contains no additional information on possible consequences of the degree of liking or disliking as, for instance, is found in the food action rating scale (FACT) suggested by Schutz (1965). For testing children, alternative scales have been developed which use fewer points and displace verbal statements with facial symbols for different degrees of liking (Chen et al., 1996; Popper and Kroll, 2003). Data derived from the scales are ordinal, but results from unstructured line scales may be regarded as quantitative numerically, especially in tests which use many panelists.

IX Extracting information

Acceptance data are usually obtained from observations of consumer behavior (with all the interference of environmental factors) or the reporting of panelists, transferring their perceptions into words or numbers. To come even closer to the processes of sensation and perception, physiologists study the explanations on how signals from food molecules are processed and transduced from receptor cells to the brain (Margolskee, 2004; Drayna, 2005; Wise and Breslin, 2013).

An emerging field of new insights into the processing of signals in the brain is offered by functional magnetic resonance imaging (FMRI). The activity of brain areas in response to food (thinking of, smelling or eating) can be depicted and located, and assigned to those areas responsible for activity or emotions. The nature of this research is very fundamental and mostly qualitative, but may help to explain the complex phenomena of perception, integration and hedonic consequences in the future (Sescousse et al., 2010; Rolls, 2012; Rudenga and Small, 2013).

X Test sites

A sensory laboratory offers the best control over the preparation and handling of samples, as well as the control of environmental factors during the sessions. Light can be used to mask, for example, sample color differences or, most often, standardized light spectra can be utilized. Data entry can easily be computerized. Panelists work in screened booths, protected from the influence of their surroundings, which could possibly draw attention away from the sample testing. A disadvantage is that the situation differs from normal product use at home. The amount of food may be smaller in the unfamiliar laboratory situation than during an in-home use, and the time for which the consumer is exposed to the product is shorter in the laboratory, where the focus is strongly on working through the testing sequence. Therefore, the repeated presentation of the same product may be used to investigate acceptance changes with time, which can decrease for some products when satiety begins. A detailed discussion of the advantages and disadvantages can be found in Köster (2009), Meiselman (2008) and Moskowitz et al. (2012c).

Other often-used test sites are central locations, such as shopping centers or similar publicly accessible locations, or even research restaurants (Restaurant of the Future, 2013). The advantage of these are the large number of subjects who can be selected and approached. The disadvantage is the limited control of the test conditions, sample preparation and handling. For fruit and vegetable testing, with limited preparation effort, it can be a feasible alternative. For improved testing facilities mobile sensory/chemical units have been used (Moskowitz et al., 2012b). Even more closely resembling actual consumption situations are home use tests (HUT), with the advantage of a natural, unbiased setting. Under these conditions, information on the performance of products during preparation can also be collected by completion of a questionnaire. Testing of complex foods, whole meals and products with a high proportion of extrinsic or credence attributes takes advantage of the familiar social context. Fruit and vegetables have seldom been tested using home use tests.

XI Consumer segments

As a good sensory practice for acceptance tests, a group of around 30 panelists is viewed as a minimum group size for testing (Moskowitz, 1997; Mammasse and Schlich, 2014). If separation of different groups of the population is intended, e.g., income groups, or urban versus rural, a larger group is recommended (Meiselman, 2013). A large number of panelists is necessary because consumers are individuals and differ from each other in what they regard as acceptable. The variability among consumers has long been recognized (Pangborn, 1981) and many attempts have been tried to relate it to socio-demographic background, but this has usually failed (Moskowitz et al., 2012a). The differences between single consumers can be even greater than the differences detected between consumers from different European countries, as shown in the case of coffee (Moskowitz et al., 2012a). Addressing a target population also means analyzing consumer panelists' data for underlying preference segments, but this has not been applied as a standard in the area of fruit and vegetable studies until recently.

Early studies using segments (Rozenbaum, 1989) showed differences in the sweetness preferences for grapefruit consumers; sweet, hard apples or juicy, acidic apples were preferred by different consumer segments (Daillant Spinnler et al., 1996); similar segments were identified for peaches and mangoes (Malundo, 1996); preferences for levels of sugars and acids differed in table grapes (Crisosto and Crisosto, 2002); and kiwifruit consumers were segmented into those who liked a new yellow-fleshed, sweet and fruity flavored cultivar or those preferring the familiar green-fleshed and sweet—tart tasting kiwifruit (Jaeger et al., 2003b). Despite a general liking for juicy, sweet pears, "ideal" color and shape differed among consumers (Jaeger et al., 2003a). Tomato consumer segments were identified (Bruckner, 2000; Pagliarini et al., 2001; Causse et al., 2010) on the basis of the preference for red color and sweetness, acidity and texture, with at least two groups preferring fruit at different stages of ripening.

There are also examples where produce details, such as cultivar, presence of a label, price and presentation (in several tray types or loose), were varied to optimize acceptance by segments of domestic and international markets (Mora et al., 2006). This research was done using conjoint analysis. Rather than measuring the acceptance of the product features alone, the contributory values of the features within this complex mix was determined through systematic variation (Moskowitz, 2005). If the inherent segmentation among consumers is neglected, differences are averaged and only a weak hedonic reaction of the panelists will be found, if any.

One possibility is to separate panelists into subgroups based on the preference for selected attributes of one or a few products (MacFie and Thomson, 1988), or on the pattern of preferences for the whole set of products, using cluster analysis (Moskowitz et al., 2012a). To level out individual differences in scale usage, usually the ratings of one subject are standardized (i.e., set to zero, standard deviation set to one), and a cluster analysis of the data will identify similar subjects, based on the way they scored for liking of the products or product attributes (if attribute liking was one of the questions). Another alternative is the possibility of internal and external preference mapping (Greenhoff and MacFie, 1994; Naes et al., 2010). In both methods individuals are identified on the basis of their preferences only (internal preference mapping) or combined with non-preference data (external preference mapping). Overviews of consumer acceptance data analysis have been published recently (Frewer et al., 2007; Stone et al., 2012; Lawless and Heymann, 2010; Moskowitz et al., 2012).

XII The necessity for acceptance testing

Four primary areas for the need to conduct acceptance tests were defined by Meilgaard et al. (2006):

- product maintenance;
- product improvement/optimization;
- development of new products;
- assessment of market potential.

One of the major reasons for recommending the implementation of consumer acceptance tests is the fact that many newly launched products fail in the marketplace if they are not properly tested (MacFie, 2007). At first glance, a new product launch seems to be atypical for the fresh fruit and vegetable sector, but new varieties of exotic fruit and vegetables, new sizes, mixtures or convenience properties (e.g., fresh-cut fruit, premixed salads) are being developed. Consumer needs are changing over time, influenced by demographic, socio-economic and cultural change, reflected in trends such as an increased average age, smaller household size, individualization and reduced willingness (and necessity) to spend time and effort in preparing food.

Retail chains now compete globally and have to attract increasingly sophisticated consumers. Large proportions of total food sales, e.g., in the United States, are reported to consist of products introduced only recently (van Trijp and Steenkamp, 2005). New fruit and vegetable products often require advanced technology to maintain or sometimes even improve quality during storage, transport and processing, such as use of chemicals to affect ripening; storage and shipment techniques like ultra-low oxygen (ULO) or dynamic controlled atmosphere (CA); modified atmosphere packaging (MAP) or new packaging materials; processing (e.g., for fresh-cut); high pressure treatments; or additives for microbial control (see also Chapter 12). Besides prolonging shelf life, all of these technologies can affect attributes relevant to acceptance. It can be very difficult, if not impossible to measure those changes instrumentally, as we have seen in experiments with peeled asparagus, where unsuitable packaging led to reduced consumer acceptance because of weak off-odors (Brueckner, 2004).

New challenges for acceptance testing will arise from the regional or global dimensions of fruit and vegetable sourcing. Acceptance testing, sometimes used to identify regional or traditional product characteristics, will increasingly be used to pave the way for global produce distribution (Guerrero et al., 2010; Koppel et al., 2014). Scale usage and vocabulary will need to be further developed to enable cross-cultural use.

The focus of acceptance testing will continuously broaden from the product itself to the product with its package and information (Grunert, 2012; Menichelli et al., 2013) as well as functional and emotional dimensions (Köster, 2009; King et al., 2013). As emotions play a role in the food context, so does wellness. Health benefits of fruit and vegetables can be specified by analysis, but wellness is experienced by the individual consumer. However, methods of measurement need to be developed (Boelsma et al., 2010).

An interesting point is raised by Meiselman (2013). Research on consumer acceptance and choices usually concentrates on a single-product/acceptance interface. But many products are purchased and consumed together or in a preset sequence following a habit or ritual. New approaches will need to include more of the consumption environment and its relation to taste perception than in the past.

Much of these new developments in the perspective of studying fruit and vegetable quality in terms of the consumer seem to divert the focus from the product, the object of this book, to the social and cultural environment of consumers. But within the systems approach we have seen, that "...the key to increasing the amount of an item consumed and the economic value of the item lies in understanding consumer desires" (Chapter 2). Feedback from consumers throughout each chain is required at each business link to provide value to ensure the flow of money needed to sustain each business link, all the way to and including the consumer.

Bibliography

Amerine, M.A., Pangborn, R.M., Roessler, E.B., 1965. Principles of Sensory Evaluation of Food. Academic Press, New York, NY, USA.

Banasiak, U., Becker, B., Beer, H., Bergthaller, W., Betschke, T., Boess, C., et al., 2004. Landwirtschaftsverlag GmbH, Munster Hiltrup. Schriftenreihe des Ministeriums für Verbraucherschutz, Ernährung und Landwirtschaft. Reihe A: Angewandte Wissenschaft.

Behr, H.C., Illert, S., 2002. ZMP-Bilanz Gemüse, Zentrale Markt- und Preisberichtstelle fur Erzeugnisse der Land-, Forst- und Ernährungswirtschaft GmbH, Bonn, 1995–2002.

Boelsma, E., Brink, E.J., Stafleu, A., Hendricks, H.J.J., 2010. Measures of postprandial wellness after single intake of two protein–carbohydrate meals. Appetite 54, 456–464.

Bruckner, B., 2000. Acceptability of tomatoes defined by sensory attributes and consumer segments. In: Florkowski, W.J., Shewfelt, R.L., Prussia, S.E. (Eds.), Integrated View of

Fruit and Vegetable Quality. Technomic Publishing, Lancaster, PA, USA, pp. 229–240.

Brueckner, B., 2004. Welche Verpackungsmaterialien bei ungeschältem und geschältem Spargel? Spargel & Erdbeerprofi 6 (2), 16–17.

Busch-Stockfisch, M., 2013. Praxishandbuch Sensorik in der Produktentwicklung und Qualitätssicherung. Behr's Verlag, Hamburg, Germany.

Cardello, A.V., 1994. Consumer expectations and their role in food acceptance. In: MacFie, H.J.H., Thomson, D.M.H. (Eds.), Measurement of Food Preferences. Blackie Academic and Professional, London, UK, pp. 253–298.

Cardello, A.V., 1996. The role of human senses in food acceptance. In: Meiselman, H.L., MacFie, H.J.H. (Eds.), Food Choice, Acceptance and Consumption. Blackie Academic and Professional, London, UK, pp. 1–82.

Cardello, A.V., Jaeger, S.R., 2010. Hedonic measurement for product development: new methods for direct and indirect scaling. In: Jaeger, S.R., MacFie, H. (Eds.), Consumer-driven Innovation in Food and Personal Care Products, pp. 135–174.

Causse, M., Friguet, C., Coriet, C., Lepicier, M., Navez, P., Lee, M., et al., 2010. Consumer preferences for fresh tomato at the European scale: a common segmentation on taste and firmness. J. Food Sci. 75 (9), 531–541.

Chen, A.W., Resurreccion, A.V.A., Paguio, L.P., 1996. Age appropriate hedonic scales to measure food preferences of young children. J. Sens. Stud. 11, 141–163.

Coetzee, H., Taylor, J.R.N., 1996. The use and adaptation of the paired-comparison method in the sensory evaluation of hamburger-type patties by illiterate/semi-literate consumers. Food Qual. Preference 7, 81–85.

Connors, M., Bisogni, C.A., Sobal, J., Devine, C.M., 2001. Managing values in personal food systems. Appetite 36, 189–200.

Costell, E., Tarrega, A., Bayarri, S., 2010. Food acceptance: the role of consumer perception and attitudes. Chemosenory Percept. 3 (1), 42–50.

Crisosto, C.H., Crisosto, G.M., 2002. Understanding American and Chinese consumer acceptance of "Redglobe" table grapes. Postharvest Biol. Technol. 24, 155–162.

Daillant Spinnler, B., MacFie, H.J.H., Beyts, P.K., Hedderley, D., 1996. Relationships between perceived sensory properties and major preference directions of 12 varieties of apples from the southern hemisphere. Food Qual. Preference 7, 113–126.

Drayna, D., 2005. Human taste genetics. Annu. Rev. Genomics Hum. Genet. 6, 217–235.

Ferquist, F., Ekelund, L., 2013. Consumer attitudes towards origin and organic – the role of credence labels on consumer's liking of tomatoes. Eur. J. Hortic. Sci. 78 (4), 184–190.

Frewer, L., van Trijp, M.J.C., Van Trijp, H., 2007. Understanding Consumers of Food Products. Woodhead Publishing, Cambridge, UK.

Greenhoff, K., MacFie, H.J.H., 1994. Preference mapping in practice. In: MacFie, H.J.H., Thomson, D.M.H. (Eds.), Measurement of Food Preferences. Chapman & Hall, Glasgow, pp. 137–166.

Grunert, K.G., 2005. Consumer behaviour with regard to food innovations: quality perception and decision making. In: Jongen, W.M.F., Meulenberg, M.T.G. (Eds.), Innovation in Agri-Food Systems. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 57–85.

Grunert K.G., 2012. Consumer acceptance of innovative food. High Level Forum for a better Functioning of the Food Supply Chain. <https://circabc.europa.eu> (accessed Oct 2013).

Guerrero, L., Claret, A., Verbeke, W., Enderli, G., Zakowska-Biermanns, S., vanHonacker, F., 2010. Perception of traditional food in six European regions using free word associations. Food Qual. Preference 19, 651–661.

Gumbel, P., 2013. To-ma-to *noun*, sing.: a round. Soft, red fruit; a way to explain Europe's economic mess, Time, March 25, 2013, pp. Business 10, 12 and 14.

Harker, F.R., Amos, R.L., White, A., Petley, M.B., Wohlers, M., 2008. Flavor differences in heterogeneous foods can be detected using repeated measures of consumer preferences. J. Sens. Stud. 23, 52–64.

Harper, R., 1981. The nature and importance of individual differences. In: Solms, J., Hall, R.L. (Eds.), Criteria of Food Acceptance: How Man Chooses What He Eats. Forester, Zurich, Switzerland, pp. 220–237.

Jaeger, S.R., Lund, C.M., Lau, K., Harker, F.R., 2003a. In search of the "ideal" pear (*pyrus* spp.): results of a multidisciplinary exploration. J. Food Sci. 68, 1108–1117.

Jaeger, S.R., Rossiter, K.L., Wismer, W.V., Harker, F.R., 2003b. Consumer-driven product development in the kiwifruit industry. Food Qual. Preference 14, 187–198.

Jaeger, S.R., Cardello, A.V., Schutz, H.G., 2013. Emotion questionnaires: a consumer-centric perspective. Food Qual. Preference 30 (2), 229–241.

King, S.C., Meiselman, H.L., Carr, T., 2013. Measuring emotions associated with foods: important elements of questionnaire and test design. Food Qual. Preference 28 (2), 8–16.

Koppel, K., Chambers, E., Vazquez-Araujo, L., Carbonell-Barrachina, A.A., Suwonsichon, S., 2014. Cross-country comparison of pomegranate juice acceptance in Estonia, Spain, Thailand, and United States. Food Qual. Preference 31 (1), 116–123.

Köster, E.P., 2009. Diversity in the determinants of food choice: a psychological perspective. Food Qual. Preference 20 (2), 70–82.

Köster, E.P., Mojet, J., 2012. Flop analysis: a useful tool for future innovations (Part 1). Agro Industry Hi-Tech 23 (1), 6–8.

Krystallis, A., 2007. Using means–end chains to understand consumers' knowledge structures. In: MacFie, H.J.H. (Ed.), Consumer-led Food Product Development. Woodhead Publishing, Cambridge, UK, pp. 158–196.

Land, D.G., 1983. What is sensory quality? In: Williams, A.A., Atkin, R.K. (Eds.), Sensory Quality in Food and Beverages: Definition, Measurement and Control. Ellis Horwood, Chichester, UK, pp. 15–29.

Lawless, H.T., Heymann, H., 2010. Ch. 14, Acceptance testing. In: Lawless, H.T., Heymann, H. (Eds.), Sensory Evaluation of Food – Principles and Practices, second ed. pp. 335–349.

MacFie, H.J.H., 2007. Consumer-led Food Product Development. Woodhead Publishing, Cambridge, UK.

MacFie, H.J.H., Thomson, D.M.H., 1988. Preference mapping and multidimensional scaling. In: Pigott (Ed.), Sensory Analysis of Foods. Elsevier, New York, NY, USA.

Malundo, T.M.M., 1996. Application of the quality enhancement (QE) approach to mango (*Mangifera indica* L.) flavour research. Thesis/Dissertation. University of Georgia, GA, USA.

Mammasse, M., Schlich, P., 2014. Adequate number of consumers in a liking test. Insights from resampling in seven studies. Food Qual. Preference 31 (1), 124–128.

Margolskee, R.F., 2004. Insights into Taste Transduction and Coding from Molecular, Biochemical, and Transgenic Studies. Amer Chemical Soc., Washington, DC, USA, pp. 44.

Marshall, D., 1995. Introduction: food choice, the food consumer and food provisioning. In: Marshall, D. (Ed.), Food Choice and the Consumer. Blackie Academic and Professional, Glasgow, pp. 3–17.

Meilgaard, M.C., Carr, B.T., Civille, G.V., 2006. Sensory Evaluation Techniques, fourth ed. CRC Press, Boca Raton, FL, USA.

Meiselman, H.L., 2007. Integrating consumer responses to food products. Part I, ch. 1. In: MacFie, H.J.H. (Ed.), Consumer Led Food Product Development. Woodhead Publishing, Cambridge, UK, pp. 3–33.

Meiselman, H.L., 2008. Experiencing products within a physical and social context. In: Schifferstein, H.N.J., Hekkert, P. (Eds.), Product Experience. Elsevier, Oxford, pp. 559–580.

Meiselman, H.L., 2013. The future in sensory/consumer research: evolving to a better science. Food Qual. Preference 27, 208–214.

Menichelli, E., Olson, V.N., Meyer, C., Naes, T., 2013. Combining extrinsic and intrinsic information in consumer acceptance studies. Food Qual. Preference 23 (2), 148–159.

Mora, M., Espinoza, J.A., Mino, R., 2006. Segments determination of fresh peaches consumers through the conjoint analysis: an approximation to the Chilean market. Proceedings of the Sixth International Peach Symposium, pp. 521–525.

Moskowitz, H.R., 1997. Base size in product testing: a psychophysical viewpoint and analysis. Food Qual. Preference 8, 24–255.

Moskowitz, H.R., 2005. Systematic variation of concept elements and the conjoint analysis approach. In: Moskowitz, H.R., Porretta, S., Silcher, M. (Eds.), Concept Research in Food Product Design and Development. Blackwell Publishing, Ames, IA, USA, pp. 77–104.

Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A., 2012c. Sensory and Consumer Research in Food Product Design and Development. Blackwell Publishing, Ames, IA, USA.

Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A., 2012a. High level product assessment. In: Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A. (Eds.), Sensory and Consumer Research in Food Product Design and Development. Blackwell Publishing, Ames, IA, USA, pp. 167–207.

Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A., 2012b. What types of sensory tests do sensory researchers do to measure sensory response to the product? In: Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A. (Eds.), Sensory and Consumer Research in Food Product Design and Development. Blackwell Publishing, Ames, IA, USA, pp. 229–283.

Naes, T., Brockhoff, P.B., Tomic, O., 2010. Ch 9. Preference Mapping for Understanding Relations between Sensory Product Attributes and Consumer Acceptance. Wiley Publishing, New Jersey, USA.

Pagliarini, E., Monteleone, E., Ratti, S., 2001. Sensory profile of eight tomato cultivars (*Lycopersicon esculentum*) and its relationship to consumer preference. Ital. J. Food Sci. 13, 285–296.

Pangborn, R., 1981. Individuality in responses to sensory stimuli. In: Solms, J., Hall, R.L. (Eds.), Criteria of Food Acceptance. Forster Verlag AG, Zurich, Switzerland, pp. 177–217.

Peryam, D.R., Pilgrim, F.J., 1957. Advanced taste test method. Food Technol. 11, 9–14.

Popper, R., Kroll, J.J., 2003. Conducting sensory research with children. Food Technol. 57 (5), 60–65.

Popper, R., Rosenstock, W., Schraidt, M., Kroll, B.J., 2004. The effect of attribute questions on overall liking ratings. Food Qual. Preference 15, 853–858.

Restaurant of the Future, 2013. <http://www.wageningenur.nl/en/Expertise-Services/Facilities/Restaurant-of-the-Future-4.htm> (accessed Oct 2013).

Rolls, E.T., 2012. Taste, olfactory and food texture reward processing in the brain and the control of appetite. Proc. Nutr. Soc. 71 (4), 488–501.

Rozenbaum, J., 1989. Consumer acceptance of a new brand of selected sweeter grapefruits. Citriculture. Proceedings of the Sixth International Citrus Congress, Middle East, March 6–11, 1988. Volume 4: economics, marketing and commercial trends; processing. Tel Aviv, Israel, pp. 1645–1650.

Rudenga, K.J., Small, D.M., 2013. Ventromedial prefrontal cortex response to concentrated sucrose reflects liking rather than sweet quality coding. Chem. Senses 38 (7), 585–594.

Schutz, H.G., 1965. A food action rating scale for measuring food acceptance. J. Food Sci. 30, 365–374.

Sescousse, G., Redoute, J., Dreher, J.C., 2010. The architecture of reward value coding in the human orbitofrontal cortex. J. Neurosci. 30 (39), 13095–13104.

Stone, H., Bleibaum, R.N., Thomas, H.A., 2012. Sensory Evaluation Practices. Academic Press, San Diego, CA, USA.

Thomson, D., 2008. Liking isn't enough! Third European Conference on Sensory and Consumer Research. A Sense of Innovation, Hamburg, Germany.

Tuorila, H., 2007. Sensory perceptions as a basis of food acceptance and consumption. In: MacFie, H.J.H. (Ed.), Consumer-led Food Product Development. Woodhead Publishing, Cambridge, UK, pp. 34–65.

van Trijp, H.C.M., Steenkamp, J.E.B.M., 2005. Consumer-oriented new product development: principles and practice. In: Jongen, W.M.F., Meulenberg, M.T.G. (Eds.), Innovation in Agri-Food Systems. Product Quality and Consumer Acceptance. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 87–124.

Wise, P.M., Breslin, P.A., 2013. Individual differences in sour and salt sensitivity detection and quality thresholds for citric acid and sodium chloride. Chem. Senses 38 (4), 333–342.

This page intentionally left blank

CHAPTER

5 Nutritional Quality of Fruits and Vegetables

Ariel R. Vincente[a], George A. Manganaris[b], Cristian M. Ortiz[a], Gabriel O. Sozzi[c] and Carlos H. Crisosto[d]

[a]*LIPA: Laboratorio de Investigación en Productos Agroindustriales Universidad Nacional de La Plata Calle 60 y 119 s/n. CP 1900 La Plata Argentina y Centro de Investigación y Desarrollo en Criotecnología de Alimentos. CIDCA (CONICET-UNLP), La Plata, Argentina* [b]*Department of Agricultural Sciences, Biotechnology & Food Science, Cyprus University of Technology, Lemesos, Cyprus* [c]*Consejo Nacional de Investigaciones Científicas y Técnicas, Ciudad de Buenos Aires, Argentina* [d]*Department of Plant Sciences, University of California, Davis, California, USA*

I Introduction

Chronic diseases such as heart disease, stroke, cancer and diabetes are a leading cause of mortality worldwide. Excess weight and outright obesity are a growing concern. Prevention of these problems is linked to lifestyle choices. There may be an evolutionary discordance between modern diets, rich in calories from fats and starches and low in fruits and vegetables, and human nutritional requirements (Martin et al., 2013). Consequently replacing some added sugars and saturated fat with more fruits and vegetables may benefit health. A growing body of research indicates that fruit and vegetable consumption reduces the risk of major diseases and possibly delays the onset of age-related disorders. Traditional eating patterns of the Mediterranean region are associated with reduced cardiovascular disease. Although there is no single definition of a Mediterranean diet, descriptions emphasize the consumption of vegetables, fruits and nuts (USDA, 2010).

The dietary constituents obtained from fruits and vegetables include water, fiber, proteins (more abundant in legumes), sometimes fats (olive, avocado, nuts), organic acids and digestible carbohydrates. Starch-based staples (potato, cassava, corn, banana, plantain) provide a major energy source in some regions. Fruits and vegetables provide minerals and vitamins. They are the main dietary source of vitamin C and a significant source of pro-vitamin A and vitamin B_6. Compared to other food sources, they are high in potassium and low in sodium. Ascorbic acid in fruits and vegetables may enhance the bio-availability of dietary iron. Fruits and vegetables provide unique and appealing textures, colors and flavor, they are relatively low in calories (excluding staple crops) and are cholesterol-free. They also include a variety of non-nutritive bioactive phytochemicals with health

Postharvest Handling.

benefits. Some constituents of horticultural crops that help to prevent disease include fiber, phytosterols, carotenoids such as lycopene, ascorbic acid, tocopherols, glucosinolates, thiosulfinates and phenolics such as flavonoids, hydroxycinnamic acid-derivatives, stilbenes and catechins (Voutilainen et al., 2006; Ignarro et al., 2007; Holst and Williamson, 2008; Chen and Chen, 2013). Fruit phytochemicals and diet constituents may exert antagonistic, additive or synergistic effects (Heinonen et al., 1998). Although the mechanisms by which fruits and vegetables promote human health are unclear, current evidence has led to recommendations that healthful diets include a variety of fresh or processed horticultural commodities (www.dietaryguidelines.gov). In spite of these guidelines, fruit and vegetable intake is often below the dietary goal of five to 10 servings or 400 g of fruits and vegetables daily. Less than a quarter of the total population reaches the recommended intake of fruits and vegetables in America and European Union countries (Martin et al., 2013).

Fruits and vegetables may be incorporated in different raw or cooked, fresh or processed forms: canned, pickled, dried, frozen, candied, and in sauces, purees or preserves. Juices are good sources of phytochemicals and vitamins and can also contribute to the overall fruit and vegetable intake. However, they contain less fiber than unprocessed commodities and may contribute extra calories if sugar is added. Care must be taken regarding added salt in processed vegetable products, since they may contribute up to one-third of the total dietary sodium intake (Hiza and Bente, 2007).

In this chapter, we describe the main nutritional components and non-nutritional antioxidants present in fruits and vegetables, with special reference to the latest advancements. The influence of species, cultivar, maturity stage and postharvest storage conditions on these components is discussed.

II Nutrient components

A Water

Water comprises ~60% of the body's weight and is essential for good health. An intake of 2.2 or 3.0 l of total beverages a day is recommended for men and women. Individual needs depend on environmental conditions, diet and physical activity. Water is also the most abundant single component of fresh fruits and vegetables and in leafy vegetables it may be up to 95% of the mass. The percentage of water varies among individual fruits and vegetables due to structural differences and the developmental stage.

B Proteins and nitrogen compounds

Proteins represent <1% of the fresh mass of most fruit and vegetable tissues. Legumes may contain 15 to 30% protein. Nuts and sprouts are also good sources of high quality proteins. Vegetables and legumes account for ~6.0% of protein intake in the United States, while fruits only contribute 1% (Hiza and Bente, 2007).

Some plant seeds, particularly legumes, contain some anti-nutritional proteins. Soybean trypsin inhibitors have been a concern since they can reduce protein utilization. However, common processing methods such as cooking may inactivate the protease inhibitory activity (Lajolo and Genovese, 2002).

A number of non-protein nitrogenous compounds including free amino acids, chlorophylls, polyamines or alkaloids are also present in fruits and vegetables. In potatoes, 50−60% of the nitrogen occurs either as free amino acids or in other non-protein metabolites, while in apples estimates range from 10 to 70% (Salunkhe et al., 1991). Senescent tissues and overripe fruits may contain greater proportions of non-protein nitrogen. Asparagine is abundant in potatoes and apples. Pears and oranges are rich in proline and black and red currants in alanine.

The nitrogen steroidal glycoalkaloids (GLS) α-solanine and α-chaconine are acetylcholine esterase inhibitors found in potato tubers which can induce neurological disorders. Solanin is present at the highest concentration immediately under the skin and usually makes up ~8 mg/100 g fresh weight (FW). Concentrations exceeding 20 mg/100 g FW are considered unsafe for human consumption (Itkin et al., 2013).

C Lipids and fatty acids

Lipids may be used as energy sources and are the main components of cellular membranes and waxes. They are mainly present as triglycerides (esters of glycerol and three fatty acids). However, diverse chemical forms co-exist within this group. Phospholipids, in which one fatty acid is replaced by phosphoric acid, are also important membrane constituents. The fat concentration varies with the commodity, but most fruits and vegetables have <1% lipid, with avocadoes, olives and nuts being the exceptions. Fats comprise 35−70% of dry mass in the avocado and olive, but only 0.2% of grape, 0.1% of banana and 0.06% of apple.

The physical and chemical properties of lipids are largely determined by their constituent fatty acids. Fatty acids in foods are usually aliphatic and monocarboxylic. They may be saturated or unsaturated to varying degrees and may contain from four to 26 carbons. Oleic (18:1) and linoleic (18:2) acids are the most prevalent. Olive oil and other fats high in monounsaturated fatty acids can help lower low-density lipoprotein (LDL)-cholesterol (so-called "bad" cholesterol), while protecting high-density lipoprotein (HDL)-cholesterol ("good" cholesterol) when consumed in moderation in place of saturated fats. Fats derived from animal sources (e.g., butter, cream, hard cheeses) have a high proportion of saturated fats, while oils from plant sources such as olive and canola have the lowest (Table 5.1).

Fatty acids are required for human body functions as they are used to produce lipids and hormone-like substances that regulate blood pressure, blood clotting and immune and inflammatory responses. The human body can produce most fatty acids except linoleic acid and α-linolenic acids, which are common in plant

Table 5.1 Fatty Acid, Vitamin E, and Cholesterol Composition of Some Common Dietary Fats

	Saturated (%)	Monounsaturated (%)	Polyunsaturated (%)	Cholesterol (mg/100 g)
Animal fats				
Lard	40.8	43.8	9.6	93
Butter	54.0	19.8	2.6	230
Vegetable fats				
Coconut oil	85.2	6.6	1.7	0
Palm oil	45.3	41.6	8.3	0
Cottonseed oil	25.5	21.3	48.1	0
Wheat germ oil	18.8	15.9	60.7	0
Soya oil	14.5	23.2	56.5	0
Olive oil	14.0	69.7	11.2	0
Corn oil	12.7	24.7	57.8	0
Sunflower oil	11.9	20.2	63.0	0
Safflower oil	10.2	12.6	72.1	0
Canola oil	5.3	64.3	24.8	0

Source: Kays (1997).

oils. These essential fatty acids are members of the omega-6 and omega-3 fatty acid series.

Plant-derived foods do not contain significant amounts of cholesterol but do contain cholesterol-like steroids or phytosterols. These are present at highest concentrations in vegetable oils but may occur at appreciable levels in some horticultural crops. Fat-rich fruits and nuts, cauliflower, broccoli and carrots are good sources of phytosterols. They are absorbed only in trace amounts but inhibit the absorption of intestinal cholesterol (Jenkins et al., 2001). Clinical trials indicated that a daily intake of 0.8 g significantly reduced LDL and total cholesterol in the blood (Moruisi et al., 2006). Natural dietary intake varies from 167 to 437 mg per day (Ostlund, 2002). However, in vegetarian diets it may be as high as 1 g per day.

D Organic acids

Organic acids (OA), defined by the presence of carboxylic acid groups, are divided into aliphatic (straight chain) and aromatic acids. Citrate, malate and tartrate, the most abundant acids in fruits and vegetables, are aliphatic. Malate is the major acid in pome- and stone-fruit species, citrate is abundant in *Citrus*, berries and tomato, and tartrate is predominant in grapes. Aromatic organic acids occur in several fruits, but at relatively low concentrations. Benzoic acid is found in cranberries; quinic acid, in bananas and kiwifruit; and chlorogenic acid, in potatoes and eggplant. OAs may be further divided into mono-, di-, or tricarboxylic acids based on the number of carboxylic acid groups present. Citrate is a tricarboxylic acid, while malate and tartrate are both dicarboxylic. Lactic and acetic acids are monocarboxylic acids and are present in significant amounts in vegetables.

Fruits are normally more acidic than most vegetables. Except for lemons, acidity normally decreases with ripening. In clingstone peaches, citrate decreases faster than malate, while the opposite is true in apples and pears. Organic acid distribution within a fruit may not be uniform.

Organic acids (OAs) play an important role in fruit taste. The sugar to acid ratio is a widely used maturity index in citrus fruit. OAs can be incorporated into the tricarboxylic acid cycle (TCA), yielding ATP, but their energy contribution is minor. The main nutritional value of OAs is as a precursor for amino acid synthesis. Some nutritionally important compounds such as vitamin C are strictly organic acids. The major OAs present in fruit may help stabilize some vitamins and prevent the oxidation of phenolic compounds during processing.

E Digestible carbohydrates

After water, carbohydrates are the most abundant constituents in fruits and vegetables, accounting for 50−80% of dry weight. Carbohydrate functions include storage of energy reserves and they make up much of the structural framework of cells. Carbohydrates and proteins yield 4 kcal/g, while fats yield 9 kcal/g. Glucose and fructose are the most common simple sugars in fruits and the disaccharide sucrose, the primary transport form of carbohydrate in most plants, yields glucose and fructose upon hydrolysis. Glucose, fructose and sucrose are water-soluble and together are primarily responsible for the sweet taste of fruits and vegetables. In many fruits (apple, pear, strawberry, or grape), glucose and fructose are more abundant than sucrose, but in vegetables such as parsnip, beetroot, carrot, onion, sweet corn, pea and sweet potato and in some ripe fruits such as banana, pineapple, peach and melon, the sucrose concentration is higher. Other mono- and disaccharide sugars such as xylose, arabinose, mannose, galactose and maltose may also be present in small amounts (Salunkhe et al., 1991). Some fruits of the *Rosaceae* family have significant concentrations of the sugar alcohol sorbitol.

Total carbohydrate also includes starches, which are organized into small grains within chloroplasts or in specialized plastids, called amyloplasts. Some non-starchy root vegetables like parsnip, beetroot and carrot are rich in simple sugars: 8−18% of total carbohydrate.

F Dietary fiber

Definition and composition

Several definitions of fiber have been proposed, either physiological or based on the analytical method employed (Slavin, 2005). An expert panel defined the term “dietary fiber” as non-digestible carbohydrates and lignin in plants (Institute of Medicine, 2001). Dietary fiber includes very diverse macromolecules exhibiting a variety of physical-chemical properties. The main components of fiber are cellulose, cross-linking glycans (CGL), pectins, lignin, resistant starch and non-digestible oligosaccharides.

Cellulose

Cellulose is a main cell wall polymer consisting of β-1,4-linked glucose (Brett and Waldron, 1996). Individual glucan chains associate through hydrogen bonds to form highly stable microfibrils (Carpita and McCann, 2000). With the exception of avocado, in which the whole cell wall is degraded (O’Donoghue et al., 1994), little change in cellulose concentration is observed during ripening (Brummell, 2006).

Cross-linking glycans (CLG)

Several alkali-soluble cell wall polymers are classified as cross-linking glycans or hemicelluloses (Brummell and Harpster, 2001). Primary cell walls contain 25−35% CLG (Carpita and McCann, 2000). The most common CLG in dicot species is xyloglucan, characterized by a backbone of β-1,4-linked glucose with α-1,6 linked xylosyl lateral chains. The pentose residues can be further decorated with galactose, arabinose and/or fucose (Brummell, 2006). Xylans are abundant CLGs in monocot species, with a backbone of β-1,4-linked xylose decorated with side chains of arabinose and/or glucuronic acid. Other hemicellulosic compounds, usually less abundant, include gluco-mannans, galacto-mannans and galacto-gluco-mannans (Carpita and McCann, 2000).

Pectins

Pectins are also a diverse group, with a high proportion of galacturonic acid as a common feature (Ridley et al., 2001). Fruit tissues are particularly rich in pectins: they constitute up to 40% of the cell wall polysaccharides. The most abundant cell wall polyuronide is homogalacturonan, a homopolymer of α-1,4-linked galacturonic acid with variable degree of methyl esterification at C6 (Willats et al., 2001). The degree of polymerization and proportion of methyl esters affect pectin solubility. Pectins are deposited in the cell walls with a high degree of esterification that usually decreases during ripening. Another modification commonly observed in ripening fruits is reduced pectin polymer size (Brummell, 2006; Vicente et al., 2007b). The extent of pectin depolymerization is variable: avocado fruit undergo a dramatic decrease in polyuronide size (Huber and O'Donoghue, 1993), while negligible changes occur in peppers and some berries (Brummell, 2006; Vicente et al., 2007a). Rhamnogalacturonan I (RG I) and II (RG II) are also pectic polysaccharides present in plant cell walls. RGI has a backbone of alternating α-1,2-rhamnosyl and α-1,4-galacturonosyl residues (Willats et al., 2001) with side chains rich in arabinose and galactose (Carpita and McCann, 2000). Losses of side chain residues are common during fruit ripening and affect pectin solubility and hydration potential (Gross and Sams, 1984; Redgwell et al., 1997). RG II is the most complex cell wall polysaccharide and forms dimers via borate diester bonds (Kobayashi et al., 1996; O'Neill et al., 2004). Pectins extracted from citrus, apples and beets are used commercially to manufacture jams and jellies (Holzwarth et al., 2013).

Lignin

Lignin, along with cellulose and chitin, is one of the most abundant biopolymers in nature (Boerjan et al., 2003). It is an aromatic hetero-polymer formed by the association of three hydroxycinnamyl alcohol derivatives (*p*-coumaryl, coniferyl and sinapyl alcohols) (Srinivasa Reddy et al., 2005). It is a highly resistant polymer present in secondary cell walls and is associated with fibers, sclereids, xylem vessels, seed coats and pith of some fruits. Lignin is present in most fruits and vegetables at low levels, but in some commodities it can negatively impact quality. Toughening of asparagus spears during storage is related to increased lignin deposition (Saltveit, 1988; Huyskens-Keila and Herppichb, 2013; Janositz et al., 2011).

Resistant starch

Starches are polysaccharides: glucosyl residues linked by α-D-(1-4) and/or α-D-(1-6) linkages (Sajilata et al., 2006). Resistant starch and its degradation products are not digested in the small intestine (Asp, 1994). Such starches can be fermented by large intestine microflora, producing products that may provide physiological benefits (Mudgil and Barak, 2013; Laurentin and Edwards, 2013). Legumes are rich in resistant starch; up to 35% of this polysaccharide could escape digestion (Marlett and Longacre, 1996). Unripe bananas, green mango and potato are also relatively rich in resistant starch. Overall, little information is available about resistant starch concentrations in foods and the amount of resistant starch in a typical diet (Dodevska et al., 2013; Chung et al., 2011; Fuentes-Zaragoza et al., 2010).

Non-digestible oligosaccharides (NDOs)

Oligosaccharides are low-molecular-weight carbohydrates, intermediate between simple sugars and polysaccharides (Mussatto and Mancilha, 2007). While several oligosaccharides are hydrolyzed in the digestive tract, others resist digestion. Examples include raffinose (a trisaccharide of galactose, fructose and glucose), stachyose (two galactosyl units with one glucosyl and one fructosyl sequentially linked) and verbascose (three galactosyl, one glucosyl and one fructosyl unit sequentially linked). Among horticultural commodities, legumes are rich in NDOs (Mussatto and Mancilha, 2007).

Benefits of fiber intake

One of the best-known benefits of dietary fiber is its modulation of the intestinal function (Institute of Medicine, 2001). Fiber-rich meals promote satiety earlier, usually have fewer calories and can assist weight control (Marlett et al., 2002). Undigested dietary fiber is fermented in the colon to form acetic, propionic and butyric acids which participate in satiety signaling (Martin et al., 2013). High fiber intake is associated with disease prevention (Meyer et al., 2000; Institute of Medicine, 2001), reduced serum cholesterol and blood pressure and lower risk of coronary disease (Rimm et al., 1996; Wolk et al., 1999). Increasing viscous fruit and vegetable fiber and whole grains improves glycemic control and bodyweight management (Martin et al., 2011). Total fruit and vegetable consumption was inversely associated with colorectal cancer risk (Terry et al., 2001). Fiber may reduce the bioavailability of some phytochemicals or may be reduced by binding or entrapment (Palafox-Carlos et al., 2011). National dietary guidelines recommend increasing dietary fiber intake to 20−35 g per day; the average fiber intake of United States adults is less than half of this (Marlett and Slavin, 1997; Casiglia et al., 2013).

Sources of fiber

Whole grains, fruits and vegetables are good sources of fiber (Anderson et al., 2007). In 2004, fruits and vegetables contributed 37.1% of the fiber in the food supply, followed by grain products (36.0%) and legumes (13.3%) (Hiza and Bente, 2007). Fruits and vegetables average 1−3% fiber on a fresh weight basis (Table 5.2). Nuts, legumes and dried fruits are particularly rich in fiber. Fiber properties differ greatly depending on the food source. For instance, pectin is low in grains, but constitutes ∼20−35% of total fiber in fruits, vegetables, legumes and nuts. Cross-linking glycans account for about half of the total fiber in grains and ∼25−35% of total fiber in other foods. Cellulose is one-third; or less of total fiber in most foods (Marlett, 1992).

Relevant properties of dietary fiber include particle size and bulk volume, surface area characteristics, water absorbing capacity, viscosity and the ability to

Table 5.2 Fiber Content of Selected Fruits, Vegetables and Nuts

Product	Dietary fiber (%)
Almond	12.2
Apple	2.4
Asparagus	2.1
Avocado	6.8
Banana	2.6
Broccoli	2.6
Carrot	2.8
Kiwifruit	3.4
Lettuce	2.1
Onion	1.7
Orange	2.4
Pea	2.6
Peach	1.5
Peanut	8.5
Pear	3.1
Pepper	2.1
Pineapple	1.4
Plum	1.4
Potato	2.2
Prune	7.1
Raisin	3.7
Spinach	2.2
Strawberry	2.0
Tomato	1.2
Walnut	6.7

Source: U.S. Department of Agriculture (2008).

adsorb or entrap minerals and organic molecules (Guillon and Champ, 2000). The main modifications in fiber during storage are increased solubility and reduced molecular size by several cell wall-loosening enzymes (Brummell, 2006; Fisher and Bennett, 1991). In some commodities (e.g., celery), excessive fiber is potentially detrimental. Processing or home preparation of fruits and vegetables does not cause major losses of fiber (Zyren et al., 1983).

G Vitamins

Vitamins are required in trace amounts for normal development that cannot be synthesized in sufficient quantities by an organism, and must be obtained from the diet. The term "vitamin" derives from "vital amine" because the first vitamin discovered (thiamine) contained an amino group. The vitamins known today are vitamin A (retinol), the B complex [B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B9 (folate/folic acid), biotin, choline and B12 (cyanocobalamine)] and vitamins C, D, E and K. They do not have common functions or structure and are usually classified as fat-soluble (A, D, E and K) or water-soluble (B complex and C) (Salunkhe et al., 1991). Fruits and vegetables are a vital source of vitamins, but concentrations vary among species, cultivars, environmental conditions and cultural practices (Rodriguez-Amaya, 2001; Asensi-Fabado and Munné-Bosch, 2010; Moretti et al., 2010; Tiwari and Cummins, 2013).

Pro-vitamin A

Carotenoids are liposoluble pigments responsible for the yellow, orange and red colors of several fruits and vegetables. They are terpenoids formed by eight isoprene units (2-methyl-1,3-butadiene) derived from isopentenyl diphosphate. Those having an unsubstituted β-ring with an 11-carbon polyene chain have pro-vitamin A activity (Meléndez-Martínez et al., 2007), like α-carotene, β-carotene and cryptoxanthin (Kopsell and Kopsell, 2006). The structural requirement is satisfied by ~60 carotenoids (Rodriguez-Amaya, 2001). Vitamin A plays a crucial role in vision, cell division and differentiation, bone development and reproduction. Adult daily vitamin A requirement is estimated at 5000 international units (1 IU = 0.3 μg retinol or 0.6 μg β-carotene). Vitamin A deficiency is particularly frequent in populations where diets are based almost exclusively on a single, starch-based crop deficient in pro-vitamin A carotenoids (Mayer et al., 2008). Vitamin A deficiency is estimated to affect ~1/3 of children under the age of five worldwide, a significant number of whom suffer blindness or die (Cuttriss et al, 2011; Fernández-García et al., 2012).

Carotenoids are further subdivided into two classes: carotenes containing C and H (e.g., α-carotene, β-carotene, lycopene) and oxygenated derivatives known as xanthophylls (lutein, violaxanthin, zeaxanthin). In plants, carotenoids have functions related to light capture in the blue–green region of the spectrum and subsequent transfer to the photosynthetic centers (Kopsell and Kopsell, 2006). They also protect photosynthetic structures from photo-inhibition (Grusak and Della Penna, 1999). Carotenoids are usually present at low concentrations that are highly variable among species. Fruits and vegetables provide 30% of the vitamin A in the American diet (Hiza and Bente, 2007). Vegetables that supply useful amounts of carotene include carrots, pumpkins and squashes. Fruits are generally less good sources, with a few notable exceptions like apricot, mango, citrus, papaya and watermelon (Table 5.3). Tomato and pepper also contain high concentrations of carotenoids, especially in the peel (Rodriguez-Amaya, 2001). More than 600 different carotenoids have been identified, but a small group is usually prevalent. Beta-carotene, the most studied carotenoid, accumulates in carrots. Lycopene is abundant in tomato and watermelon. Other carotenoids found in fruits and vegetables include α-carotene, lutein, cryptoxanthin and zeaxanthin. In

Table 5.3 Carotene Concentration (Mean Values) of Selected Fruits

Product	Carotene (μg/100 g)
Mango	1800
Cantaloupe	1000
Pawpaw	810
Guava	435
Apricot	405
Plum	295
Watermelon	230

Source: Rodriguez-Amaya (2001).

tomato and peach, carotene biosynthesis continues after harvest. There is little difference in carotene between cooked and raw vegetables, but food preparation may affect carotene availability. Carrot puree allows better absorption than shredded or whole carrots. Absorption of carotene is more effective if the diet includes at least 15% fat.

Vitamin B complex

Thiamine pyrophosphate is a co-factor, present in all living systems, that catalyzes several biochemical reactions. It is particularly important in carbohydrate metabolism. A daily intake of 1−2 mg is recommended for adults. Legumes are especially rich in thiamine. Compared to other vitamins such as ascorbic acid, thiamine is relatively stable at cooking temperatures, especially in a slightly acidic solution. However, losses of 25−40% may occur.

Riboflavin is the central component of flavoproteins. The average human requires ∼1−2 mg/day. Green vegetables such as bean, beet, pepper and spinach are particularly good while starchy vegetables and fruits are relatively poor sources of riboflavin. Niacin, or nicotinic acid, is a precursor of NADH, NAD, NADPH and NADP, which play essential roles in living organisms. A daily intake of 10−15 mg niacin is recommended. Niacin can be synthesized in the body from tryptophan. Almonds are a good source, but the best are cape gooseberries and avocadoes. The stability of niacin in food is better than vitamins C and A. Unlike vitamins A and D, niacin cannot be stored for long periods (10−14 days) in the body. Consequently, deficiency symptoms can develop rapidly with improper intake (Martin et al., 2011).

Vitamin B_6 (pyridoxal phosphate) is a co-factor in many transamination, decarboxylation and deamination reactions (e.g., formation of ACC by ACC synthase in plants requires pyridoxal phosphate as a co-factor) (Ramalingam et al., 1985). It is present in appreciable amounts in bean, cabbage, cauliflower, spinach, sweet potato, grape, avocado and banana and is fairly heat stable.

Pantothenic acid can be obtained from fresh, canned or frozen fruits and vegetables. It occurs widely in peas, beans, nuts, broccoli, mushrooms, potatoes and sweet potatoes. Pantothenic acid deficiency leads to fatigue, headaches, sleep disturbances, tingling of hands and impaired immune responses. Biotin is stable during cooking, processing and storage of fresh, canned and frozen fruits and vegetables. However, it is synthesized in the intestinal tract (Salunkhe et al., 1991). Folic acid is essential for reproduction and normal growth (Bar-Oz et al, 2008). It is present in fruits, spinach, cabbage and other green vegetables. Choline is heat stable and occurs in dried legumes and vegetables. Choline deficiency in humans has never been reported. Vitamin B_{12} does not occur in fruits and vegetables.

Vitamin C

Ascorbic acid (AsA) and its first oxidation product dehydroascorbic acid (which is reduced in the human body) are both considered to be vitamin C. AsA is a water soluble, carbohydrate-derived compound with antioxidant and acidic properties due to a 2,3-enediol moiety (Figure 5.1). Humans and a few other species cannot synthesize AsA (Chatterjee, 1973) because the gene coding for the last enzyme in the pathway (L-gulono-1,4-lactone oxidase) is not functional (Valpuesta and Botella, 2004). Plants synthesize AsA via a pathway that uses L-galactose as a precursor (Smirnoff and Wheeler, 2000; Smirnoff, 2000). Another pathway using galacturonic acid recycled from cell wall pectin degradation is present in plants (Agius et al., 2003). AsA is involved in collagen biosynthesis (Murad et al., 1981). Even though nutritional deficiencies are rare in modern western cultures, it is generally recognized that dietary AsA has important health benefits (Carr and Frei, 1999; Hancock and Viola, 2005). In meat-poor diets, dietary AsA can improve iron uptake (Frossard et al., 2000). The recommended dietary allowance of vitamin C is 75 and 90 mg per day for men and young women, respectively (Levine et al., 2001).

Fruits, vegetables and juices are the main dietary sources of vitamin C. Fruits and vegetables account for 90% of the vitamin C in the United States food supply (Hiza and Bente, 2007). Vitamin C concentration varies depending on the commodity (Noctor and Foyer, 1998), from 1 to 150 mg/100 g FW (Lee and Kader, 2000).

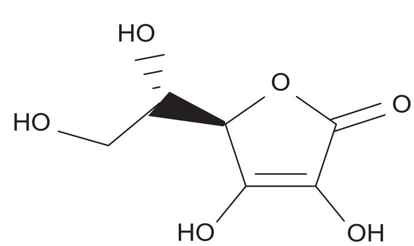

FIGURE 5.1

Structure of ascorbic acid, a main antioxidant present in fruits and vegetables.

Table 5.4 Vitamin C Concentration (Mean Values) of Selected Fruits

Product	Vitamin C (mg/100 g)
Guava, raw	184
Kiwi, raw	118
Litchi, raw	72
Pawpaw, raw	62
Strawberry, raw	57
Citrus fruits	31–53
Cantaloupe	42

Source: *Salunkhe et al. (1991).*

In berry fruits, AsA ranges from 14 to 103 mg/100 g FW (Pantelidis et al., 2007). Several tropical fruit species and leafy vegetables are rich in ascorbic acid, particularly rosehip, jujube and guava (see also Chapter 11). Other good sources include persimmon, strawberry, kiwifruit, peppers, citrus fruit, spinach, broccoli and cabbage (Table 5.4). Wide variations in vitamin C concentrations may exist among cultivars or species of the same genus: in one study, AsA in *Actinidia* species varied from 29 to 80 mg/100 g FW (Nishiyama et al., 2004). For any given product, AsA concentrations may vary due to genetic and environmental factors (reviewed in Lee and Kader, 2000) (see also Chapter 20). Sunlight exposure is a main factor that determines the AsA concentration. In general, more sunlight received during growth increases ascorbic acid. Retention of AsA is also affected by storage and processing conditions. Potatoes lose up to 80% of their original AsA over nine months' storage. AsA stability is reduced at high temperatures and bruising increases AsA degradation. Ascorbic acid is highly susceptible to oxidation, either directly or through the enzyme ascorbate oxidase (Sanmartin et al., 2007). The first oxidation product of AsA, dehydroascorbic acid, still has vitamin C activity, but this is lost on further oxidation (Salunkhe et al., 1991). When vegetables are cooked, high losses of vitamin C are expected. Starchy vegetables lose 40–80% of the vitamin C during cooking due to leaching and oxidation. Losses can be reduced by steam cooking. Freezing reduces vitamin C content slightly, but during long-term frozen storage (12 months), significant losses may occur (33–55%) (de Ancos et al., 2000).

Vitamin E

Vitamin E includes tocopherols and tocotrienols. These compounds exist in eight forms (four tocopherols and four tocotrienols). All isomers have aromatic rings with a hydroxyl group that donates hydrogen atoms to reduce reactive oxygen species (ROS). The terms α, β, γ and δ refer to the number and position of methyl groups on the chromanol ring. Each form has vitamin E activity, but α-tocopherol is the most active (Figure 5.2). Vitamin E deficiency stunts growth. Vitamin E is most abundant in oily seeds, olives, nuts, peanuts, avocados and almonds.

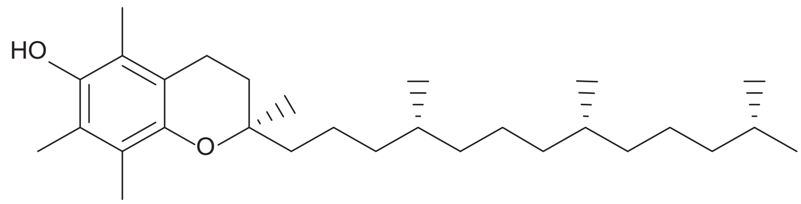

FIGURE 5.2

Structure of tocopherol.

Broccoli and leafy vegetables have less tocopherol than fats and oils, but are still better sources than other fruits and vegetables.

Vitamins D and K

Vitamin D promotes the absorption and use of calcium and phosphate. The main forms are ergocalciferol and cholecalciferol. They occur only in trace amounts in fruits and vegetables, but are found in fortified dairy products, eggs, liver and salmon (Hanson et al., 2013; Pludowski et al., 2013; Holick, 2013; Malone and Kessenich, 2008).

Vitamin K is essential for blood coagulation; the recommended daily intake is 120 μg. Dietary deficiency of vitamin K is uncommon. It is abundant in lettuce, spinach, cauliflower and cabbage, and it can also be produced by gut microflora (Presse et al., 2013).

H Minerals

Dietary minerals concern health specialists and consumers because of the number of processes they are involved in and continuous research highlighting the benefits of an adequate and balanced intake. Although there is no universally accepted definition or classification, the dietary focus on "minerals" derives from an interest in supporting the biosynthetic apparatus with required elemental components other than carbon, hydrogen and oxygen.

Minerals in food items are defined as the total ash content. The classification of many elements as essential minerals for human nutrition is not definitive, and there is still debate over the natural biological roles of vanadium, chromium, boron, aluminum and silicon in human health. Minerals are usually classified as macronutrients or micronutrients, based on the relative concentrations of each nutrient considered adequate for normal tissue function. Macronutrients include potassium (K), calcium (Ca), magnesium (Mg), nitrogen (N) and phosphorus (P), and their concentrations in plant tissues range from 1000 to 15,000 μg/g dry weight. Micronutrient concentrations are 100- to 10,000-fold less than those of macronutrients. Mineral micronutrients considered essential for human nutrition include manganese (Mn), copper (Cu), iron (Fe), zinc (Zn), cobalt (Co), sodium (Na), chlorine (Cl), iodine (I), fluorine (F), sulfur (S) and selenium (Se). Macronutrients

Table 5.5 Fruit and Vegetable Sources of Potassium, Ranked by Mg Potassium/Standard Amount, also Showing Calories in the Standard Amount*

Fruits and Vegetables, Standard Amount	Potassium (mg)	Calories
Sweet potato, baked, 1 potato (146 g)	694	131
Tomato paste, 1/4; cup	664	54
Beet greens, cooked, 1/2; cup	655	19
Potato, baked, flesh, 1 potato (156 g)	610	145
White beans, canned, 1/2 cup	595	153
Tomato puree, 1/2 cup	549	48
Prune juice, 3/4 cup	530	136
Carrot juice, 3/4 cup	517	71
Lima beans, cooked, 1/2 cup	484	104
Winter squash, cooked, 1/2 cup	448	40
Banana, 1 medium	422	105
Spinach, cooked, 1/2 cup	419	21
Tomato juice, 3/4 cup	417	31
Tomato sauce, 1/2 cup	405	39
Peaches, dried, uncooked, 1/4; cup	398	96
Prunes, stewed, 1/2 cup	398	133
Apricots, dried, uncooked, 1/4; cup	378	78
Cantaloupe, 1/4; medium	368	47
Honeydew melon, 1/8; medium	365	58
Plantains, cooked, 1/2 cup slices	358	90
Kidney beans, cooked, 1/2 cup	358	112
Orange juice, 3/4 cup	355	85
Split peas, cooked, 1/2 cup	355	116

**U.S. Department of Health and Human Services and U.S. Department of Agriculture (2005).*
The dietary reference intake (DRI) for potassium for adults and adolescents is 4700 mg/day.

can also be classified into those that maintain their identity as ions within plant tissues (e.g., K^+, Ca^{2+} and Mg^{2+}) and those that are assimilated into organic compounds (e.g., N, P and S). In general, vegetables are a richer source of minerals than fruits (Table 5.5).

Minerals have both direct and indirect effects on human health. The direct effects of minerals are the consequences of their consumption by humans, while indirect effects are their impact on fruit and vegetable quality and subsequent consumer acceptance (see also Chapter 4). From a direct nutrition standpoint, potassium is the most abundant in both fruits and vegetables, but nitrogen and calcium have major impacts on food quality.

Until recently, nutrition research focused on single-mineral effects on human health, generally with incongruent results (Aaron and Sanders, 2013). The recognition that minerals are not consumed individually but as combined constituents of a varied diet has shifted efforts to unraveling the role of overall diet, or dietary patterns, in blood pressure, cardiovascular diseases, bone diseases and other chronic disorders. Epidemiological surveys suggest that total diet has more influence on health than specific components. It is increasingly clear that it is not only an excess or deficiency of a single mineral but also of multiple nutrients in combination that have dietary effects on health.

Fruits and vegetables are not recognized as primary sources of mineral nutrition (Fairweather-Tait and Hurrell, 1996). Nevertheless, the Dietary Approaches to Stop Hypertension (DASH) emphasize fruits, vegetables and low-fat dairy products as a source of minerals. In the DASH dietary pattern, vegetables contribute 14.3, 15.5, 16.2 and 10.4% of required calcium, magnesium, potassium and zinc, respectively (Lin et al., 2003). There has been a trend towards lower mineral contents in fruits and vegetables over the past decades (Mayer, 1997; Ekholm et al., 2007) which has not been fully offset by increased fruit and vegetable consumption. Vegetable contribution of potassium, phosphorus, magnesium, calcium, copper, iron and zinc to the United States food supply decreased significantly during the last century, while the fruit contribution of potassium, phosphorus, magnesium and copper increased (Table 5.6).

Strategies for improving our mineral intake from fruits and vegetables have been implemented. These comprise increasing the consumption of fruits and vegetables and increasing concentrations of essential nutrients through fortification. Alternative approaches include improving nutrient bioavailability and retention.

Table 5.6 Minerals (%) Contributed from Fruits and Vegetables to the U.S. Food Supply in Selected Years

	Fruit (Year/s)			Vegetables (Year/s)		
Mineral	**1909–1919**	**1960–1969**	**2004**	**1909–1919**	**1960–1969**	**2004**
Potassium	8.0	8.7	11.2	36.7	27.1	26.6
Calcium	2.6	2.2	2.6	8.7	6.0	7.0
Phosphorus	1.5	1.5	1.8	10.4	7.7	7.7
Magnesium	4.5	5.6	6.1	18.2	15.9	13.9
Copper	5.2	6.1	6.1	30.2	22.8	17.2
Iron	3.3	3.1	2.5	18.4	13.5	10.1
Zinc	1.2	1.3	1.2	9.1	7.4	6.4
Sodium	0.8	1.3	2.0	10.4	23.4	28.9
Selenium	0.5	0.6	0.4	1.2	2.4	2.3

Source: Hiza and Bente (2007).

Potassium (K)

A potassium-rich diet contributes to lower blood pressure, blunting the effects of NaCl (Salunkhe et al., 1991). Inadequate potassium intake has long been associated with higher blood pressure (McCarron and Reusser, 2001). Potassium also regulates heartbeat, assists in muscle contraction and is needed to send nerve impulses and to release energy from fat, carbohydrates and protein. Different nutrients and phytochemicals in fruits and vegetables, including potassium, may independently or jointly reduce cardiovascular disease risk (Ignarro et al., 2007). Potassium is a systemic electrolyte that co-regulates ATP with sodium. Potassium favorably affects acid–base metabolism, which may reduce the risk of developing kidney stones (Zerwekh et al., 2007), and possibly decreases bone loss with age. Although calcium intake is an important determinant of peak bone mass and in retarding bone loss in postmenopausal women, findings of higher bone mass and lower bone resorption in women with high intakes of potassium, magnesium, zinc and vitamin C emphasize the importance of considering the impact of other nutrients when focusing on a particular mineral (Cohen and Roe, 2000). Up to 11 different groups of compounds, vitamins, minerals, antioxidants among others, in fruits and vegetables could influence bone health (MacDonald, 2007).

Potassium is the most abundant individual mineral element in fruits and vegetables at between 60 and 600 mg/100 g FW. It is active in many cellular and whole plant functions: it serves as an osmoticum for cellular growth and stomatal function, balances the charges of anions, activates ~60 plant enzymes and participates in many metabolic processes, including protein synthesis, oxidative metabolism and photosynthesis. In fruits and vegetables, potassium occurs mainly in combination with organic acids. Examples of potassium-rich fruits and vegetables include bananas and plantains, leafy green vegetables, many dried fruits, oranges and orange juice, cantaloupes and honeydew melons, tomatoes and root vegetables (Table 5.7).

Calcium (Ca)

Calcium is essential for bone and tooth formation. Thus, calcium requirements are higher during adolescence. Calcium is also very important during later adulthood from a public health perspective, because inadequate calcium intake may increase the risk of osteoporosis, a condition in which decreased bone mass weakens bone (Nordin, 1997; Cohen and Roe, 2000). Nearly half of American women over 50 have low mineral bone density or osteoporosis and an estimated 1.3 million osteoporosis-related fractures occur each year at an estimated annual cost of a billion dollars (DeBar et al., 2004; Quesada-Gómez et al., 2013; Yesil et al., 2012; Emkey and Emkey, 2012) so osteoporosis prevention is a major public health target. Calcium fluxes are important mediators of hormonal effects on target organs through the phosphoinositol system and are closely linked with cyclic AMP systems. There is evidence linking hypertension to calcium deficiency (Appel et al., 1997; McCarron and Reusser, 2001).

Table 5.7 Mineral Composition of Some Fruits in mg/100 g FW

Fruit	Mineral									
	K	**Ca**	**Mg**	**P**	**Mn**	**Cu**	**Fe**	**Zn**	**Na**	**Se**
Apples, raw, with skin	107	6	5	11	0.035	0.027	0.12	0.04	1	0.0
Apricots, raw	259	13	10	23	0.077	0.078	0.39	0.2	1	0.1
Avocado, raw (California)	507	13	29	54	0.149	0.170	0.61	0.68	8	0.4
Avocado, raw (Florida)	351	10	24	40	0.095	0.311	0.17	0.4	2	–
Bananas, raw	358	5	27	22	0.270	0.078	0.26	0.15	1	1.0
Blackberries, raw	162	29	20	22	0.646	0.165	0.62	0.53	1	0.4
Blueberries, raw	77	6	6	12	0.336	0.057	0.28	0.16	1	0.1
Cherries, sweet, raw	222	13	11	21	0.070	0.060	0.36	0.07	0	0.0
Figs, raw	232	35	17	14	0.128	0.070	0.37	0.15	1	0.2
Grapefruit, raw, pink and red (California and Arizona)	147	11	9	12	0.020	0.032	0.08	0.07	1	–
Grapefruit, raw, pink and red (Florida)	127	15	8	9	0.010	0.044	0.12	0.07	0	1.4
Grapes, red or green (European type, e.g., "Thompson seedless"), raw	191	10	7	20	0.071	0.127	0.36	0.07	2	0.1
Kiwifruit, fresh, raw	312	34	17	34	0.098	0.130	0.31	0.14	3	0.2
Lemons, raw, without peel	138	26	8	16	0.030	0.037	0.60	0.06	2	0.4
Mangoes, raw	156	10	9	11	0.027	0.110	0.13	0.04	2	0.6
Melons, Cantaloupe, raw	267	9	12	15	0.041	0.041	0.21	0.18	16	0.4
Oranges, raw, California, "Valencia"	179	40	10	17	0.023	0.037	0.09	0.06	0	–
Papayas, raw	257	24	10	5	0.011	0.016	0.10	0.07	3	0.6
Peaches, raw	190	6	9	20	0.061	0.068	0.25	0.17	0	0.1
Pears, raw	119	9	7	11	0.049	0.082	0.17	0.10	1	0.1
Pineapples, raw, all varieties	109	13	12	8	0.927	0.110	0.29	0.12	1	0.1
Plums, raw	157	6	7	16	0.052	0.057	0.17	0.10	0	0.0
Pomegranates, raw	259	3	3	8	–	0.070	0.30	0.12	3	0.6
Raspberries, raw	151	25	22	29	0.670	0.090	0.69	0.42	1	0.2
Strawberries, raw	153	16	13	24	0.386	0.048	0.41	0.14	1	0.4
Watermelon, raw	112	7	10	11	0.038	0.042	0.24	0.10	1	0.4

U.S. Department of Agriculture (2008).

In plants, calcium is primarily associated with pectins. It has a major influence on the rheological properties of the cell wall and, consequently, on the texture and storage life of fruits and vegetables. Ca^{2+} can interact with anionic pectic polysaccharides, coordinating with the oxygen functions of two adjacent pectin chains to form the so-called "eggbox structure" and cross-linking the chains (Rose et al., 2003). Also, intracellular Ca^{2+} occupies a pivotal role in cell signal transduction (Sanders et al., 1999). Plant signals associated with Ca^{2+} signatures include wounding, temperature stress, fungal elicitors, oxidative stress, anaerobiosis, abscisic acid, osmotic stress, red or blue light and mineral nutrition. Transient increases in intracellular Ca^{2+} are often associated with initiation of responses. Thus, Ca^{2+} is a prominent second messenger and must be maintained in the cytoplasm at concentrations many orders of magnitude lower than in the cell wall.

Horticultural crops are a secondary source of calcium compared to dairy products, but fruits and vegetables account for almost 10% of the calcium in the United States food supply (Table 5.7; Cook and Friday, 2003). Dark green, leafy cabbage family vegetables and turnip greens are good calcium sources and most green leafy vegetables are potential sources of absorbable calcium (Jodral-Segado et al., 2003; Titchenal and Dobbs, 2007). Projects designed to test the efficacy of a health plan-based lifestyle intervention for increasing bone mineral density propose not only increased consumption of high-calcium foods, but also of fruits and vegetables (DeBar et al., 2004).

Magnesium (Mg)

Magnesium is important in protein synthesis, release of energy from muscle storage and body temperature regulation. It is critical for proper heart function and bone formation as previously described. Magnesium activates over 100 enzymes. In plants, the porphyrin-like ring structure of chlorophyll contains a central magnesium atom coordinated to the four pyrrole rings. Magnesium is also involved in energy metabolism as a constituent of the Mg-ATP or Mg-ADP complex. The Calvin cycle pathway that produces a three-carbon compound as the first stable product in the multistep conversion of CO_2 into carbohydrates is partially regulated via stromal Mg^{2+} concentration. This nutrient also serves important biochemical functions in protein synthesis (Mengel and Kirkby, 1982).

The vegetable contribution to total magnesium in the United States food supply was 14% (Table 5.6) (Allen, 2013; Zhang et al., 2012). Magnesium intake was less than adequate for both adults and children (Sigman-Grant et al., 2003). Mixed users, who are more likely to consume grains, fruit and dairy products, had higher magnesium densities than high-fat users, who consumed significantly more meat (Sigman-Grant et al., 2003). Generally, magnesium concentrations are significantly higher in vegetables than in fruits, while nuts are good sources of this nutrient. Overall, dry fruits and legumes are high in magnesium (Jodral-Segado et al., 2003).

Phosphorus (P)

Inorganic phosphate is essential for skeletal mineralization and for multiple cellular functions including glycolysis, gluconeogenesis, DNA synthesis, RNA synthesis, cellular protein phosphorylation, phospholipid synthesis and intracellular regulatory roles (DiMeglio et al., 2000). Phosphorus is a primary bone-forming mineral. Because most Westerners eat high-phosphate diets, isolated dietary phosphate deficiency is exceedingly rare except for occasional metabolic disorders such as hyperphosphatemia (DiMeglio et al., 2000).

Phosphorus exists in plants as both inorganic phosphate anions and organophosphate compounds (Raghothama, 1999). Unlike sulfate and nitrate, phosphate is not reduced during assimilation, but remains in its oxidized state, forming phosphate esters in a variety of organic compounds. Inorganic phosphorus is a main structural component of nucleic acids and phospholipids, plays a central role in energy conversion in the form of high-energy phosphoester and diphosphate bonds, is important as a substrate and a regulatory factor in oxidative metabolism and photosynthesis, participates in signal transduction and regulates the activities of an assortment of proteins through covalent phosphorylation/dephosphorylation reactions. Fruit and vegetable contribution to total phosphorus was 9.5% (Table 5.6). Among tree fruits, nuts are significant sources of phosphorus.

Nitrogen (N)

The largest requirement for nitrogen in eukaryotic organisms is for amino acid biosynthesis, building blocks of proteins and precursors of many other compounds. Proteins represent a large percentage of the human body and carry out many different cell functions. Therefore, protein synthesis is central to cell growth, differentiation and reproduction.

Nitrogen is also an essential component of nucleic acids, co-factors and other metabolites. Several plant hormones (indole-3-acetic acid, zeatine, spermidine) contain nitrogen or are derived from nitrogenous precursors. Alkaloids and other secondary compounds contain nitrogen and various phenolics derived from the amino acid phenylalanine. Nitrogen is also a major constituent of chlorophyll. The characteristic preharvest yellow color of nitrogen-starved vegetables – a physiological disorder called chlorosis – reflects their inability to synthesize adequate amounts of green chlorophyll under nitrogen-limiting conditions.

Sulfur (S)

Sulfur is an essential nutrient for growth, being primarily used to synthesize cysteine and methionine. These sulfur-containing amino acids are pivotal for structural and catalytic functions of proteins and are used to form numerous essential and secondary metabolites. Oxidized thiol groups of two cysteine residues form disulfide bonds; covalent linkages that establish tertiary and sometimes quaternary protein structures. The dithiol ↔ disulfide interchange can be a regulatory mechanism that mediates redox reactions.

Sulfur nutrition is important for species in the order Brassicales (e.g., white cabbage, broccoli, cauliflower, capers) to synthesize anticarcinogenic glucosinolate compounds (reviewed in Sozzi, 2001). In caper (*Capparis spinosa* L.), 160 flavor components were identified, including elemental sulfur (S_8) and >40 sulfur-containing compounds, among them thiocyanates and isothiocyanates. Although essential for human and plant life, sulfur is a relatively minor component compared to nitrogen. Generally, it is not a growth-limiting nutrient, since sulfate, the oxidized anion, is relatively abundant in the environment.

Manganese (Mn)

Manganese is a key component of some enzymes, including oxygen-handling enzymes. It supports brain function and reproduction and is required for blood sugar regulation. In addition, it is part of bone structure. Manganese is a co-factor for antioxidant enzymes like the mitochondrial superoxide dismutase.

In plants, manganese atoms undergo successive oxidations to yield a strongly oxidizing complex that can oxidize water during photosynthesis. Like magnesium, manganese is required in enzyme reactions involving carbon assimilation. Chloroplasts are most sensitive to manganese deficiency. Among horticultural crops, spinach is a good source of manganese (Pennington and Fisher, 2010).

Copper (Cu)

Copper, a redox-active metal, is critical for the oxidative defense system; oxidative stress is a characteristic of copper deficiency (Uriu-Adams and Keen, 2005). Copper is necessary to form hemoglobin and is a cofactor for over 30 proteins including superoxide dismutase, ceruloplasmin, lysyl oxidase, cytochrome c oxidase, tyrosinase and dopamine-β-hydroxylase (Arredondo and Núñez, 2005). During the past decade there has been increasing interest in the concept that marginal copper deficits (López de Romaña et al., 2011) can contribute to the development and progression of cardiovascular disease and diabetes. Deficits in this nutrient during pregnancy can cause gross structural malformations in the fetus and persistent neurological and immunological abnormalities in the offspring (Uriu-Adams and Keen, 2005).

In plants, copper is required for chlorophyll synthesis and several copper-containing enzymes that reduce molecular oxygen. As with other trace minerals, the availability of copper to plants decreases as the pH rises above seven. At high pH, copper is strongly adsorbed to clays, iron and aluminum oxides and organic matter. Of the micronutrients required by plants, copper often has the lowest total concentration in soil.

Between 1909 and 1919 in the United States, vegetables were the leading source of copper (30%). In 2004, grains (21%) and legumes, nuts and soy (20%) replaced vegetables (17%) as the leading sources of copper (Table 5.7; Hiza and Bente, 2007).

Iron (Fe)

The metabolic fates of copper and iron are intimately related. Their essential role resides in their capacity to participate in one-electron exchange reactions. Systemic copper deficiency generates cellular iron deficiency, which in humans results in diminished work capacity, reduced intellectual capacity, stunted growth, altered bone mineralization and compromised immune response. Iron is required in numerous essential proteins including heme-containing proteins, electron transport chain and microsomal electron transport proteins and iron−sulfur proteins, and in enzymes such as ribonucleotide reductase, prolyl hydroxylase phenylalanine hydroxylase, tyrosine hydroxylase and aconitase (Arredondo and Núñez, 2005; Guss et al., 2011; Pettit et al., 2011; Horowitz et al., 2013).

Iron is a constituent of the hem complex, a naturally occurring plant chelate involved in electron transfer in several important plant enzymes (Mengel and Kirkby, 1982). The plant plastid stroma may contain deposits of phytoferritin, an iron storage form similar to the ferritin of animal cells. Phytoferritin occurs almost exclusively in plastids, especially those of storage organs (Briat and Lobreaux, 1997). In vegetable green leaves, there is a good correlation between iron and chlorophyll concentrations. Inadequate iron nutrition results in abnormal chlorophyll development: deficiency begins as interveinal chlorosis on younger leaves, resulting in prominently green veins. The resultant reduced photosynthetic capability also reduces the weight and area of affected leaves. Description and causes of iron deficiency have been extensively reviewed for horticultural crops (Korcak, 1987).

Adult users of lower-fat foods consume more nutrient-dense diets and more iron (Kennedy et al., 2001; Sigman-Grant et al., 2003). The predominant source of iron in the American food supply is grain products, followed by meat, poultry and fish. Between 1909 and 1919, vegetables furnished 18% of the iron in the food supply, but in 2004 that share dropped to 10% (Table 5.6), partially due to less use of white potatoes after 1920. Although potatoes are not a good source of iron, their contribution increases when eaten in large quantities (Hiza and Bente, 2007), particularly if the skin is consumed: baked potato skin has 20-fold more iron than the flesh. Almonds, pistachio nuts, walnuts and pecans are good sources of iron. Green vegetables (parsley, broccoli, kale, turnip greens and collards) and legumes (green peas and beans) are also good sources of iron.

Zinc (Zn)

Zinc is a pervasive microelement that plays a catalytic or a structural role in >200 enzymes involved in digestion (carboxypeptidase, liver alcohol dehydrogenase, carbonic anhydrase), metabolism, reproduction and wound healing. Zn^{2+} is a cation with various coordination possibilities and several potential geometries. Thus, it easily adapts to different ligands. The main role of structural Zn^{2+} in proteins is to stabilize tertiary structures. In addition, zinc has a critical role in the immune response and is an important antioxidant.

Zinc activates many plant cell enzymes (Romheld and Marschner, 1991) but only a few (alcohol dehydrogenase, superoxide dismutase, carbonic anhydrase and RNA polymerase) contain the micronutrient. Zinc affects carbohydrate metabolism because Zn-dependent enzymes participate in biochemical reactions of sugars. Zinc also plays a role in maintaining cell membrane integrity, protecting from $O_2^{-\bullet}$ damage and synthesizing RNA and tryptophan, a precursor of indole-3-acetic acid. A comprehensive review of soil, plant and management factors associated with zinc nutrition of crops is available (Swietlik, 1999).

Fruits and vegetables account for only 1.2% and 6.4%, respectively, of the zinc in the American food supply (Hiza and Bente, 2007). As with magnesium, zinc intakes may be insufficient in both adults and children (Sigman-Grant et al., 2003). Fruits are poor in zinc, but pecans and walnuts are good sources.

Sodium (Na)

Sodium is important for electrolyte balance and blood pressure. Along with potassium, it co-regulates ATP. Sodium intake from vegetables increased during the last decades (Table 5.6), due to increased consumption of processed vegetables, largely tomatoes and white potatoes. Except for canned vegetables, food supply sodium estimates do not include sodium added in processing. Thus, the relative contribution of vegetables to sodium in the food supply is likely overstated (Hiza and Bente, 2007). Table salt (NaCl) is by far the main dietary source of sodium. Olives and spinach are horticultural sources of sodium. In general, fruits are poor in sodium and are recommended for low-sodium diets.

Factors influencing mineral content of fruits and vegetables

Species and cultivar

Mineral composition varies widely in raw fruits (Table 5.7) and vegetables. Leafy vegetables have higher concentrations of nutrients that are less mobile in the plant (e.g., calcium) and depend on direct water flow rather than recycling from older leaves. Tissues with higher transpiration rates generally have higher tissue calcium concentrations (Witney et al., 1990a). Mineral concentrations may vary widely among cultivars. For example, both “Dwarf Brazilian” bananas (Santa Catarina Prata, *Musa* sp. AAB) and “Williams” (Cavendish subgroup, *Musa* sp. AAA) are considered good sources of potassium. Nevertheless, “Dwarf Brazilian” bananas have more P, Ca, Mg, Mn and Zn than “Williams” bananas (Wall, 2006). In contrast, no strawberry variety was a superior source of minerals (Hakala et al., 2003).

As a result of the distribution of vascular tissue, sink characteristics and metabolic rates, higher mineral concentrations are usually found in the skin and seeds than in the flesh of fruits. Tissues with higher metabolic rates (epicarp, core) may accumulate more nitrogen and phosphorus. Rapidly expanding or large-celled tissues are unlikely to have high calcium concentrations. In mature fruit, the calcium concentration is highest in the peel (Saure, 2005).

Preharvest factors

Orchard location has important effects on fruit and vegetable mineral concentrations (Table 5.7). For example, potassium in bananas differs among locations/microclimates in Hawaii (Wall, 2006). Similar fluctuations in potassium among growing areas is seen in “Rainbow” papaya fruits (Wall, 2006).

Mineral composition fluctuates widely in raw fruits and vegetables due to preharvest factors (soil fertility, including both pH and concentrations of nutrients, soil moisture, growth temperature) and cultural practices (amount and timing of fertilization and irrigation, application of plant growth regulators, pruning and thinning of tree fruit species). Most agricultural practices are established primarily to increase productivity, not to improve human health, horticultural crop postharvest life or flavor (Crisosto and Mitchell, 2002). Usually, fertilizers are applied directly to the soil to raise nutrient concentrations that are inadequate for successful crop growth, and to maintain soil fertility, which will decline if nutrient removal from the soil via crop uptake, leaching, volatilization, or denitrification exceeds nutrients added via weathering of minerals and mineralization of organic matter. Nitrogen is the most frequently deficient element and most commonly applied fertilizer in orchards, while phosphorus and potassium are added when soil test results, plant response or tissue analysis indicate a need. N-P-K addition with irrigation water has several advantages, including the ability to transport soluble nutrients directly to the root zone whenever water is applied to the plant. Thus, fertilizer amounts and timing can be precise and adjusted to coincide more closely with actual plant demand. Calcium additions can be large when lime is applied to increase soil pH. Most micronutrients are rarely applied to soil but are sprayed directly on the canopy in dilute concentrations. In fruits, the quantity of nutrients absorbed through the waxy cuticle is often small relative to nutrient demand, but can ameliorate deficiency symptoms and improve fruit quality (Lysiak et al., 2008).

An excessive supply of nutrients relative to photosynthesis develops when the rate of nutrient assimilation is high relative to net photosynthesis. When this happens, nutrients can accumulate in fruits and vegetables to levels toxic for the plant or consumers. Excessive nitrogen leads to potentially harmful accumulations of nitrate in leafy greens and potatoes (Pavlou et al., 2007; Zhao et al., 2011). Such nutrient imbalances also affect crop quality.

Nutrient transport and source−sink relations also affect nutrient accumulation. For example, altered water economy affects calcium uptake, since calcium is transported mainly in the transpiration stream (Grange and Hand, 1987). Bagging fruit may decrease calcium concentrations and increase calcium-related disorders due to increased relative humidity (Witney et al., 1991; Hofman et al., 1997), although the evidence is inconclusive (Saure, 2005). Canopy position and crop load also influence calcium uptake. Tree vigor is usually associated with less calcium and magnesium in fruits (Witney et al., 1990a, b). Fruit from upper parts of the canopy tend to have less calcium (Ferguson and Triggs, 1990), and heavily cropped trees have fruit with more calcium and less potassium (Ferguson and

Watkins, 1992). Calcium transport to fruit is under hormonal control: gibberellins inhibit calcium translocation (Saure, 2005).

Tree size, spacing, row orientation, canopy shape and training system influence light distribution within fruit trees, which affects fruit mineral composition. In grapes, improving light penetration into the canopy increased anthocyanins and soluble phenols, but reduced potassium (Prange and DeEll, 1997). In kiwifruit, light promoted calcium accumulation (Montanaro et al., 2006). This finding was not fully explained by fruit transpiration: regulation by phytohormones could help determine calcium concentrations. The effect of sunlight is not universal: avocado fruit from the sunny side of trees had the same calcium levels as fruit from the shaded side (Witney et al., 1990b).

The mineral concentrations in some horticultural species are affected by intensive culture systems (glasshouse) or organic conditions. Tomato fruit contained more calcium and less potassium, magnesium and sodium when grown in an organic compost/soil mix than in hydroponic substrates (Premuzic et al., 1998). Organically cultivated apples, pears, potatoes and corn had higher mineral concentrations than conventionally cultivated ones (Smith, 1993). In contrast, Petersen and Pedersen (1991) found no differences in mineral concentrations between organically and conventionally cultivated vegetables. Organic cultivation did not affect strawberry mineral concentrations consistently (Hakala et al., 2003; Bedbabis et al., 2010).

Postharvest practices

Postharvest treatments with minerals, primarily calcium, can increase the storage life and quality of some fruits and vegetables. In the last decade, the industry has been encouraged to fortify food and beverages with calcium. Increasing the calcium concentration of horticultural crops gives consumers new ways to enhance calcium intake without supplements. In addition, phosphorous-free sources of calcium can help provide a good balance of dietary calcium and phosphorus (Martín-Diana et al., 2007).

There are two primary ways to apply postharvest calcium to horticultural crops: (1) dipping-washing, and (2) impregnation (Martín-Diana et al., 2007). Immersion treatments are used for fresh, sensitive products like leafy vegetables. The delicate texture of berries does not withstand vacuum infiltration, so dips in $CaCl_2$ solution are performed (García et al., 1996), followed by the removal of excess solution. Impregnation modifies the composition of food through partial water removal and replacement with solutes, without damaging integrity. The driving forces can be an osmotic gradient between sample and solution, application of vacuum followed by normal atmospheric pressure, or both. $CaCl_2$ is widely used as a firming agent and preservative for whole and fresh-cut fruits and vegetables (see also Chapter 10). Mineral concentrations were similar in fresh, canned and frozen fruit and vegetable products; this is expected, since these nutrients are inert and thus not sensitive to degradation by the thermal processes used in food preservation.

Incidence of minerals on fruit and vegetable quality and consumer acceptance

Consumers buy certain products as good sources of specific minerals: potato and sweet potato for potassium, banana for magnesium and potassium, spinach for iron, potassium, magnesium and as a non-dairy source of calcium. Mineral analysis is performed by ashing and atomic absorption (Pomeranz and Meloan, 1987). Without such advanced analytical equipment, the consumers cannot detect differences in individual products at the point of purchase (Institute of Food Technologists, 1990) (see also Chapter 14). Minerals are thus credence attributes because they cannot be detected by visual inspection or consumption. Thus, there is no incentive to measure minerals in a quality control program unless specific nutritional claims can be made.

To judge quality, consumers use purchase attributes (size, color, firmness, aroma and absence of defects) and consumption attributes (flavor and mouth feel) (see also Chapter 3). Many of these qualities are affected by mineral concentrations and are part of many factors leading to fruit and vegetable acceptability. Acceptability, defined as "the level of continued purchase or consumption by a specific population" (Land, 1988), determines the consumption of many essential nutrients: vitamins, antioxidants and fiber. Thus, the effect of minerals on crop quality and consumer acceptance should be considered. The effect of minerals on color, flavor, firmness and other attributes of specific horticultural commodities is described below.

Effect of minerals on color

In apples and pears, both leaf and fruit nitrogen positively correlate with fruit green background color (Raese, 1977; Marsh et al., 1996), regardless of the rootstock (Fallahi et al., 1985). Manganese is also associated with green ground color in apples (Deckers et al., 1997). Excessive nitrogen inhibits background color change from green to yellow, inhibits reddish blush development and decreases edibility in peaches (Sistrunk, 1985; Crisosto et al., 1995, 1997). High nitrogen also decreases fruit color in grapes (Kliewer, 1977). In *Citrus*, nitrogen retards endogenous chlorophyll catabolism (Koo et al., 1974) and postharvest ethylene may be required to accelerate de-greening. In apples, correcting potassium deficiency can increase fruit red color, but applications in excess of need have no effect (Neilsen and Neilsen, 2003). In tomato, potassium deficiency is associated with less lycopene and increased β-carotene (Trudel and Ozbun, 1971).

Effect of minerals on flavor

Nitrogen status correlates negatively with soluble solids in apples (Fallahi et al., 1985; Dris et al., 1999) and in pears (Raese, 1977). In contrast, soluble solids increase with increased nitrogen in tomatoes (Barringer et al., 1999). Apple calcium and phosphorus both correlated negatively with fruit soluble solids at harvest and after six months of 0°C storage, while fruit K/Ca ratio correlated positively with titratable acidity (Fallahi et al., 1985). In mango, total soluble solids increased when zinc sulphate fertilizer was applied to the soil (Bahadur et al., 1998). In "Fino 49" lemon, salinity reduced juice percentage and impaired juice quality by decreasing soluble solid sugars and titratable acidity (García-Sánchez et al., 2003). Reduced titratable acidity could be due to the accumulation of Cl^- instead of Na^+, a charge imbalance compensated by degradation of organic acids.

Minerals also affect the production of several classes of volatile compounds in pome fruit (reviewed in Mattheis and Fellman, 1999). In fresh onions, increased sulfur availability enhances pungency and total sulfur flavor but decreases the concentrations of precursors for synthesis of volatiles, imparting "green" and "cabbage" notes (Randle, 1997).

Effect of minerals on firmness

Excess nitrogen can decrease tissue firmness (Reeve, 1970; Prange and DeEll, 1997). Also, low phosphorus decreases firmness in low-calcium fruits (Sharples, 1980). The relationship between calcium and fruit firmness has been extensively studied and reviewed (Ferguson, 1984; Poovaiah et al., 1988; Harker et al., 1997; Sams, 1999). Higher firmness and/or slower softening after harvest/storage are associated with higher calcium concentrations or calcium applications in apples and pears (Fallahi et al., 1985; Raese and Drake, 1993, 2000a, b, 2002; Gerasopoulos and Richardson, 1999; Benavides et al., 2001), kiwifruit (Hopkirk et al., 1990; Gerasopoulos and Drogoudi, 2005) and strawberries (Chéour et al., 1990). Calcium foliar sprays on peaches and nectarines increased calcium slightly (Manganaris et al., 2005a, 2006). In California, no consistent effect on the quality of mid- or late-season peaches and nectarines was found (reviewed in Crisosto et al., 1997).

Postharvest calcium treatments can retain fruit firmness in apples (Wang, et al., 1993; Conway et al., 1994), peaches (Manganaris et al., 2005b, 2007; Lysiak et al., 2009), strawberries (Morris et al., 1985; García, et al., 1996), lemons (Valero et al., 1998; Martínez-Romero et al., 1999) and sliced pears and strawberries (Rosen and Kader, 1989). Calcium effects on fruit firmness are attributable to calcium's ability to cross-link with pectic polysaccharides by ionic association. Calcium binding may reduce the accessibility of cell wall degrading enzymes to their substrates.

Effect of minerals on rots, physiological disorders and nutritional value

Calcium-treated fruit has increased firmness and reduced rot incidence. Calcium may affect both processes through its role in strengthening plant cell walls (García et al., 1996; Fallahi et al., 1997; Conway et al., 1999). High nitrogen increases susceptibility to decay caused by *Monilinia fructicola* (brown rot) in nectarines (Daane et al., 1995). Wounded and inoculated "Fantasia" and "Flavortop" nectarines from trees with more than 2.6% leaf nitrogen were more susceptible to *M. fructicola* than fruit from trees with less leaf nitrogen (Michailides et al., 1993).

Consumers consider that fruits have less predictable quality than manufactured snacks. The effect of nutrients on the final quality of horticultural products may not become evident until harvest, distribution or consumption. The expression "latent damage" was coined by Peleg (1985) and later defined by Shewfelt (1986) as "damage incurred at one step but not apparent until a later step" to describe this quality loss. Physiological disorders are a type of latent damage. Some physiological disorders are related to nutrient imbalance. Calcium is the nutrient most commonly associated with postharvest disorders. Calcium deficiency is an important preharvest factor for fruit and vegetable physiological disorders such as bitter pit in pome fruit, blossom-end rot in tomato, blackheart in celery, cracking and cavity spot in carrot and tipburn in lettuce and cabbage (reviewed in Ferguson et al., 1999), although some authors question the role of calcium in these disorders (Saure, 1998, 2001). Other calcium-related disorders are associated with long-term cold storage, such as chilling injury (CI) in muskmelon (Combrink et al., 1995) and avocado (Chaplin and Scott, 1980). Postharvest calcium applications limited the incidence of chilling injury (CI) in peach fruit, expressed as flesh browning, after four weeks cold storage at 5°C and additional ripening at room temperature for five days (Manganaris et al., 2007). Nevertheless, preharvest calcium applications did not affect the onset of CI in peaches and nectarines (reviewed in Lurie and Crisosto, 2005).

Magnesium and potassium are part of an index to predict bitter pit (Bramlage et al., 1985; Autio et al., 1986). Fallahi and Righetti (1984) considered the ratio of nitrogen and calcium as an important component of a diagnosis and recommendation system (DRIS) for apple. High rates of nitrogen application exacerbated the incidence of physiological disorders, such as apricot pit burn (Bussi and Amiot, 1998, 2003).

Minerals can influence the concentrations of other nutrients in horticultural crops. Nitrogen fertilizers applied at high rates decrease the concentration of vitamin C in fruits (citrus juices) and vegetables (potatoes, cauliflower, white cabbage and crisphead lettuce), while increased potassium fertilization increases ascorbic acid (reviewed in Lee and Kader, 2000).

III Antioxidants

A Oxidative damage and antioxidants

Reactive oxygen species (ROS) are partially reduced forms of oxygen such as singlet oxygen, hydrogen peroxide (H_2O_2), superoxide ($O_2^{-\bullet}$) or hydroxyl radical ($OH^{-\bullet}$) (Asada, 1999; Mittler, 2002). ROS cause deleterious modifications in proteins, lipids and nucleic acids by altering normal metabolism in living organisms (Waris and Ahsan, 2006; Jeremy et al., 2004). The protective effects of fruit and vegetables are attributed in part to the presence of antioxidants (Cao et al., 1996; Wang et al., 1996). Antioxidants are compounds that prevent uncontrolled cellular

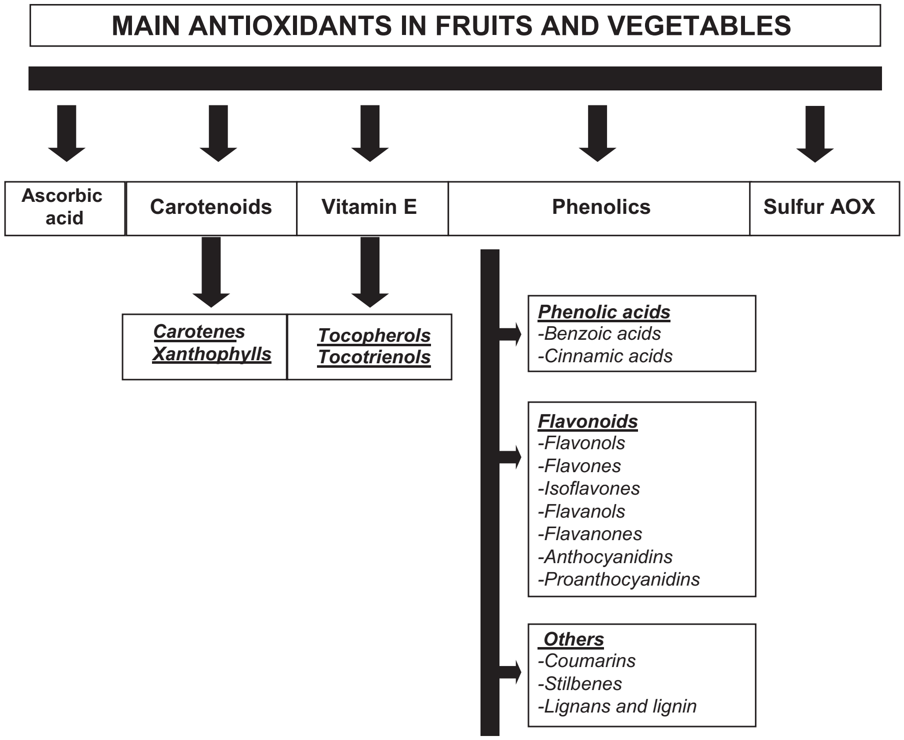

FIGURE 5.3

Main dietary antioxidants present in fruits and vegetables.

oxidation (Ames et al., 1993; Dragsted, 2003). They are present in all plant organs and include metabolites such as ascorbic acid, carotenoids, vitamin E, phenolics, glucosinolates and thiosulfinates (Figure 5.3).

B Ascorbic acid

Ascorbic acid is one of the most important compounds for human nutrition present in fruits and vegetables (Larson, 1988). Besides its vitamin functions, the role of AsA in disease prevention is associated with its capacity to neutralize ROS.

C Carotenoids

Fruits and vegetables are the main sources of carotenoids (Rao and Rao, 2007). The presence of conjugated double bonds in carotenoids is central to their antioxidant properties (Sandmann, 2001) and potential for preventing some diseases. They reduce LDL cholesterol oxidation, protecting against cerebral infarction, acute coronary events and stroke (Rinassen et al., 2001). Lycopene and β-carotene are the most studied carotenoids and protect against some digestive disorders (Kris-Etherton et al., 2002; Tan et al., 2010). The general properties of carotenoids were described above.

D Tocopherols and tocotrienols

Tocopherols and tocotrienols are fat-soluble compounds with vitamin E activity. Their distribution in fruits and vegetables was described above.

E Phenolic compounds

Phenolics are diverse compounds derived from aromatic amino acids. Their distinctive feature is the presence of aromatic rings with variable degrees of hydroxylation (Mattila et al., 2006). They contribute to fruit pigmentation and act as predator deterrents and antimicrobials. Phenolic compounds contribute to astringency and impart bitter taste in some products. They may also protect plant tissues against excessive UV radiation. They can be oxidized by plant peroxidases (PODs) and polyphenol oxidases (PPOs), leading to undesirable tissue browning. They are generally present at low concentrations, but in blueberries, levels can be over 0.1%. Phenolics accumulate preferentially in the peel, but this varies depending on species and chemical group. Eggplant anthocyanins are concentrated in the peel, while chlorogenic acid, the main antioxidant, predominates in the pulp, surrounding the seeds. As with other compounds, the health-promoting effects of phenolics depend on their bioavailability (Duthie et al., 2003; Seeram et al., 2006; Konic Ristic et al., 2011), but paradoxically their concentration in plasma is usually very low (Manach et al., 2005). Many phenolic compounds have been identified in plants (Tsao and Deng, 2004). They are grouped into sub-classes such as phenolic acids, flavonoids, lignans, stilbenes, tannins, coumarins and lignin.

Phenolic acids

Phenolic acids are derivatives of benzoic and cinnamic acids (Benbrook, 2005) (Figure 5.4). The most abundant benzoic acid derivatives are *p*-hydroxybenzoic, vanillic, syringic and gallic acids, while common cinnamic acid derivatives include *p*-coumaric, caffeic, ferulic and sinapic acids. The derivatives differ in the degree of hydroxylation and methoxylation of the aromatic ring. Caffeic acid is the most abundant phenolic acid in berry fruits (Mattila et al., 2006), while coumaric acid is usually present at lower concentrations (Rice-Evans et al., 1997). Ferulic acid comprises 90% of total phenolic acids in cereals (Manach et al., 2004; Scalbert and Williamson, 2000).

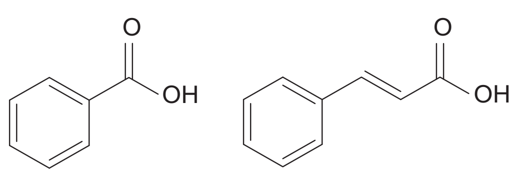

FIGURE 5.4

Structure of benzoic acid (left) and cinnamic acid (right), precursors of the two main classes of phenolic acids present in fruits and vegetables.

Flavonoids

Flavonoids are a large group of phenolic compounds with two aromatic rings associated by a 3 C oxygenated heterocycle. They are usually present as glycosides, which are more soluble than the corresponding aglycons, and are compartmentalized into the vacuoles (Rice-Evans et al., 1997). There are different flavonoid sub-classes: flavones and flavonols, flavanones and flavanols, isoflavones, proanthocyanidins and anthocyanidins (Le Marchand, 2002).

Flavones and flavonols

Flavonols have a central 3-hydroxypyran-4-one ring (Rice-Evans et al., 1997). Flavones lack the OH in position 3 (Figure 5.5). Rutin, luteolin and apigenin are common flavones, while the most abundant flavonols are quercetin and kampferol (Manach et al., 2004). Onions are rich in quercetin. Blueberries also have high concentrations, especially in peel, because their biosynthesis is stimulated by light exposure. Celery is a good source of flavones. In citrus, they are also abundant, but mainly in the peel.

Flavanones and flavanols

Flavanones have no double bond in position 2,3 of the central ring, while flavanols lack a carbonyl group at position 4 (Figure 5.6). The genus *Citrus* accumulates flavanone glycosides. Orange juice contains the flavanone glycoside

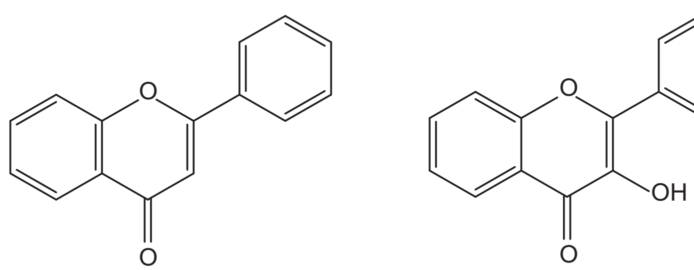

FIGURE 5.5

General structure of flavones (left) and flavonols (right).

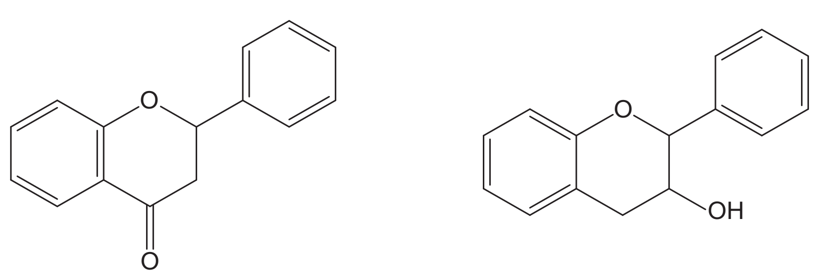

FIGURE 5.6

General structure of flavanones (left) and flavanols (right).

hesperidin (Tripoli et al., 2007). The flavanols catechin and epicatechin are common in grape (Rice-Evans et al., 1997).

Isoflavones

Isoflavones are phytoestrogens present in legumes. Soybean products are a good source of these compounds (Manach et al., 2004). The three most common isoflavones are genistein, glycitein and daidzein.

Proanthocyanidins

Proanthocyanidins are oligomeric flavonoids (usually dimers or oligomers of catechin and epicatechin). They are common in the peel and seeds of grape (Gu et al., 2004). Other sources include apple, almond and blueberry.

Anthocyanidins

The term anthocyanin is derived from the Greek words *anthos* and *cyan*, meaning flower and blue, respectively. They are pigments that provide the characteristic red or purple colors to some fruits. However, some forms are uncolored. Anthocyanidins contribute significantly to the antioxidant capacity of fruits and vegetables (Table 5.8). Because of their widespread distribution, anthocyanins are common antioxidants in the human diet. The *in vitro* antioxidant capacity of anthocyanins is associated with their ability to donate an H atom from an aromatic hydroxyl group to the free radicals and to delocalize an unpaired electron. The basic structure of anthocyanidins is derived from the flavilium cation (2-phenyl-benzopyril). Owing to their polarity, anthocyanins are readily soluble in water.

Six anthocyanidins are commonly found in fruits and vegetables: pelargonidin, cyanidin, delphinidin, peonidin, petunidin and malvidin. They differ in the substituents (OH, H or OCH_3) associated with the phenolic rings. Their distribution in fruits is: cyanidin 30%, delphinidin 22%, pelargonidin 18%, peonidin 7.5%, malvidin 7.5% and petunidin 5% (Andersen and Jordheim, 2006). Hydroxyl

Table 5.8 Fruits and Vegetables Particularly Rich in Specific Antioxidant Groups

Ascorbic acid	Vitamin E	Carotenoids	Phenolics
Strawberry	Almond	Pineapple	Blueberry
Pepper	Corn	Plum	Plum
Kiwifruit	Broccoli	Peach	Raspberry
Orange	Spinach	Pepper	Strawberry
Pepper	Peanut	Mango	Apple
Broccoli	Avocado	Melon	Blackberry
Guava		Tomato	
Rosehip		Carrot	
Persimmon			

distribution influences both the hue and antioxidant capacity of anthocyanidins. As a general rule, hydroxylation induces a shift of the visible max toward longer wavelengths (bathochromic effect, also known as blueing effect) (Gómez-Míguez et al., 2006). Methylation of hydroxyl groups causes the reverse trend. Consequently, the anthocyanidins with more hydroxyls are bluish, while those with methoxyl groups are red (Delgado-Vargas and Paredes-López, 2003). They are usually glycosylated or acylated, which increases or reduces their solubility, respectively. Sugars may be present as mono-, di- or trisaccharides. The major form of anthocyanins in most fruits is the monoglycoside, usually 70–100% of the total. Glucose, galactose, rhamnose and arabinose are the most common sugars in anthocyanins. Acylating agents include caffeic, *p*-coumaric, ferulic and sinapic acids (Castañeda-Ovando et al., 2009). These forms make up 0–6% of the total, except for blackberries and blueberries, in which they can be 15% (Wu et al., 2006). Anthocyanins form co-pigments with some metallic ions or colorless organic compounds in complex associations. Such interactions may change pigment hues and increase intensity (Boulton, 2001). Anthocyanin color is affected by pH. At low pH, the flavylium cation contributes purple and red colors. At higher pH (2–4), the quinoidal blue species predominate. Anthocyanin concentrations range from undetectable levels up to 611 mg/100 g FW in bilberries (Table 5.9). The structural diversity of anthocyanins in fruits has been analytically described in a recent review (Goulas et al., 2012).

Others

Lignans are diphenolic structures formed by the association of two cinnamic acid derivatives (Liu, 2007). They are present in linseed, cereals and legumes, but not significantly in fruits and vegetables. Stilbenes have received much attention due to their suggested anti-carcinogenic properties (Figure 5.7). Resveratrol belongs to this group; it accumulates in response to pathogens and other stresses in grapes (Langcake and Pryce, 1976). It has also been identified in other fruits, such as blueberries. Lignin was described above. Due to its very low solubility and digestibility, its contribution to antioxidant activity is negligible.

Relationship between phenolics structure and antioxidant capacity

The structure of phenolic compounds is directly related to their antioxidant properties. Increasing the degree of hydroxylation of the aromatic rings increases the antioxidant activity of hydroxycinnamic acids (Fan et al., 2009). Caffeic acid has more AOX capacity than *p*-coumaric acid. More hydroxyls in the B ring also increases the antioxidant activity of anthocyanins (Cao et al., 1997). Hydroxyls in the *ortho* configuration enhance antioxidant activity (Zheng and Wang, 2003; Kähkönen and Heinonen, 2003). The antioxidant activity of phenolic acids is enhanced by other electron-donating groups associated with the rings (Jing et al., 2012).

Glycosylation has variable effects on the antioxidant capacity of phenolic compounds. Often anthocyanins have similar or slightly less antioxidant activity than the corresponding anthocyanidin. Cyanidin, delphinidin and malvidin have

Table 5.9 Anthocyanidin Concentrations in Common Fruits

Fruit	Content (mg/100 g FW)
Acai	53.6
Acerola	22.6
Apple Fuji	0.7
Apple Gala	1.1
Apple Golden	0
Apple Granny Smith	0
Apple Red Delicious	3.8
Avocado	0.3
Blackberry	90.6
Blueberry	141.0
Cherry	27.7
Cranberry	85.5
Currant black	154.8
Currant red	75.0
Currant white	0
Eldberry	485.3
Grape Concord	65.6
Grape red	44.0
Grape green	0
Kiwifruit	0
Melon	0
Nectarine and peach	1.8
Pear	12.2
Pineapple	0
Plum red	7.0
Plum black	39.7
Plum yellow	0.3
Raspberry	40.9
Strawberry	23.8
Watermelon	0

Adapted from Bhagwat et al. (2011).

similar AOX capacity to their glycosylated derivatives. However, arabinose and rutinoside glycosides have less antioxidant capacity than glycosyl derivatives. The 3,5-diglucosides of cyanidin and malvidin have less AOX activity than the corresponding monoglycosides (Kähkönen and Heinonen, 2003; Zheng and Wang, 2003). Flavonols are usually more potent antioxidants than anthocyanins due to a 2,3 double bond associated with a 4-oxo function. (Zheng and Wang, 2003; Melidou et al., 2005).

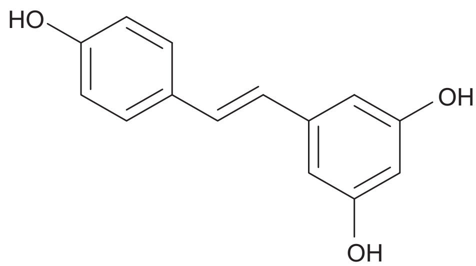

FIGURE 5.7

Structure of resveratrol. This compound has been studied in detail in grapes and may have anti-carcinogenic properties.

F Sulfur antioxidants

Sulfoxides and glucosinolates are among the most important sulfur antioxidants present in vegetables. Sulfoxides are common in vegetables of the genus *Allium*, particularly garlic (*Allium sativum*), one of the oldest medicinal plants. The major sulfur compounds in intact garlic are δ-glutamyl-S-allyl-L-cysteine and S-allyl-L-cysteine sulfoxide (alliin) (Butt et al., 2009). When raw garlic is chopped, the sulfoxides are converted to unstable thiosulfinates like allicin (Lawson et al., 1991). Other thiosulfinates include allylmethyl-, methylallyl- and trans-1-propenyl-thiosulfinate. Glucosinolates are present in plants of the order Brassicales. They have received great attention because their degradation products are powerful anti-carcinogenic compounds. They consist of a β-D-thioglucose group, a sulphonated oxime moiety, and a side chain derived from methionine, an aromatic, or a branched amino acid (Mahn and Reyes, 2012). In broccoli, the most abundant is glucoraphanin (80%) followed by glucobrassicin.

G Factors regulating the concentrations of antioxidants in fruits and vegetables

Several factors influence the accumulation of antioxidants in fruits and vegetables. Changes in composition from harvest to consumption depend on the compound, commodity, cultural practices, postharvest handling, processing and home cooking conditions (Figure 5.8).

Genetic factors

Species

The species determines the prevalence of specific antioxidants. With some exceptions, most fruits accumulate typical antioxidants (Table 5.6). Berries are particularly rich in phenolics (Zheng and Wang, 2003) and vitamin C (Kevers et al., 2007). Total phenolics correlate with total antioxidant capacity and phenolic compounds in these fruits. In ripe blueberries, ascorbic acid contributes only

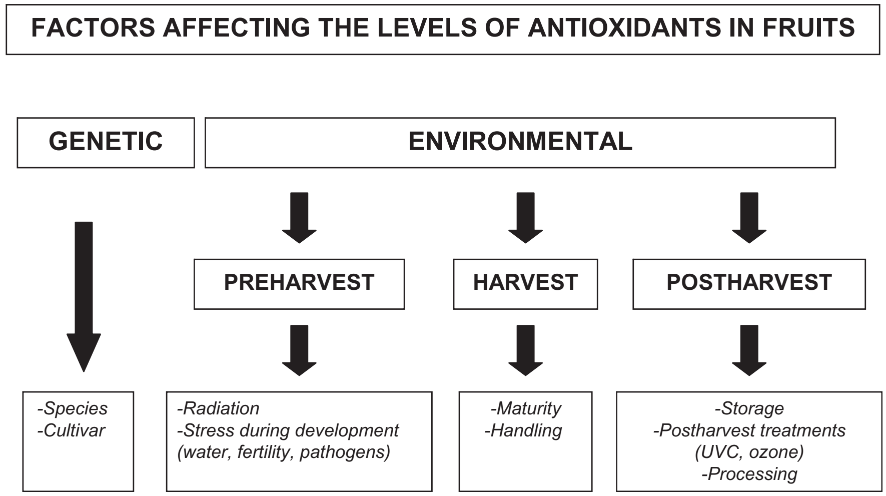

FIGURE 5.8

Factors affecting the concentrations of antioxidants in fruits and vegetables.

0.4−9.0% of total antioxidant capacity (Kalt et al., 1999). The distribution of antioxidants varies among the tissues of a fruit. Water-soluble polyphenolic compounds are found primarily in the skins of peaches, pears and apples. In strawberries, the achenes form only 1% of the total mass but contribute ∼11% of the phenolics and 14% of the antioxidant capacity (Aaby et al., 2005). In eggplants, chlorogenic acid is the main antioxidant that accumulates in the inner pulp.

Cultivar

For a given species, antioxidant concentrations vary by cultivar. In six strawberry cultivars, Nelson et al. (1972) found from 19 to 71 mg ascorbic acid/100 g FW. Similar differences among varieties have been reported for phenolics (Wang and Lin, 2000). The identification of lines or mutants that accumulate antioxidants might be useful in breeding programs to improve the nutritional value of fruits and vegetables. Overexpression of high-pigment (*hp*) in tomato increased carotenoid accumulation (Liu et al., 2004). Also in tomato, overexpression of phytoene synthase and lycopene cyclase increased β-carotene and lycopene (Fraser et al., 2002; D'Ambrosio et al., 2004). In carrot, overexpression of β-carotene ketolase from *Haematococcus pluvialis* led to accumulation of the ketocarotenoid astaxanthin (Jayaraj et al., 2007).

Transgenic approaches have increased the concentrations of phenolic compounds. Transformation of tomato with a *Petunia* gene for chalcone isomerase increased the flavonol concentration in the peel by 80-fold (Muir et al., 2001). While the biosynthetic pathway of ascorbic acid is established (Smirnoff, 2000) and most of the genes have been cloned and expressed in various plant species, these strategies have had only limited success.

Environmental factors

Radiation

Modifications in the concentrations of phenolic compounds, ascorbic acid and carotenoids are associated with changes in sunlight exposure. Sun-exposed fruit sides have more phenolics and vitamin C than shaded regions (Lee and Kader, 2000). In leafy vegetables, there are 10 times more flavonols in surface leaves than in internal leaves. Total phenolics doubled in tomato plants exposed to more light. These plants also accumulated more carotenoids and ascorbic acid (Gautier et al., 2008). Thus, radiation interception is important for producing commodities with increased antioxidants. However, the optimal irradiance to maximize accumulation of different antioxidants in fruits and vegetables is not established.

Cultural practices

Several works have analyzed the effect of cultural practices on antioxidants. Strawberries grown with plastic mulch had higher antioxidant capacity than fruits from uncovered beds (Wang et al., 2002). High nitrogen is associated with reduced ascorbic acid (Lee and Kader, 2000). Adding compost as a soil supplement significantly enhanced ascorbic acid (Wang and Lin, 2003). Vitamin C accumulation is inversely correlated with rainfall (Toivonen et al., 1994). Some studies found that organic products accumulated more antioxidants and vitamins than conventionally grown commodities (Woese et al., 1997; Weibel et al., 2000; Asami et al., 2003; Chassy et al., 2006). Other studies found no differences or opposite results (Barrett et al., 2007). A review found that it is not possible to conclude that organically grown products are nutritionally superior to conventional ones (Winter and Davis, 2006).

Maturity at harvest

Fruit developmental stage has a great impact on total antioxidant capacity (Prior et al., 1998) (see also Chapter 15). These changes are highly dependent on the commodity. In tomato and pepper, total antioxidant capacity increases as carotenoids and vitamin C accumulate during ripening. Total anthocyanin increases during ripening in all berries (Wang and Lin, 2000). However, the antioxidant capacity peaks in other species early in development. During blueberry ripening, anthocyanins accumulate while phenolic acids decrease (Rodarte Castrejón et al., 2008). The result is a net reduction of total antioxidant capacity. A similar pattern occurs in strawberry and blackberry (Wang and Lin, 2000). Carotenoids increase during development in pepper, tomato, mango and *Prunus* species (de Azevedo and Rodriguez-Amaya, 2005). In products in which anthocyanins or chlorophylls dominate, carotenoids usually drop during development (Rodriguez-Amaya, 2001).

Wounding

Tissue damage greatly affects total antioxidant concentration. Cell disruption exacerbates the turnover of AsA and phenolic compounds. Eliminating cellular compartmentalization triggers the oxidation of pre-existing phenolics by PPOs and increases hydrogen peroxide, providing the co-substrate for POD-mediated degradation. Wounding also alters phenolic biosynthesis (Tomás-Barberán et al., 1997; Loaiza Velarde et al., 1997). In lettuce, cutting induced phenylalanine ammonia lyase and led to accumulation of chlorogenic acid (Choi et al., 2005). Carotenoid turnover is also accelerated by oxygen, but they are more stable than other AOX groups. Careful handling to minimize physical damage is recommended to reduce antioxidant losses.

Storage

Refrigeration slows the deterioration of vitamin C; in broccoli, losses after seven days storage were 0 at 0°C but 56% at 20°C (see also Chapter 17). Excluding broccoli and banana, most products lose visual quality before significant losses of antioxidant capacity occur (Kevers et al., 2007). Improper temperature management significantly reduces visual quality and thus, consumer acceptance (see also Chapter 13). Ethylene induces accumulation of the bitter iso-coumarin 6-methoxymellein.

Other treatments

Biosynthesis of phenolics is triggered by elicitors like ultraviolet radiation or ozone. In grape, postharvest UV-C and ozone increased accumulation of resveratrol (Cantos et al., 2001; Versari et al., 2001; González-Barrio et al., 2006). Elicitation and accumulation of antioxidant compounds also occurs in other fruits. In blueberry cv. “Bluecrop”, reduced UV-C radiation exposure (2 or 4 kJ/m^2) increased the accumulation of anthocyanins and antioxidants (Perkins-Veazie et al., 2008). In strawberry, UV-C also increased phenolic compounds and antioxidants (Ayala-Zavala, et al., 2004). Further studies are needed to determine the feasibility of increasing AOX capacity of fruits and vegetables through manipulation of the postharvest environment (Kalt et al., 1999).

Bibliography

Aaby, K., Skrede, G., Wrolstad, R.E., 2005. Phenolic composition and antioxidant activities in flesh and achenes of strawberries (*Fragaria ananassa*). J. Agric. Food Chem. 53, 4032−4040.

Aaron, K.J., Sanders, P.W., 2013. Role of dietary salt and potassium intake in cardiovascular health and disease: a review of the evidence. Mayo Clin. Proc. 88 (9), 987−995.

Agius, F., Gonzalez-Lamothe, R., Caballero, J.L., Muñoz-Blanco, J., Botella, M.A., Valpuesta, V., 2003. Engineering increased vitamin C levels in plants by overexpression of a D-galacturonic acid reductase. Nat. Biotechnol. 21, 177−181.

Allen, L.H., 2013. Magnesium. Encyclopedia of Human Nutrition, third ed., 131−135.

Ames, B.M., Shigena, M.K., Hagen, T.M., 1993. Oxidants, antioxidants and the degenerative diseases of aging. Proc. Natl. Acad. Sci. U.S.A. 90, 7915−7922.

Andersen, Ø.M., Jordheim, M., 2006. The anthocyanins. In: Andersen, Ø.M., Markham, K.R. (Eds.), Flavonoids: Chemistry, Biochemistry and Applications. CRC Press, Boca Raton, FL, pp. 471–552.

Anderson, J.S., Perryman, S., Young, L., Prior, S., 2007. Dietary fiber. Colorado State University Nutrition Resources. N 9333. In: <http://www.ext.colostate.edu/PUBS/FOODNUT/09333.html> (accessed 30.01.14).

Appel, L.J., Moore, T.J., Oberzanek, E., Vollmer, W.M., Svetkey, L.P., Sacks, F.M., 1997. A clinical trial of the effect of dietary patterns on blood pressure. N. E. J. Med. 336, 1117–1124.

Arredondo, M., Núñez, M.T., 2005. Iron and copper metabolism. Mol. Aspects Med. 26, 313–327.

Asada, K., 1999. The water–water cycle in chloroplasts: scavenging of active oxygen and dissipation of excess photons. Annu. Rev. Plant Physiol. Plant Mol. Biol. 50, 601–639.

Asami, D.K., Hong, Y.H., Barrett, D.M., Mitchell, A.E., 2003. A comparison of the total phenolic and ascorbic acid contents of freeze-dried and air-dried marionberry, strawberry and corn grown using conventional, organic and sustainable agricultural practices. J. Agric. Food Chem. 51, 1237–1241.

Asensi-Fabado, M.A., Munné-Bosch, S., 2010. Vitamins in plants: occurrence, biosynthesis and antioxidant function. Trends Plant. Sci. 15 (10), 582–592.

Asp, N.G., 1994. Nutritional classification of food carbohydrates. Am. J. Clin. Nutr. 59, S679–S681.

Autio, W.R., Bramlage, W.J., Weis, S.A., 1986. Predicting disorders of 'Cox's Orange Pippin' and 'Bramley's Seedling' apples by regression equations. J. Am. Soc. Hort. Sci. 111, 738–742.

Ayala-Zavala, J.F., Wang, S.Y., Wang, C.Y., Gonzalez-Aguilar, G.A., 2004. Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. Lebensm. Wiss. Technol. 37, 687–695.

Bahadur, L., Malhi, C.S., Singh, Z., 1998. Effect of foliar and soil applications of zinc sulphate on zinc uptake, tree size, yield, and fruit quality of mango. J. Plant Nutr. 21, 589–600.

Bar-Oz, B., Koren, G., Nguyen, P., Kapur, B.M., 2008. Folate fortification and supplementation—are we there yet? Reprod. Toxicol. 25 (4), 408–412.

Barrett, D.M., Weakley, C., Diaz, J.V., Watnik, M., 2007. Qualitative and nutritional differences in processing tomatoes grown under commercial organic and conventional production systems. J. Food Sci. 72, C441–C450.

Barringer, S.A., Bennett, M.A., Bash, W.D., 1999. Effect of fruit maturity and nitrogen fertilizer levels on tomato peeling efficiency. J. Veg. Crop Prod. 5, 3–11.

Bedbabis, S., Ferrara, G., Rouina, B.B., Boukhris, M., 2010. Effects of irrigation with treated wastewater on olive tree growth, yield and leaf mineral elements at short term. Sci. Hort. 126 (3), 345–350.

Benavides, A., Recasens, I., Casero, T., Puy, J., 2001. Chemometric analyses of 'Golden Smoothee' apples treated with two preharvest calcium spray strategies in the growing season. J. Sci. Food Agric. 81, 943–952.

Benbrook, C.M., 2005. Elevating antioxidant levels in food through organic farming and food processing. An Organic Center state of science review. In: <www.organic-center.org/reportfiles/Antioxidant_SSR.pdf> (accessed 30.01.14).

Bhagwat, S., Haytowitz, D.B., Holden, J.M., 2011. USDA database for the flavonoid content of selected foods. Release 3. Nutrient Data Laboratory Beltsville Human Nutrition Research Center Agricultural Research Service U.S. Department of Agriculture.

Boerjan, W., Ralph, J., Baucher, M., 2003. Lignin biosynthesis. Annu. Rev. Plant Biol. 54, 519−546.

Boulton, R., 2001. The copigmentation of anthocyanins and its role in the color of red wine: a critical review. Am. J. Enol. Vitic. 52, 67−87.

Bramlage, W.J., Weis, S.A., Drake, M., 1985. Predicting poststorage disorders of 'McIntosh' apples from preharvest mineral analyses. J. Am. Soc. Hort. Sci. 110, 493−498.

Brett, C.T., Waldron, K.W., 1996. Physiology and biochemistry of plant cell walls. In: Black, M., Charlwood, B. (Eds.), Topics in Plant Functional Biology. Chapman and Hall, London, U.K., 230 p.

Briat, J.-F., Lobreaux, S., 1997. Iron transport and storage. Trends Plant Sci. 2, 187−193.

Brummell, D.A., 2006. Cell wall disassembly in ripening fruit. Funct. Plant Biol. 33, 103−119.

Brummell, D.A., Harpster, M.H., 2001. Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants. Plant Mol. Biol. 47, 311−339.

Bussi, C., Amiot, M.J., 2003. Effects of fertilizer rates and dates of application on apricot (cv Bergeron) cropping and pitburn. Sci. Hort. 98, 139−147.

Bussi, C., Amiot, M.J., 1998. Effects of nitrogen and potassium fertilization on the growth, yield and pitburn of apricot (cv. Bergeron). J. Hort. Sci. Biotechnol. 73, 387−392.

Butt, M.S., Sultan, M.T., Butt, M.S., Iqbal, J., 2009. Garlic: nature's protection against physiological threats. Crit. Rev. Food Sci. Nutr. 49 (6), 538−551.

Cantos, E., Espín, J.C., Tomás-Barberán, F.A., 2001. Postharvest induction modeling method using UV irradiation pulses for obtaining resveratrol-enriched table grapes: a new "functional" fruit?. J. Agric. Food. Chem. 49, 5052−5058.

Cao, G., Sofic, E., Prior, R.L., 1996. Antioxidant capacity of tea and common vegetables. J. Agric. Food Chem. 44, 3426−3431.

Cao, G., Sofic, E., Prior, R.L., 1997. Antioxidant and prooxidant behavior of flavonoids: structure−activity relationships. Free Rad. Biol. Med. 22, 749−760.

Carpita, N., McCann, M., 2000. The plant cell wall. In: Buchanan, B., Gruissem, W., Jones, R. (Eds.), Biochemistry and Molecular Biology of Plants. American Society of Plant Physiologists, pp. 52−109.

Carr, A.C., Frei, B., 1999. Toward a new recommended dietary allowance for vitamin C based on antioxidant and health effects in humans. Am. J. Clin. Nutr. 69, 1086−1107.

Casiglia, E., Tikhonoff, V., Caffi, S., Boschetti, G., Grasselli, C., Saugo, M., et al., 2013. High dietary fiber intake prevents stroke at a population level. Clin. Nutr. 32 (5), 811−818.

Castañeda-Ovando, A., Pacheco-Hernandez, M.D.L., Paez-Hernandez, M.E., Rodriguez, J.A., Galan-Vidal, C.A., 2009. Chemical studies of anthocyanins: a review. Food Chem. 113, 859−871.

Chaplin, G.R., Scott, K.C., 1980. Association of calcium in chilling injury susceptibility of stored avocados. HortScience 15, 514−515.

Chassy, A., Bui, L., Renaud, E.N.C., Van Horn, M., Mitchell, A., 2006. Three-year comparison of the content of antioxidant microconstituents and several quality characteristics in organic and conventionally managed tomatoes and bell peppers. J. Agric. Food Chem. 54, 8244−8252.

Chatterjee, I.B., 1973. Evolution and the biosynthesis of ascorbic acid. Science 182, 1271–1272.

Chen, A.Y., Chen, Y.C., 2013. A review of the dietary flavonoid, kaempferol on human health and cancer chemoprevention. Food Chem. 138, 2099–2107.

Chéour, F., Willemot, C., Arul, J., Desjardins, Y., Makhlouf, I., Charest, P.M., et al., 1990. Foliar application of calcium chloride delays postharvest ripening of strawberry. J. Am. Soc. Hort. Sci. 115, 789–792.

Choi, Y.J., Tomás-Barberán, F.A., Saltveit, M.E., 2005. Wound-induced phenolic accumulation and browning in lettuce (*Lactuca sativa* L.) leaf tissue is reduced by exposure to n-alcohols. Postharvest Biol. Technol. 37, 47–55.

Chung, H.J., Donner, E., Liu, Q., 2011. Resistant starches in foods. Comprehensive Biotechnology, second ed., vol. 4, 527–534.

Cohen, A.J., Roe, F.J.C., 2000. Review of risk factors for osteoporosis with particular reference to a possible aetiological role of dietary salt. Food Chem. Toxicol. 38, 237–253.

Combrink, N.J.J., Jacobs, G., Maree, P.C.J., 1995. The effect of calcium and boron on the quality of muskmelons. J. Southern African Soc. Hort. Sci. 5, 33–38.

Conway, W.S., Janisiewicz, W.J., Klein, J.D., Sams, C.E., 1999. Strategy for combining heat treatment, calcium infiltration, and biocontrol to reduce postharvest decay of 'Gala' apples. HortScience 34, 700–704.

Conway, W.S., Sams, C.E., Wang, C.Y., Abbott, J.A., 1994. Additive effects of postharvest calcium and heat treatment on reducing decay and maintaining quality in apples. J. Am. Soc. Hort. Sci. 119, 49–53.

Cook, A.J., Friday, J.E., 2003. Food mixture of ingredient sources for dietary calcium: shifts in food group contributions using four grouping protocols. J. Am. Diet. Assoc. 103, 1513–1519.

Cuttriss, A.J., Cazzonelli, C.I., Wurtzel, E.T., Pogson, B.J., 2011. Carotenoids. Adv. Bot. Res. 58, 1–36.

Crisosto, C.H., Mitchell, J.P., 2002. Preharvest factors affecting fruit and vegetable quality. In: Kader, A.A. (Ed.), Postharvest Technology of Horticultural Crops. University of California, Agriculture and Natural Resources, California, pp. 49–54. , Publication 3311.

Crisosto, C.H., Johnson, R.S., DeJong, T., Day, K.R., 1997. Orchard factors affecting postharvest stone fruit quality. HortScience 32, 820–823.

Crisosto, C.H., Mitchell, F.G., Johnson, R.S., 1995. Factors in fresh market stone fruit quality. Postharvest News Inf. 6, 17N–21N.

D'Ambrosio, C., Giorio, G., Marino, I., Merendino, A., Petrozza, A., Salfi, L., et al., 2004. Virtually complete conversion of lycopene into β-carotene in fruits of tomato plants transformed with the tomato lycopene β-cyclase (tlcy-b) cDNA. Plant Sci. 166, 207–214.

Daane, K.M., Johnson, R.S., Michailides, T.J., Crisosto, C.H., Dlott, J.W., Ramirez, H.T., et al., 1995. Excess nitrogen raises nectarine susceptibility to disease and insects. Calif. Agric. 49 (4), 13–17.

de Ancos, B., Gonzalez, E.M., Cano, M.P., 2000. Ellagic acid, vitamin C, and total phenolic contents and radical scavenging capacity affected by freezing and frozen storage in raspberry fruit. J. Agric. Food Chem. 48, 4565–4570.

de Azevedo, C.H., Rodriguez-Amaya, D.B., 2005. Carotenoid composition of kale as influenced by maturity, season and minimal processing. J. Sci. Food Agric. 85, 591–597.

DeBar, L.L., Rittenbaugh, C., Vuckovik, N., Stevens, V.J., Aickin, M., Elliot, D., et al., 2004. YOUTH: decisions and challenges in designing an osteoporosis prevention intervention for teen girls. Preventive Med. 39, 1047−1055.

Deckers, T., Daemen, E., Lemmens, K., Missotten, C., Val, J., 1997. Influence of foliar applications on Mn during summer on the fruit quality of Jonagold. Acta Hort. 448, 467−473.

Delgado-Vargas, F., Paredes-López, O., 2003. Natural Colorants for Food and Nutraceutical Uses. CRC Press, Boca Raton, Florida, USA.

DiMeglio, L.A., White, K.E., Econs, M.J., 2000. Disorders of phosphate metabolism. Endocrinol. Metab. Clin. North Am. 29, 591−609.

Dragsted, L.O., 2003. Antioxidant actions of polyphenols in humans. Int. J. Vitam. Nutr. Res. 73, 112−119.

Dris, R., Bennett, M.A., Bash, E., 1999. Relationship between leaf and fruit minerals and fruit quality attributes of apples grown under northern conditions. J. Plant Nutr. 22, 1839−1851.

Dodevska, M.S., Djordjevic, B.I., Sobajic, S.S., Miletic, I.D., Djordjevic, P.B., Dimitrijevic-Sreckovic, V.S., 2013. Characterisation of dietary fibre components in cereals and legumes used in Serbian diet. Food Chem. 141 (3), 1624−1629.

Duthie, G.G., Gardner, P.T., Kyle, J.A.M., 2003. Plant polyphenols: are they the new magic bullet? Proc. Nutr. Soc. 62, 599−603.

Ekholm, P., Reinivuo, H., Mattila, P., Pakkala, H., Koponen, J., Happonen, A., et al., 2007. Changes in the mineral and trace element contents of cereals, fruits and vegetables in Finland. J. Food Compos. Anal. 20, 487−495.

Emkey, R.D., Emkey, G.R., 2012. Calcium metabolism and correcting calcium deficiencies. Endocrinol. Metab. Clin. North Am. 41 (3), 527−556.

Fairweather-Tait, S., Hurrell, R.F., 1996. Bioavailability of minerals and trace elements. Nutr. Res. Rev. 9, 295−324.

Fallahi, E., Righetti, T.L., 1984. Use of diagnosis and recommendation integrated system (DRIS) in apple. HortScience 19, 54.

Fallahi, E., Richardson, D.G., Westwood, M.N., Chaplin, M.H., 1985. Relationships among mineral nutrition, ethylene and post-harvest physiology in apples on six rootstocks. Sci. Hort. 25, 163−175.

Fallahi, E., Conway, W.S., Hickey, K.D., Sams, C.E., 1997. The role of calcium and nitrogen in postharvest quality and disease resistance of apples. HortScience 32, 831−835.

Fan, G.J., Jin, X.L., Qian, Y.P., Wang, Q., Yang, R.T., Dai, F., et al., 2009. Hydroxycinnamic acids as DNA-cleaving agents in the presence of Cu^{II} ions: mechanism, structure−activity relationship, and biological implications. Chem. Eur. J. 15, 12889−12899.

Ferguson, I.B., 1984. Calcium in plant senescence and fruit ripening. Plant Cell Environ. 7, 477−489.

Ferguson, I.B., Triggs, C.M., 1990. Sampling factors affecting the use of mineral analysis of apple fruit for prediction of bitter pit. N. Z. J. Crop Hort. Sci. 18, 147−152.

Ferguson, I.B., Watkins, C.B., 1992. Crop load affects mineral concentrations and incidence of bitter pit in 'Cox's Orange Pippin' apple fruit. J. Am. Soc. Hort. Sci. 117, 373−376.

Ferguson, I., Volz, R., Woolf, A., 1999. Preharvest factors affecting physiological disorders of fruit. Postharvest Biol. Technol. 15, 255−262.

Fernández-García, E., Carvajal-Lérida, I., Jarén-Galán, M., Garrido-Fernández, J., Pérez-Gálvez, A., Hornero-Méndez, D., 2012. Carotenoids bioavailability from foods: from plant pigments to efficient biological activities. Food Res. Int. 46 (2), 438–450.

Fisher, R.L., Bennett, A.B., 1991. Role of cell wall hydrolases in fruit ripening. Annu. Rev. Plant Physiol. Plant Mol. Biol. 42, 675–703.

Fraser, P.D., Romer, S., Shipton, C.A., Mills, P.B., Kiano, J.W., Misawa, N., et al., 2002. Evaluation of transgenic tomato plants expressing an additional phytoene synthase in a fruit-specific manner. Proc. Natl. Acad. Sci. U.S.A. 99, 1092–1097.

Frossard, E., Bucher, M., Machler, F., Mozafar, A., Hurrell, R., 2000. Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J. Sci. Food Agric. 80, 861–879.

Fuentes-Zaragoza, E., Riquelme-Navarrete, M.J., Sánchez-Zapata, E., Pérez-Álvarez, J.A., 2010. Resistant starch as functional ingredient: a review. Food Res. Int. 43 (4), 931–942.

García, J.M., Herrera, S., Morilla, A., 1996. Effects of postharvest dips in calcium chloride on strawberry. J. Agric. Food Chem. 44, 30–33.

García-Sánchez, F., Carvajal, M., Porras, I., Botía, P., Martínez, V., 2003. Effects of salinity and rate of irrigation on yield, fruit quality and mineral composition of 'Fino 49' lemon. Eur. J. Agron. 19, 427–437.

Gautier, H., Diakou-Verdin, V., Bernard, C., Reich, M., Buret, M., Bourgaud, R., et al., 2008. How does tomato quality (sugar, acid, and nutritional quality) vary with ripening stage, temperature, and irradiance? J. Agric. Food. Chem. 56, 1241–1250.

Gerasopoulos, D., Drogoudi, P.D., 2005. Summer-pruning and preharvest calcium chloride sprays affect storability and low temperature breakdown incidence in kiwifruit. Postharvest Biol. Technol. 36, 303–308.

Gerasopoulos, D., Richardson, D.G., 1999. Storage temperature and fruit calcium alter the sequence of ripening events of 'd'Anjou' pears. HortScience 34, 316–318.

Gómez-Míguez, M., González-Manzano, S., Escribano-Bailón, M.T., Heredia, F.J., Santos-Buelga, C., 2006. Influence of different phenolic copigments on the color of malvidin 3-glucoside. J. Agric. Food Chem. 54, 5422–5429.

González-Barrio, R., Beltrán, D., Cantos, E., Gil, M.I., Espín, J.C., Tomás-Barberán, F.A., 2006. Comparison of ozone and UV-C treatments on the postharvest stilbenoid monomer, dimer, and trimer induction in var. 'Superior' white table grapes. J. Agric. Food Chem. 54, 4222–4228.

Goulas, V., Vicente, A.R., Manganaris, G.A., 2012. Structural diversity of anthocyanins in fruits. In: Motohashi, N. (Ed.), Anthocyanins: Structure. Biosynthesis and Health Benefits, Hauppauge, NY, Nova, pp. 225–250.

Grange, R.I., Hand, D.W., 1987. A review of the effects of atmospheric humidity on the growth of horticultural crops. J. Hort. Sci. 62, 125–134.

Gross, K.C., Sams, C.E., 1984. Changes in cell wall neutral sugar composition during fruit ripening: a species survey. Phytochemistry 23, 2457–2461.

Grusak, M.A., Della Penna, D., 1999. Improving the nutrient composition of plants to enhance human nutrition and health. Annu. Rev. Plant Physiol. Plant Mol. Biol. 50, 133–161.

Gu, L., Kelm, M., Hammerstone, J., Beecher, G., Holde, J., Haytowitz, D., et al., 2004. Concentrations of proanthocyanidins in common foods and estimations of normal consumption. J. Nutr. 134, 613–617.

Guillon, F., Champ, M., 2000. Structural and physical properties of dietary fibres, and consequences of processing on human physiology. Food Res. Int. 33, 233–245.

Guss, D.A., Koenig, M., Castillo, E.M., 2011. Severe iron deficiency anemia and lice infestation. J. Emergency Med. 41 (4), 362–365.

Hakala, M., Lapveteläinen, A., Huopalahti, R., Kallio, H., Tahvonen, R., 2003. Effects of varieties and cultivation conditions on the composition of strawberries. J. Food Compos. Anal. 16, 67–80.

Hancock, R.D., Viola, R., 2005. Improving the nutritional value of crops through enhancement of L-ascorbic acid (vitamin C) content: rationale and biotechnological opportunities. J. Agric. Food Chem. 53, 5248–5257.

Hanson, C., Rutten, E.P.A., Wouters, E.F.M., Rennard, S., 2013. Diet and vitamin D as risk factors for lung impairment and COPD. Transl. Res. 162 (4), 219–236.

Harker, F.R., Redgwell, R.J., Hallett, I.C., Murray, S.H., 1997. Texture of fresh fruit. Hort. Rev. 20, 121–224.

Heinonen, I.M., Meyer, A.S., Frankel, E.N., 1998. Antioxidant activity of berry phenolics on human low-density lipoprotein and liposome oxidation. J. Agric. Food Chem. 46, 4107–4112.

Hiza, H.A.B., Bente, L., 2007. Nutrient Content of the U.S. Food Supply, 1909–2004: A Summary Report. Home Economics Research Report Number 57. U.S. Department of Agriculture, Center for Nutrition Policy and Promotion, Washington, DC.

Hofman, P.J., Smith, L.G., Joyce, D.C., Johnson, G.I., Meiburg, G.F., 1997. Bagging of mango (*Mangifera indica* cv. 'Keitt') fruit influences fruit quality and mineral composition. Postharvest Biol. Technol. 12, 83–91.

Holick, M.F., 2013. Vitamin D: physiology, dietary sources, and requirements. Encyclopedia of Human Nutrition, third ed., 370–382.

Holst, B., Williamson, G., 2008. Nutrients and phytochemicals: from bioavailability to bioefficacy beyond antioxidants. Curr. Opin. Biotechnol. 19, 73–82.

Holzwarth, M., Korhummel, S., Siekmann, T., Carle, R., Kammerer, D.R., 2013. Influence of different pectins, process and storage conditions on anthocyanin and colour retention in strawberry jams and spreads. Food Sci. Technol. 52 (2), 131–138.

Hopkirk, G., Harker, F.R., Harman, J.E., 1990. Calcium and firmness of kiwifruit. N. Z. J. Crop Hort. Sci. 18, 215–219.

Horowitz, K.M., Ingardia, C.J., Borgida, A.F., 2013. Anemia in pregnancy. Clin. Lab. Med. 33 (2), 281–291.

Huber, D.J., O'Donoghue, E.M., 1993. Polyuronides in avocado (Persea americana) and tomato (*Lycopersicon esculentum*) fruits exhibit markedly different patterns of molecular weight downshifts during ripening. Plant Physiol. 102, 473–480.

Huyskens-Keila, S., Herppichb, W.B., 2013. High CO_2 effects on postharvest biochemical and textural properties of white asparagus (*Asparagus officinalis* L.) spears. Postharvest Biol. Technol. 75, 45–53.

Ignarro, L.J., Balestrieri, M.L., Napoli, C., 2007. Nutrition, physical activity, and cardiovascular disease: an update. Cardiovasc. Res. 73, 326–340.

Institute of Food Technologists, 1990. Quality of fruits and vegetables. A scientific status summary by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition. Food Technol. 44 (6), 99–106.

Institute of Medicine, 2001. Dietary Reference Intakes Proposed Definition of Dietary Fiber. A Report of the Panel on the Definition of Dietary Fiber and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. Food and Nutrition Board, National Academy Press, Washington, DC.

Itkin, M., Heinig, U., Tzfadia, O., Bhide, A.J., Shinde, B., Cardenas, P.D., et al., 2013. Biosynthesis of antinutritional alkaloids in Solanaceous crops is mediated by clustered genes. Science 341, 175–178.

Janositz, A., Semrau, J., Knorr, D., 2011. Impact of PEF treatment on quality parameters of white asparagus (*Asparagus officinalis* L.). Innovative Food Sci. Emerg. Technol. 12 (3), 269–274.

Jayaraj, J., Devlin, R., Punja, Z., 2007. Metabolic engineering of novel ketocarotenoid production in carrot plants. Transgenic Res.. Available from: http://dx.doi.org/10.1007/s11248-007-9120-0.

Jenkins, D.J.A., Kendall, C.W.C., Popovich, D.G., Vidgen, E., Mehling, C.C., Vuksan, V., et al., 2001. Effect of a very-high fiber vegetable, fruit, and nut diet on serum lipids and colonic function. Metabolism 50, 494–503.

Jeremy, J.Y., Shukla, N., Muzaffar, S., Handley, A., Angelini, G.D., 2004. Reactive oxygen species, vascular disease and cardiovascular surgery. Curr. Vasc. Pharmacol. 2, 229–236.

Jing, P., Zhao, S.J., Jian, W.J., Qian, B.J., Dong, Y., Pang, J., 2012. Quantitative studies on structure–DPPH scavenging activity relationships of food phenolic acids. Molec. 17, 12910–12924.

Jodral-Segado, A.M., Navarro-Alarcón, M., López-G de la Serrana, H., López Martínez, M.C., 2003. Magnesium and calcium contents in foods from SE Spain: influencing factors and estimation of daily dietary intakes. Sci. Total Environ. 312, 47–58.

Kähkönen, M.P., Heinonen, M., 2003. Antioxidant activity of anthocyanins and their aglycons. J. Agric. Food Chem. 51, 628–633.

Kalt, W., Forney, C.F., Martin, A., Prior, R.L., 1999. Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. J. Agric. Food Chem. 47, 4638–4644.

Kays, S.J., 1997. Postharvest Physiology of Perishables Plant Products. Exon Press, Athens, GA.

Kennedy, E., Bowman, S., Powell, R., 2001. Assessment of the effect of fat-modified foods on diet quality in adults, 19–50 years, using data from the Continuing Survey of Food Intake by Individuals. J. Am. Diet. Assoc. 101, 455–460.

Kevers, C., Falkowski, M., Tabart, J., Defraigne, J.O., Dommes, J., Pincemail, J., 2007. Evolution of antioxidant capacity during storage of selected fruits and vegetables. J. Agric. Food Chem. 55, 8596–8603.

Kliewer, W.M., 1977. Influence of temperature, solar radiation, and nitrogen on coloration and composition of 'Emperor' grapes. Am. J. Enol. Vit. 28, 96–103.

Kobayashi, M., Matoh, T., Azuma, J., 1996. Two chains of rhamnogalacturonan II are cross-linked by borate-diol ester bonds in higher plant cell walls. Plant Physiol. 110, 1017–1020.

Konic-Ristic, A., Šavikin, K., Zdunic, G., Tankovic, T., Juranic, Z., Menkovic, N., et al., 2011. Biological activity and chemical composition of different berry juices. Food Chem. 125, 1412–1417.

Koo, R.J.C., Young, T.W., Reese, R.L., Kesterson, J.W., 1974. Effect of nitrogen, potassium and irrigation on yield and quality of lemon. J. Am. Soc. Hort. Sci. 99, 289–291.

Kopsell, D.A., Kopsell, D.E., 2006. Accumulation and bioavailability of dietary carotenoids in vegetable crops. Trends Plant Sci. 11, 499–507.

Korcak, R.F., 1987. Iron deficiency chlorosis. Hort. Rev. 9, 133–186.

Kris-Etherton, P.M., Hecker, K.D., Bonanome, A., Coval, S.M., Binkoski, A.E., Hilpert, K.F., et al., 2002. Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. Am. J. Med. 113, 715–885.

Lajolo, F.M., Genovese, M.I., 2002. Nutritional significance of lectins and enzyme inhibitors from legumes. J. Agric. Food Chem. 50, 6592–6598.

Land, D.G., 1988. Negative influences on acceptability and their control. In: Thomson, D.M.H. (Ed.), Food Acceptability. Elsevier, New York, pp. 475–483.

Langcake, P., Pryce, R.J., 1976. The production of resveratrol by *Vitis vinifera* and other members of the Vitaceae as a response to infection and injury. Physiol. Plant Pathol. 9, 77–86.

Larson, R.A., 1988. The antioxidants of higher plants. Phytochemistry 27, 969–972.

Laurentin, A., Edwards, C.A., 2013. Fiber: resistant starch and oligosaccharides. Encyclopedia of Human Nutrition, third ed., 246–253.

Lawson, L.D., Wood, S.G., Hughes, B.G., 1991. HPLC analysis of allicin and other thiosulfinates in garlic clove homogenates. Planta Med. 57, 263–270.

Le Marchand, L., 2002. Cancer preventive effects of flavonoids—a review. Biomed. Pharmacother. 56, 296–301.

Lee, S.K., Kader, A.A., 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol. 20, 207–220.

Levine, M., Wang, Y.H., Padayatty, S.J., Morrow, J., 2001. A new recommended dietary allowance of vitamin C for healthy young women. Proc. Natl. Acad. Sci. U.S.A. 98, 9842–9846.

Lin, P.-H., Aickin, M., Champagne, C., Craddick, S., Sacks, F.M., McCarron, P., et al., 2003. Food group sources of nutrients in the dietary patterns of the DASH-Sodium trial. J. Am. Diet. Assoc. 103, 488–496.

Liu, R.H., 2007. Whole grain phytochemicals and health. J. Cereal Sci. 46, 207–219.

Liu, Y., Roof, S., Ye, Z., Barry, C., van Tuinen, A., Vrebalov, J., et al., 2004. Manipulation of light signal transduction as a means of modifying fruit nutritional quality in tomato. Proc. Natl. Acad. Sci. U.S.A. 101, 9897–9902.

Loaiza-Velarde, J.G., Tomás-Barberán, F.A., Saltveit, M.E., 1997. Effect of intensity and duration of heat-shock treatments on wound-induced phenolic metabolism in Iceberg lettuce. J. Am. Soc. Hort. Sci. 122, 873–877.

López de Romaña, D., Olivares, M., Uauy, R., Araya, M., 2011. Risks and benefits of copper in light of new insights of copper homeostasis. J. Trace Elem. Med. Biol. 25, 3–13.

Lurie, S., Crisosto, C.H., 2005. Chilling injury in peach and nectarine. Postharvest Biol. Technol. 37, 195–208.

Lysiak, G., Florkowski, W.J., Prussia, S.E., 2008. Postharvest calcium chloride application and moisture barrier influence on peach fruit quality. HortTechnol 18 (1), 100–105.

MacDonald, H.M., 2007. Influence of organic salts of potassium on bone health: possible mechanisms of action for the role of fruit and vegetables. Int. Congr. Ser. 1297, 268–281.

Mahn, A., Reyes, A., 2012. An overview of health-promoting compounds of broccoli (*Brassica oleracea* var. *italica*) and the effect of processing. Food Sci. Int. 18, 503–514.

Malone, R.W., Kessenich, C., 2008. Vitamin D deficiency: implications across the lifespan. J. Nurse Pract. 4, 448–454.
Manach, C., Scalbert, A., Morand, C., Remesy, C., Jimenez, L., 2004. Polyphenols: food sources and bioavailability. Am. J. Clin. Nutr. 79, 727–747.
Manach, C., Williamson, G., Morand, C., Scalbert, A., Remesy, C., 2005. Bioavailability and bioefficacy of polyphenols in humans. I. Review of 97 bioavailability studies. Am. J. Clin. Nutr. 81, 230s–242s.
Manganaris, G.A., Vasilakakis, M., Mignani, I., Diamantidis, G., Tzavella-Klonari, K., 2005a. The effect of preharvest calcium sprays on quality attributes, physicochemical aspects of cell wall components and susceptibility to brown rot of peach fruits (Prunus persica L. cv. Andross). Sci. Hort. 107, 43–50.
Manganaris, G.A., Vasilakakis, M., Diamantidis, G., Mignani, I., 2005b. Effect of post-harvest calcium treatments on the physicochemical properties of cell wall pectin in nectarine fruit during ripening after harvest or cold storage. J. Hort. Sci. Biotechnol. 80, 611–617.
Manganaris, G.A., Vasilakakis, M., Diamantidis, G., Mignani, I., 2006. Effect of in-season calcium applications on cell wall physicochemical properties of nectarine fruit (*Prunus persica* var. *nectarina* Ait. Maxim) after harvest or cold storage. J. Sci. Food Agric. 86, 2597–2602.
Manganaris, G.A., Vasilakakis, M., Diamantidis, G., Mignani, I., 2007. The effect of postharvest calcium application on tissue calcium concentration, quality attributes, incidence of flesh browning and cell wall physicochemical aspects of peach fruits. Food Chem. 100, 1385–1392.
Marlett, J.A., 1992. Content and composition of dietary fiber in 117 frequently consumed foods. J. Am. Diet. Assoc. 92, 175–186.
Marlett, J.A., Longacre, M.J., 1996. Comparisons of *in vitro* and *in vivo* measures of resistant starch in selected grain products. Cereal Chem. 73, 63–68.
Marlett, J.A., Slavin, J.L., 1997. Position of the American Dietetic Association health implications of dietary fiber. J. Am. Diet. Assoc. 97, 1157–1159.
Marlett, J.A., McBurney, M.I., Slavin, J.L., 2002. Position of the American Dietetic Association health implications of dietary fiber. J. Am. Diet. Assoc. 102, 993–1000.
Marsh, K.B., Volz, R.K., Cashmore, W., Reay, P., 1996. Fruit colour, leaf nitrogen level, and tree vigour in 'Fuji' apples. N. Z. J. Crop Hort. Sci. 24, 393–399.
Martin, C., Butelli, E., Petroni, K., Tonelli, C., 2011. How can research on plants contribute to promoting human health? Plant Cell 23, 1685–1699.
Martin, C., Zhang, Y., Tonelli, C., Petroni, K., 2013. Plants, diet, and health. Annu. Rev. Plant Biol. 64, 19–46.
Martín-Diana, A.B., Rico, D., Frías, J.M., Barat, J.M., Henehan, G.T.M., Barry-Ryan, C., 2007. Calcium for extending the shelf life of fresh whole and minimally processed fruits and vegetables: a review. Trends Food Sci. Technol. 18, 210–218.
Martínez-Romero, D., Valero, D., Serrano, M., Riquelme, F., 1999. Effects of postharvest putrescine and calcium treatments on reducing mechanical damage and polyamine and ABA levels during lemon storage. J. Sci. Food Agric. 79, 1589–1595.
Mattheis, J.P., Fellman, J.K., 1999. Preharvest factors influencing flavor of fresh fruit and vegetables. Postharvest Biol. Technol. 15, 227–232.
Mattila, P., Hellstrom, J., Torronen, R., 2006. Phenolic acids in berries, fruits, and beverages. J. Agric. Food Chem. 54, 7193–7199.
Mayer, A.M., 1997. Historical changes in the mineral content of fruits and vegetables. British Food J. 99, 207–221.

Mayer, J.E., Pfeiffer, W.H., Beyer, P., 2008. Biofortified crops to alleviate micronutrient malnutrition. Curr. Opin. Plant Biol. 11, 166−170.

McCarron, D.A., Reusser, M.E., 2001. Are low intakes of calcium and potassium important causes of cardiovascular disease? Am. J. Hypertens 14, S206−S212.

Meyer, K.A., Kushi, L.H., Jacobs Jr., D.R., Slavin, J., Sellers, T.A., Folsom, A.R., 2000. Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. Am. J. Clin. Nutr. 71, 921−930.

Meléndez-Martínez, A.J., Vicario, I.M., Heredia, F.J., 2007. Provitamin A carotenoids and ascorbic acid contents of the different types of orange juices marketed in Spain. Food Chem. 101, 177−184.

Mengel, K., Kirkby, E.A., 1982. Principles of Plant Nutrition. International Potash Institute, Worblaufen-Bern, Switzerland.

Michailides, T.J., Ramirez, H.T., Morgan, D.P., Crisosto, C.H., Johnson, R.S., 1993. Effects of nitrogen fertilization on susceptibility of stone fruits (peach and nectarine) to brown rot. 1992 Research Reports for California Peaches and Nectarines. California Tree Fruit Agreement, Sacramento, California.

Mittler, R., 2002. Oxidative stress, antioxidants and stress tolerance. Trends Plant Sci. 7, 405−410.

Montanaro, G., Dichio, B., Xiloyannis, C., Celano, G., 2006. Light influences transpiration and calcium accumulation in fruit of kiwifruit plants (*Actinidia deliciosa* var. *deliciosa*). Plant Sci. 170, 520−527.

Moretti, C.L., Mattos, L.M., Calbo, A.G., Sargent, S.A., 2010. Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: a review. Food Res. Int. 43 (7), 1824−1832.

Morris, J.R., Sistrunk, W.A., Sims, C.A., Main, G.L., 1985. Effects of cultivar, postharvest storage, preprocessing dip treatments and style of pack on the processing quality of strawberries. J. Am. Soc. Hort. Sci. 110, 172−177.

Moruisi, K.G., Oosthuizen, W., Opperman, A.M., 2006. Phytosterols/stanols lower cholesterol concentrations in familial hypercholesterolemic subjects: a systematic review with meta-analysis. J. Am. Coll. Nutr. 25, 41−48.

Mudgil, D., Barak, S., 2013. Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fiber: a review. Int. J. Biol. Macromol. 61, 1−6.

Muir, S.R., Collins, G.J., Robinson, S., Hughes, S., Bovy, A., Ric De Vos, C.H., et al., 2001. Overexpression of petunia chalcone isomerase in tomato results in fruit containing increased levels of flavonols. Nat. Biotechnol. 19, 470−474.

Murad, S., Grove, D., Lindberg, K.A., Reynolds, G., Sivarajah, A., Pinnell, S.R., 1981. Regulation of collagen synthesis by ascorbic acid. Proc. Natl. Acad. Sci. U.S.A. 78, 2879−2882.

Mussatto, S.I., Mancilha, I.M., 2007. Non-digestible oligosaccharides: a review. Carbohydr. Polym. 68, 587−597.

Neilsen, G.H., Neilsen, D., 2003. Nutritional requirements of apple. In: Ferree, D.C., Warrington, I.J. (Eds.), Apples: Botany, Production and Uses. CABI Publishing, Wallingford, Oxon, pp. 267−302.

Nelson, J.W., Barritt, B.H., Wolford, E.R., 1972. Influence of location and cultivar on color and chemical composition of strawberry fruit. Wash. Agric. Exp. Stn. Tech. Bull. 74, 1−7.

Nishiyama, I., Yamashita, Y., Yamanaka, M., Shimohashi, A., Fukuda, T., Oota, T., 2004. Varietal difference in vitamin C content in the fruit of kiwifruit and other Actinidia species. J. Agric. Food Chem. 52, 5472–5475.

Noctor, G., Foyer, C., 1998. Ascorbate and glutathione: keeping active oxygen under control. Annu. Rev. Plant Physiol. Plant Mol. Biol. 49, 249–279.

Nordin, B.E.C., 1997. Calcium and osteoporosis. Nutrition 13, 664–686.

O'Donoghue, E.M., Huber, D.J., Timpa, J.D., Erdos, G.W., Brecht, J.K., 1994. Influence of avocado (*Persea americana*) Cx-cellulase on the structural features of avocado cellulose. Planta 194, 573–584.

O'Neill, M.A., Ishii, T., Albersheim, P., Darvill, A.G., 2004. Rhamnogalacturonan II: structure and function of a borate cross-linked cell wall pectic polysaccharide. Ann. Rev. Plant Biol. 55, 109–139.

Ostlund Jr., R.E., 2002. Phytosterols in human nutrition. Annu. Rev. Nutr. 22, 533–549.

Palafox-Carlos, H., Ayala-Zavala, J.F., González-Aguilar, G.A., 2011. The role of dietary fiber in the bioaccessibility and bioavailability of fruit and vegetable antioxidants. J. Food Sci. 76, R6–R15.

Pantelidis, G.E., Vasilakakis, M., Manganaris, G.A., Diamantidis, G., 2007. Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and cornelian cherries. Food Chem. 102, 777–783.

Pavlou, G.C., Ehaliotis, C.D., Kavvadias, V.A., 2007. Effect of organic and inorganic fertilizers applied during successive crop seasons on growth and nitrate accumulation in lettuce. Sci. Hort. 111 (4), 319–325.

Peleg, K., 1985. Produce handling, Packaging, and Distribution. AVI/Van Nostrand Reinhold, New York.

Pennington, J.A.T., Fisher, R.A., 2010. Food component profiles for fruit and vegetable subgroups. J. Food Compos. Anal. 23 (5), 411–418.

Perkins-Veazie, P., Collins, J.K., Howard, L., 2008. Blueberry fruit response to postharvest application of ultraviolet radiation. Postharvest Biol. Technol. 47, 280–285.

Petersen, J., Pedersen, G., 1991. Sporelementer I økologisk dyrkede grønsaker. Levnedsmiddelstyrelsen. Rapport nr. F 91001 Levnedsmiddelstyrelsen, Copenhagen, Denmark, 10 pp. (in Danish).

Pettit, K., Rowley, J., Brown, N., 2011. Iron deficiency. Paediatr. Child Health 21 (8), 339–343.

Pludowski, P., Holick, M.F., Pilz, S., Wagner, C.L., Hollis, B.W., Grant, W.B., et al., 2013. Vitamin D effects on musculoskeletal health, immunity, autoimmunity, cardiovascular disease, cancer, fertility, pregnancy, dementia and mortality—A review of recent evidence. Autoimmun. Rev. 12 (10), 976–989.

Pomeranz, Y., Meloan, C.E., 1987. Food Analysis Theory and Practice, second ed. AVI/Van Nostrand Reinhold, New York.

Poovaiah, B.W., Glenn, G.M., Reddy, A.S.N., 1988. Calcium and fruit softening: physiology and biochemistry. Hort. Rev. 10, 107–152.

Prange, R., DeEll, J.R., 1997. Preharvest factors affecting quality of berry crops. HortScience 32, 824–830.

Premuzic, Z., Bargiela, M., García, A., Rendina, A., Iorio, A., 1998. Calcium, iron, potassium, phosphorus, and vitamin C content of organic and hydroponic tomatoes. HortScience 33, 255–257.

Presse, N., Belleville, S., Gaudreau, P., Greenwood, C.E., Kergoat, M., Morais, J.A., et al., 2013. Vitamin K status and cognitive function in healthy older adults. Neurobiol. Aging 34 (12), 2777−2783.

Prior, R.L., Cao, G., Martin, A., Sofic, E., McEwen, J., O'Brien, C., et al., 1998. Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species. J. Agric. Food Chem. 46, 2686−2693.

Quesada-Gómez, J.M., Diaz-Curiel, M., Sosa-Henriquez, M., Malouf-Sierra, J., Nogues-Solan, X., Gomez-Alonso, C., et al., 2013. Low calcium intake and inadequate vitamin D status in postmenopausal osteoporotic women. J. Steroid Biochem. Mol. Biol. 136, 175−177.

Raese, J.T., 1977. Response of young 'd'Anjou' pear trees to triazine and triazole herbicides and nitrogen. J. Am. Soc. Hort. Sci. 102, 215−218.

Raese, J.T., Drake, S.R., 1993. Effects of preharvest calcium sprays on apple and pear quality. J. Plant Nutr. 16, 1807−1819.

Raese, J.T., Drake, S.R., 2000a. Effect of calcium sprays, time of harvest, cold storage, and ripeness on fruit quality of 'Anjou' pears. J. Plant Nutr. 23, 843−853.

Raese, J.T., Drake, S.R., 2000b. Effect of calcium spray materials, rate, time of spray application, and rootstocks on fruit quality of 'Red' and 'Golden Delicious' apples. J. Plant Nutr. 23, 1435−1447.

Raese, J.T., Drake, S.R., 2002. Calcium spray materials and fruit calcium concentrations influence apple quality. J. Am. Pom. Soc. 56, 136−143.

Raghothama, K.G., 1999. Phosphate acquisition. Annu. Rev. Plant Physiol. Plant Mol. Biol. 50, 665−693.

Ramalingam, K., Lee, K.M., Woodard, R.M., Bleecker, A.B., Kende, H., 1985. Stereochemical course of the reaction catalyzed by the pyridoxal phosphate-dependent enzyme 1-aminocyclopropane-1-carboxylate synthase. Proc. Natl. Acad. Sci. U. S. A. 82, 7820−7824.

Randle, W., 1997. Onion flavor chemistry and factors influencing flavor intensity. In: Risch, S.J., Ho, C.T. (Eds.), Spices: Flavor Chemistry and Antioxidant Properties. ACS Symposium Series 660. Washington, DC, ACS Press, pp. 41−52.

Rao, A.V., Rao, L.G., 2007. Carotenoids and human health. Pharmacol. Res. 55, 207−216.

Redgwell, R.J., MacRae, E., Hallett, I., Fisher, M., Perry, J., Harker, R., 1997. In vivo and in vitro swelling of cell walls during fruit ripening. Planta 203, 162−173.

Reeve, R.M., 1970. Relationships of histological structure to texture of fresh and processed fruits and vegetables. J. Texture Stud. 1, 247−284.

Rice-Evans, C.A., Miller, N., Paganga, G., 1997. Antioxidant properties of phenolic compounds. Trends Plant Sci. 2, 152−159.

Ridley, B.L., O'Neill, M.A., Mohnen, D., 2001. Pectins: structure, biosynthesis, and oligogalacturonide-related signaling. Phytochemistry 57, 929−967.

Rimm, E.B., Ascherio, A., Giovannucci, E., Spiegelman, D., Stampfer, M.J., Willett, W.C., 1996. Vegetable, fruit, and cereal fiber intake and risk of coronary heart disease among men. J. Am. Med. Assoc. 275, 447−451.

Rissanen, T.H., Voutilainen, S., Nyyssonen, K., Lakka, T.A., Sivenius, J., Salonen, R., et al., 2001. Low serum lycopene concentration is associated with an excess incidence of acute coronary events and stroke: the Kuopio Ischaemic Heart Disease Risk Factor Study. Br. J. Nutr. 85, 749–754.

Rodarte Castrejón, A.D., Eichholz, I., Rohn, S., Kroh, L.W., Huyskens-Keil, S., 2008. Phenolic profile and antioxidant activity of highbush blueberry (*Vaccinium corymbosum* L.) during fruit maturation and ripening. Food Chem. 109, 564–572.

Rodriguez-Amaya, D.B., 2001. A Guide to Carotenoid Análisis in Foods. ILSI Press. International Life Sciences Institute, One Thomas Circle, N.W. Washington, D. C., 20005-5802 ISBN 1-57881-072-8.

Romheld, V., Marschner, H., 1991. Function of micronutrients in plants. In: Mortvedt, J.J., Cox, F.R., Shuman, L.M., Welch, R.M. (Eds.), Micronutrients in Agriculture, second ed. Soil Science Society of America, Madison, WI, pp. 297–328.

Rose, J.K.C., Catalá, C., Gonzalez-Carranza, Z.H., Roberts, J.A., 2003. Cell wall disassembly. In: Rose, J.K.C. (Ed.), The Plant Cell Wall. Blackwell Publishing Ltd., Oxford, UK, pp. 264–324.

Rosen, J.C., Kader, A.A., 1989. Postharvest physiology and quality maintenance of sliced pear and strawberry fruit. J. Food Sci. 54, 656–659.

Sajilata, M.G., Singhal, R.S., Kulkarni, P.R., 2006. Resistant starch – a review. Compr. Rev. Food Sci. Nutr..

Saltveit, M.E., 1988. Postharvest glyphosate application reduces toughening fiber content and lignification of stored asparagus spears. J. Am. Soc. Hort. Sci. 113, 569–572.

Salunkhe, D.K., Bolin, H.R., Reddy, N.R. (Eds.), 1991. Storage, Processing, and Nutritional Quality of Fruits and Vegetables. Volume I. Fresh Fruits and Vegetables. CRC Press, Boston.

Sams, C.E., 1999. Preharvest factors affecting postharvest texture. Postharvest Biol. Technol. 15, 49–254.

Sanders, D., Brownlee, C., Harper, J.F., 1999. Communicating with calcium. Plant Cell 11, 691–706.

Sandmann, G., 2001. Genetic manipulation of carotenoid biosynthesis: strategies, problems and achievements. Trends Plant Sci. 6, 14–17.

Sanmartin, M., Pateraki, I., Chatzopoulou, F., Kanellis, A.K., 2007. Differential expression of the ascorbate oxidase multigene family during fruit development and in response to stress. Planta 225, 873–885.

Saure, M.C., 1998. Causes of the tipburn disorder in leaves of vegetables. Sci. Hort. 76, 131–147.

Saure, M.C., 2001. Blossom-end rot of tomato (*Lycopersicon esculentum* Mill.) – a calcium – or a stress-related disorder? Sci. Hort. 90, 193–208.

Saure, M.C., 2005. Calcium translocation to fleshy fruit: its mechanism and endogenous control. Sci. Hort. 105, 65–89.

Scalbert, A., Williamson, G., 2000. Dietary intake and bioavailability of polyphenols. J. Nutr. 130, 20735–20855.

Seeram, N.P., Adams, L.S., Zhang, Y., Lee, R., Sand, D., Scheuller, H.S., et al., 2006. Raspberry, blueberry, cranberry, red raspberry, and strawberry extracts inhibit growth and stimulate apoptosis of human cancer cells in vitro. J. Agric. Food Chem. 54, 9329–9339.

Sharples, R.O., 1980. The influence of orchard nutrition on the storage quality of apples and pears grown in the United Kingdom. In: Atkinson, D., Jackson, J.E., Sharples, R.O., Waller, W.M. (Eds.), Mineral Nutrition of Fruit Trees. Butterworths, London, pp. 17–28.

Shewfelt, R.L., 1986. Postharvest treatment for extending the shelf life of fruits and vegetables. Food Technol. 40, 70–89.

Sigman-Grant, M., Warland, R., Hsieh, G., 2003. Selected lower-fat foods positively impact nutrient quality in diets of free-living Americans. J. Am. Diet. Assoc. 103, 570–576.

Sistrunk, W.A., 1985. Peach quality assessment: fresh and processed. In: Patee, H.E. (Ed.), Evaluation of Quality of Fruits and Vegetables. AVI, Westport, pp. 1–42.

Slavin, J.L., 2005. Dietary fiber and body weight. Nutrition 21, 411–418.

Smirnoff, N., 2000. Ascorbic acid: metabolism and functions of a multifaceted molecule. Curr. Opin. Plant Biol. 3, 229–235.

Smirnoff, N., Wheeler, G.L., 2000. Ascorbic acid in plants: biosynthesis and function. Crit. Rev. Biochem. Mol. Biol. 35, 291–314.

Smith, B., 1993. Organic food vs. supermarket food: element levels. J. Appl. Nutr. 45, 35–39.

Sozzi, G.O., 2001. Caper bush: botany and horticulture. Hort. Rev. 27, 125–188.

Srinivasa Reddy, M.S., Chen, F., Shadle, G., Jackson, L., Aljoe, H., Dixon, R.A., 2005. Targeted down-regulation of cytochrome P450 enzymes for forage quality improvement in alfalfa (*Medicago sativa* L.). Proc. Nat. Acad. Sci. USA 102, 16573–16578.

Swietlik, D., 1999. Zinc nutrition in horticultural crops. Hort. Rev. 23, 109–178.

Tan, H.L., Thomas-Ahner, J.M., Grainger, E.M., Wan, L., Francis, D.M., Schwartz, S.J., et al., 2010. Tomato-based food products for prostate cancer prevention: what have we learned? Cancer Met. Rev. 29, 553–568.

Terry, P., Giovannucci, E., Michels, K.B., Bergkvist, L., Hansen, H., Holmberg, L., et al., 2001. Fruit, vegetables, dietary fiber, and risk of colorectal cancer. J. Nat. Canc. Instit. 93, 525–533.

Titchenal, C.A., Dobbs, J., 2007. A system to assess the quality of food sources of calcium. J. Food Compos. Anal. 20, 717–724.

Tiwari, U., Cummins, E., 2013. Factors influencing levels of phytochemicals in selected fruit and vegetables during pre- and post-harvest food processing operations. Food Res. Int. 50 (2), 497–506.

Toivonen, P.M.A., Zebarth, B.J., Bowen, P.A., 1994. Effect of nitrogen fertilization on head size, vitamin C content and storage life of broccoli (*Brassica oleracea* var. *italica*). Can. J. Plant Sci. 74, 607–610.

Tomás-Barberán, F.A., Loaiza-Velarde, J., Bonfanti, A., Saltveit, M.E., 1997. Early wound- and ethylene-induced changes in phenylpropanoid metabolism in harvested lettuce. J. Am. Soc. Hort. Sci. 122, 399–404.

Tripoli, E., La Guardia, M., Giammanco, S., Di Majo, D., Giammanco, M., 2007. Citrus flavonoids: molecular structure, biological activity and nutritional properties: a review. Food Chem. 104, 466–479.

Trudel, M.J., Ozbun, J.L., 1971. Influence of potassium on carotenoid content of tomato fruit. J. Am. Soc. Hort. Sci. 96, 763–765.

Tsao, R., Deng, Z., 2004. Separation procedures for naturally occurring antioxidant phytochemicals. J. Chromatogr. 812, 85–99.

Uriu-Adams, J.Y., Keen, C.L., 2005. Copper, oxidative stress, and human health. Molec. Aspects Med. 26, 268–298.

U.S. Department of Agriculture, 2008. Composition of foods, raw, processed, prepared. USDA national nutrient database for standard reference, release 20. USDA–ARS, Beltsville Human Nutrition Research Center, Nutrient Data Laboratory, Beltsville, Maryland. <http://www.ars.usda.gov/nutrientdata> (accessed 04/2008).

U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010. Dietary Guidelines for Americans, seventh ed. U.S. Government Printing Office, Washington, DC.

U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2005. Dietary Guidelines for Americans, sixth ed. U.S. Government Printing Office, Washington, D.C..

Valero, D., Martínez-Romero, D., Serrano, M., Riquelme, F., 1998. Influence of postharvest treatment with putrescine and calcium on endogenous polyamines, firmness, and abscisic acid in lemon (*Citrus limon* L. Burn Cv. Verna). J. Agric. Food Chem. 46, 2102–2109.

Valpuesta, V., Botella, M.A., 2004. Biosynthesis of L-ascorbic acid in plants: new pathways for an old antioxidant. Trends Plant Sci. 9, 573–577.

Versari, A., Parpinello, G.P., Tornielli, G.B., Ferrarini, R., Giulivo, C., 2001. Stilbene compounds and stilbene synthase expression during ripening, wilting, and UV treatment in grape cv. Corvina. J. Agric. Food. Chem. 49, 5531–5536.

Vicente, A.R., Ortugno, C., Rosli, H., Powell, A.L.T., Greve, C., Labavitch, J.M.L., 2007a. Temporal sequence of cell wall disassembly events in developing fruits. 2. Analysis of blueberry (*Vaccinium* Species). J. Agric. Food Chem. 55, 4125–4130.

Vicente, A.R., Saladié, M., Rose, J.K.C., Labavitch, J.M., 2007b. The linkage between cell wall metabolism and fruit softening: looking to the future. J. Sci. Food Agric. 87, 1435–1448.

Voutilainen, S., Nurmi, T., Mursu, J., Rissanen, T.H., 2006. Carotenoids and cardiovascular health. Amer. J. Clin. Nutr. 83, 1265–1271.

Wall, M.M., 2006. Ascorbic acid, vitamin A, and mineral composition of banana (*Musa* sp.) and papaya (*Carica papaya*) cultivars grown in Hawaii. J. Food Compos. Anal. 19, 434–445.

Wang, C.Y., Conway, W.S., Abbott, J.A., Kramer, G.F., Sams, C.E., 1993. Postharvest infiltration of polyamines and calcium influences ethylene production and texture changes in 'Golden Delicious' apples. J. Am. Soc. Hort. Sci. 118, 801–806.

Wang, H., Cao, G., Prior, R.L., 1996. Total antioxidant capacity of fruits. J. Agric. Food Chem. 44, 701–705.

Wang, S.Y., Lin, H.S., 2000. Antioxidant activity in fruits and leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. J. Agric. Food Chem. 48, 140–146.

Wang, S.Y., Lin, H.S., 2003. Compost as a soil supplement increases the level of antioxidant compounds and oxygen radical absorbance capacity in strawberries. J. Agric. Food Chem. 51, 6844–6850.

Wang, S.Y., Zheng, W., Galletta, G.J., 2002. Cultural system affects fruit quality and antioxidant capacity in strawberries. J. Agric. Food Chem. 50, 6534–6542.

Waris, G., Ahsan, H., 2006. Reactive oxygen species: role in the development of cancer and various chronic conditions. J. Carcinog. 6, 14–21.

Weibel, F., Bickel, R., Leuthold, S., Alfoldi, T., 2000. Are organically grown apples tastier and healthier? A comparative field study using conventional and alternative methods to measure fruit quality. Acta Hort. 57, 417–426.

Willats, W.G.T., McCartney, L., Mackie, W., Knox, J.P., 2001. Pectin: cell biology and prospects for functional analysis. Plant Mol. Biol. 47, 9–27.
Winter, C.K., Davis, C.F., 2006. Organic foods. J. Food Sci. 71, R117–R124.
Witney, G.W., Hofman, P.M., Wolstenholme, B.N., 1990a. Effect of cultivar, tree vigour and fruit position on calcium accumulation in avocado fruits. Sci. Hort. 44, 269–278.
Witney, G.W., Hofman, P.J., Wolstenholme, B.N., 1990b. Mineral distribution in avocado trees with reference to calcium cycling and fruit quality. Sci. Hort. 44, 279–291.
Witney, G.W., Kushad, M.M., Barden, J.A., 1991. Induction of bitter pit in apple. Sci. Hort. 47, 173–176.
Woese, K., Lange, D., Boess, C., Bogel, K.W., 1997. A comparison of organically and conventionally grown foods—results of a review of the relevant literature. J. Sci. Food Agric. 74, 281–293.
Wolk, A., Manson, J.A.E., Stampfer, M.J., Colditz, G.A., Hu, F.B., Speizer, F.E., et al., 1999. Long-term intake of dietary fiber and decreased risk of coronary heart disease among women. J. Am. Med. Assoc. 281, 1998–2004.
Wu, X., Beecher, G.R., Holden, J.M., Haytowitz, D.B., Gebhardt, S.E., Prior, R.L., 2006. Concentrations of anthocyanins in common foods in the United States and estimation of normal consumption. J. Agric. Food Chem. 54, 4069–4075.
Yesil, Y., Kuyumcu, M.E., Ozturk, Z.A., Ulger, Z., Sahin, U., Cankurtaran, M., et al., 2012. The relationship between metabolic bone diseases and fingernail calcium levels in the elderly. Eur. Geriatr. Med. 3 (6), 341–344.
Zerwekh, J.E., Odvina, C.V., Wuermser, L.-A., Pak, C.Y.C., 2007. Reduction of renal stone risk by potassium–magnesium citrate during 5 weeks of bed rest. J. Urol. 177, 2179–2184.
Zhang, W., Iso, H., Ohira, T., Date, C., Tamakoshi, A., 2012. Associations of dietary magnesium intake with mortality from cardiovascular disease: the JACC study. Atherosclerosis 221 (2), 587–595.
Zhao, M., Shi, Y., Chen, X., Ma, J., 2011. Soil nitrogen accumulation in different ages of vegetable greenhouses. Procedia Environ. Sci. 8, 21–25.
Zheng, W., Wang, S.W., 2003. Oxygen radical absorbing capacity of phenolics in blueberries, cranberries, chokeberries, and lingonberries. J. Agric. Food Chem. 51, 502–509.
Zyren, J., Elkins, R., Dudek, J.A., Hagen, R.E., 1983. Fiber contents of selected raw and processed vegetables, fruits and fruit juices as served. J. Food Sci. 48, 600–603.

CHAPTER

6 Value Chain Management and Postharvest Handling

Ray Collins
School of Food and Agricultural Sciences, University of Queensland, Australia

I Introduction

A Firms, competitiveness and supply chains

The traditional economic view is that a firm's competitiveness is determined by how efficiently and effectively its management is able to organize the firm's internal processes, structures, resources and people so as to maximize profits. This allows firms to compete against each other for a share of a particular market or market segment based on their ability to keep prices low and/or to differentiate their product from competitors' products (Williamson, 1971; Porter, 1980; Wernerfelt, 1984).

To some extent this model still applies. Firms *do* have to price competitively; and firms *do* have to differentiate their products and services from those of their competitors. However, the traditional view of how firms become and remain competitive has been challenged by an alternative view that sees a firm as part of a supply chain that links the production of goods and services with the consumers of those goods and services (Figure 6.1).

In this alternative view, the competitiveness of a firm is influenced by how it interacts with other firms in the supply chains to which it belongs. As van Roekel (in Gifford et al., 1997, p. 4) pointed out, "it is becoming increasingly evident that achievement of the desired market position cannot be achieved solely through the company's own efforts. Because each company is just one link in the production chain, with upstream and downstream links, it has to co-operate. The more effectively it does this, the stronger its competitive position in the market". Van Roekel's statement captures the essence of this alternative view of competitiveness: that co-operation among firms in a supply chain can positively improve their competitiveness. This view is in sharp contrast to the idea of a competitive firm as being independent and internally efficient and effective.

Among traditionally competitive firms, linkages in supply chains are usually at arm's length and adversarial. Typically, firms attempt to buy inputs at the cheapest possible price from their suppliers, and sell outputs at the highest possible price to their customers. These transactions are at the expense of the buyers or suppliers in the chain, i.e., actions between chain members are self-optimizing and tend to shift costs to other firms in the chain, and ultimately to the

Postharvest Handling.

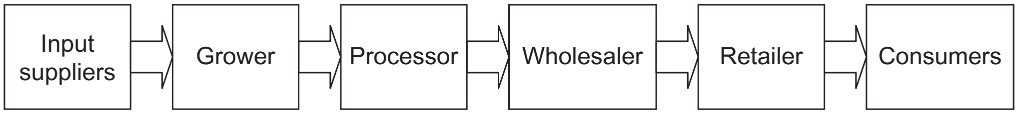

FIGURE 6.1

Simplified supply chain showing flow of product from input suppliers to consumers.

consumer. Many authors have pointed to the shortcomings of this approach to business, most noting that it does not necessarily improve the efficiency of the chain, does not lead to the best prices for consumers, and does not make the individual firms more competitive (Bowersox, 1990; Mentzer et al., 2001). Under adversarial conditions, independent, efficient firms do not lead to the most efficient supply chains.

B Supply chain management

When firms that belong to a supply chain work together to address inter-firm efficiencies and take more notice of what consumers want, a different picture of competitiveness emerges. Here there is an opportunity for collaboration to replace adversarial behavior and for the focus to move away from price and onto customers' needs. This business model, called Supply Chain Management (SCM), is built on the proposition that there are gains from co-operation and co-ordination between firms in a supply chain that are simply not available to firms that operate independently of each other. Thus a firm's ability to collaborate becomes intimately linked with its ability to compete, a proposition that is well supported in the literature (O'Keeffe, 1998; Gunasekaran et al., 2001; Halldorsson et al., 2007).

It has been suggested that the practices of SCM have existed for hundreds of years (Hugos, 2003), but supply chain management as a modern business strategy has its origins in manufacturing industries in the 1960s (Mentzer et al., 2001). More recently it has taken hold in agri-food industries, including horticulture (Fearne and Hughes, 1999). Originally, SCM referred to approaches that ensured the logistical and distributional efficiency of flows of materials along a supply chain (Cooper and Ellram, 1990). Over time, however, the focus of SCM became less tactical and less concerned with achieving logistical efficiency alone. It evolved to encompass what Spekman et al. (2002, p. 41) called a "competitive reality", where "firms compete as constellations of collaborating partners". More than any other factor, this change in orientation away from just the logistical aspects of the supply chain was driven by the increasing attention being paid to two factors: the importance of relationships in achieving inter-firm co-ordination; and the importance of identifying and satisfying the end consumer as the "target" of the supply chain.

Today, a widely accepted view is that SCM is "an integrated approach that aims to satisfy the expectations of consumers through continual improvement of processes and relationships that support the efficient development and flow of products and services from the producer to the consumer" (Gifford et al., 1997, p. 2). The key elements of this definition are:

- the need for integration between firms;
- a focus on consumers;
- the importance of relationships;
- a whole-of-supply-chain perspective.

Integration of business systems and processes between firms is necessary to achieve operational efficiencies and to improve the flow and transparency of information (Kouvelis et al., 2006). A focus on consumers acknowledges the need for the supply chain to have information about consumers' needs and wants, including feedback as to how they are being met. Effective relationships drive successful SCM because they are the antecedents of information exchange, conflict resolution and co-innovation between supply chain partners (Morgan and Hunt, 1994). Finally, the view of the supply chain as a dynamic, complex system linking input suppliers and producers through to consumers reinforces the idea that the whole is more than an aggregation of parts that can be improved independently of each other, and that performance of the whole system fundamentally depends on the interactions among its parts (Lambert and Cooper, 2000; Jackson, 2003).

II Value chain management

In spite of being what appears as an all-embracing concept, SCM has been criticized as being too supply oriented, having an upstream focus and not attaching enough importance to the role of consumers in the chain. For example, Mudimigh et al. (2004, p. 309) argue that "SCM does not extend far enough to capture customers' (end user) future needs and how these get addressed, and furthermore, it does not encompass the post-delivery, post-evaluation and relationship-building aspects". These authors, and others such as Anderson et al. (2007), argue that a focus on *value* rather than *supply* is more appropriate. As a result, the term Value Chain Management (VCM) is frequently used in preference to SCM (Martinez and Bititci, 2006), even though the terms are sometimes used interchangeably in the literature. Recently, the term "supply chain network" has been proposed (Christopher, 2010) and it implies a focus on the demand, i.e., consumer, and the interaction of various agents supplying a product.

A The concept of value

In the context of VCM, *value* is usually defined in terms of the customer (the next firm downstream) or the consumer (the final purchaser of the finished goods). Mudimigh et al. (2004, p. 311) list three themes that run through definitions of value:

1. Customer value is linked to the use of a product or service;
2. Value is perceived by the customer not determined by the seller; and
3. Customer value typically involves a trade-off between what the customer wants and what must be given up in order to acquire and use a product or service.

Sources of value have been shown to lie in features of products and services such as price, convenience, appearance, nutrition, safety and reliability (see also Chapters 3−5, and 11). Thus the concept of value is framed by the perspective of the user or consumer looking back to the chain that produced and delivered the product or service. Having a focus on the consumer as the ultimate "target" of the activities of a chain is a distinguishing feature of VCM (Collins, 2006). Explanations of VCM such as that given by the Agriculture and Food Council of Alberta (2002, p. 3) highlight this orientation: "a value chain begins and ends with the MARKET. Interaction with the marketplace provides information to decision makers for every link in the chain".

B Sources and drivers of value

In the context of food in general and horticultural produce in particular, the sources and drivers of value have some special features. Because food is "consumed", attributes associated with safety, nutrition, well-being, freshness and the overall sensory experience of food each play a role in determining how individual consumers attach value to the product as part of their purchase decision making. If these attributes are loosely bundled together under the general banner of "quality" then, as Collins (2006) points out, it is the interaction of price and quality that results in what buyers regard as "value for money". The challenge for the chain is therefore to understand and deliver this value in ways that profitably meet consumers' needs.

The ability of an agri-food chain to deliver consumer value is driven by a combination of its ability to be as efficient as possible and its ability to innovate (Taylor, 2005). Lean manufacturing principles, originally devised by the Toyota Corporation to reduce waste and maximize value adding activities in car manufacturing, have been adapted to value chains in the food industry (Simons et al., 2002). A lean agri-food value chain achieves efficiency through operating with minimal waste and a clear focus on only doing those activities that are necessary and that add value in the eyes of the consumer. Being lean, however, does not necessarily mean being innovative. Innovation occurs when a chain discovers and captures new sources of value, either for the individual firms in the chain or for the consumer. New sources of value are a critical source of competitive advantage in fast-changing environments such as the food sector. Firms seek these sources of value through process innovation (new ways to manufacture products) or product innovation (new product development), and in a value chain they may do so in association with a chain partner (Bonney et al., 2007). The process of pairs or groups of firms innovating with a common purpose is referred to as co-innovation, and has been described as a powerful driver of value in chains (Collins et al., 2002; Bonney et al., 2007).

C Value orientation in fresh produce chains

It has already been argued that the value chain needs to be viewed as a system. Food value chains are systems driven by the interaction of their technical (production, processing, transport, etc.), economic (profitability), information-related (communication) and governance (human relationships) sub-systems. Evaluating their performance is thus a multidisciplinary task that may combine measures drawn from fields as diverse as engineering, biology, economics, strategy and psychology. A review of literature on the performance of food supply/value chains carried out by Collins (2006) revealed the following indicators of performance:

1. The balance of focus between price and value
2. The amount and type of information shared
3. The time orientation of chain participants
4. The nature of the business to business relationships
5. The basis of the interactions between chain members
6. Dependence in the chain
7. Use of power in the chain
8. Orientation of chain members to self or chain

Collins used each of these criteria to evaluate the performance of fresh produce value chains. Table 6.1 shows a value chain orientation matrix.

The balance of focus between price and value

On one end of the scale, the members of a fresh produce value chain may focus entirely on price. The goal of buyers in the chain is always to achieve the lowest possible price. On the other end of the scale, chain members may focus entirely on value creation through strategies such as product and process innovation, extensive market research and the adoption of lean manufacturing principles. Note that a value orientation does not mean that price is not important; rather, price is a consequence of value created.

The amount and type of information shared

In traditional, price-oriented chains, individual members can wield power by withholding critical information, such as price signals from buyers, or supply signals from suppliers. Such information is usually used as a bargaining tool to maximize returns to one chain member at the expense of another, but as noted earlier, this behavior does not result in the greatest value being delivered to the consumer. In contrast, in value-based chains it is regarded as important by chain members to

Table 6.1 Value Chain Orientation Matrix

Evaluative Criterion	**Characteristics of Chain Activities Least Value Orientation < > Greatest Value Orientation**			
Balance between price and value	Always price	Usually price	Usually value	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	Some information shared	Extensive information shared
Time orientation	Short term, transaction to transaction	Short term, periodic	Short to medium term	Medium to long term
The nature of relationships	Adversarial	Occasionally co-operative	Mostly co-operative	Collaborative
Interactions between chain members	Transaction based	Mostly transaction based	More relationship based	Strongly relationship based
Dependence in the chain	Independence	Occasionally relies on others	Usually relies on others	Interdependence
Power in the chain	The individual has the power	The individual has the power	Some recognition of the consumer	The consumer has the power
Orientation of chain members	Always self maximizing	Self first, chain second	Chain first, self second	Strongly towards chain optimization

share information freely so that the needs of chain participants can be fully understood and met, and so that signals from the marketplace can be transmitted undistorted back down the chain to where they are needed so as to evaluate how well the chain is creating value for its consumers.

The time orientation

A short-term orientation does not allow chain members to properly understand each other's needs, nor to build stronger relationships. Short-term thinking is associated with an orientation to price rather than value, leading to low levels of innovation.

The nature of business to business relationships

Relationships may be adversarial, as in the case of bargaining to get the lowest price, or collaborative, as in the case of trying to achieve a better understanding of chain members' needs. Value chains cannot deliver superior value to consumers in the absence of collaborative relationships among chain members.

The basis of the interactions between chain members

Interactions may be on a transaction-by-transaction basis, or on the basis of ongoing relationships. Transaction-based interactions are common where relationships are adversarial and the focus is on price.

Dependence in the chain

Members of a chain may operate totally independently of each other, typically in a price based environment, or more interdependently, for example when collaborating to establish and deliver value to consumers.

Use of power in the chain

Power in a chain may lie in the hands of one or a few individuals who use it to their advantage. Alternatively, the chain as a whole may acknowledge that the consumer exercises the ultimate power in the act of making the decision to purchase or not to purchase, and that the chain as a competitive unit can direct its power towards meeting the needs of the consumer.

Orientation of chain members

Chain members may orient themselves towards maximizing gains for themselves at the expense of other chain members, or optimizing returns for the whole chain, in which they share.

Using these eight performance related criteria it is possible to map a range of characteristics of a fresh produce chain's orientation, activities and behavior from the least value-conscious, to the most highly value oriented (Collins, 2006). Such a mapping exercise can profile the "value orientation" of a particular fresh produce chain, as shown by the bold text in the examples in Tables 6.2−6.4.

The typical profile of a traditional, price based, adversarial chain where product flows through centralized wholesale marketing channels is shown in Table 6.2. These types of chains are still common, especially in developing countries. Features of this profile are that chain members only co-operate when absolutely necessary, meaning that very occasionally they have to rely on each other, but otherwise the chain is driven by negotiations around price.

A second type of value profile is that of "category managed" chains. Category management firms make a bridge between suppliers and retailers, especially large supermarket operators. Upstream in the chain, the category manager organizes and manages supply of product to clear specifications that include parameters of quality, quantity, safety, delivery and price. Downstream they manage supply of product to retailers, may plan marketing strategies with them, or may undertake market research upon which to base these strategies. In fresh produce, category managers typically ameliorate problems faced by retailers as a result of the impacts of seasonality, environmental conditions and wholesale price fluctuations. They are also increasingly involved in innovation related to new product development. They achieve these outcomes through their relationships with both suppliers and retailers, and their ability to focus the chain on reliably delivering value for

Table 6.2 Traditional Fresh Produce Chains

Evaluative Criterion	Characteristics of Chain Activities Least Value Orientation < > Greatest Value Orientation			
Balance between price and value	**Almost always price**	Usually price	Usually value	Almost always value
Amount and type of information shared	**No significant information shared**	Little information shared	Some information shared	Extensive information shared
Time orientation	**Short term, transaction to transaction**	Short term, periodic	Short to medium term	Medium to long term
The nature of relationships	Adversarial	**Occasionally co-operative**	Mostly co-operative	Collaborative
Interactions between chain members	**Transaction based**	Mostly transaction based	More relationship based	Always relationship based
Dependence in the chain	Independence	**Occasionally relies on others**	Usually relies on others	Interdependence
Power in the chain	**The individual has the power**	The individual has the power	Some recognition of the consumer	The consumer has the power
Orientation of chain members	**Always self maximizing**	Self first, chain second	Chain first, self second	Always chain optimizing

money, as opposed to price alone. Table 6.3 shows a typical value orientation profile for a "category managed" fresh produce value chain.

There are very few examples of best practice value chain management in fresh produce, but the trends are pointing in that direction. A small number of value chains have gone beyond the profile of category managers shown in Table 6.3 and have embraced a strategy of total focus on the consumer, absolute transparency of information and full collaboration among chain members. Their typical profile is shown in Table 6.4.

It is also possible to compare the performance of the three types of fresh produce chains described above using criteria that are associated with competitiveness. These criteria, shown in Table 6.5, focus on attributes such as agility (speed and flexibility), the ability to innovate and not easily be copied by competitors, and the ability to guarantee product integrity.

It is interesting to note from Table 6.5 that the overall competitiveness of each of the three models can be high. At their best, each business model is capable of delivering high returns to the managers of the firms involved. But as the

Table 6.3 Contemporary, Category-Managed Fresh Produce Value Chain

Evaluative Criterion	Characteristics of Chain Activities Least Value Orientation < > Greatest Value Orientation			
Balance between price and value	Almost always price	**Usually price**	Usually value	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	**Some information shared**	Extensive information shared
Time orientation	Short term, transaction to transaction	**Short term, periodic**	Short to medium term	Medium to long term
The nature of relationships	Adversarial	Occasionally co-operative	**Mostly co-operative**	Collaborative
Interactions between chain members	Transaction based	Mostly transaction based	**More relationship based**	**Always relationship based**
Dependence in the chain	Independence	Occasionally relies on others	**Usually relies on others**	**Interdependence**
Power in the chain	The individual has the power	The individual has the power	**Some recognition of the consumer**	**The consumer has the power**
Orientation of chain members	Always self maximizing	**Self first, chain second**	**Chain first, self second**	Always chain optimizing

environment in which fresh produce chains are operating continues to change, firms using traditional adversarial business models will come under increasing pressure as they are forced to compete with more closely aligned value chains with the capacity to innovate and whose primary focus is on meeting consumers' needs. This pressure could become disabling for traditional operators in fresh produce retail environments that demand a combination of innovation, traceability (see Chapter 17), differentiation and responsiveness.

III Value chain management and postharvest systems

A The changing environment of VCM in the food industry

To understand how VCM and postharvest horticulture are interrelated, it is necessary first to examine the factors that have driven the adoption of more collaborative whole-of-chain business models. Three broad forces are at work here: the forces of globalization, technology and consumerism, and they are shaping the

Table 6.4 Best Current Examples of Fresh Produce Value Chains

Evaluative Criterion	**Characteristics of Chain Activities Least Value Orientation < > Greatest Value Orientation**			
Balance between price and value	Almost always price	Usually price	**Usually value**	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	Some information shared	**Extensive information shared**
Time orientation	Short term, transaction to transaction	Short term, periodic	**Short to medium term**	Medium to long term
The nature of relationships	Adversarial	Occasionally co-operative	Mostly co-operative	**Collaborative**
Interactions between chain members	Transaction based	Mostly transaction based	More relationship based	**Always relationship based**
Dependence in the chain	Independence	Occasionally relies on others	Usually relies on others	**Interdependence**
Power in the chain	The individual has the power	The individual has the power	Some recognition of the consumer	**The consumer has the power**
Orientation of chain members	Always self maximizing	Self first, chain second	**Chain first, self second**	Always chain optimizing

Table 6.5 Comparison of Competitiveness Performance of Different Types of Chains

	Traditional Chain	**Category Managed Chain**	**Best Current Practice Value Chain**
Speed of response	High	Medium	Medium
Flexibility	High	High	High
Innovation potential	Low	Medium	High
Ease of copying by competitors	Easy	Moderate	Difficult
Traceability of product	Low	High	High
Overall competitiveness	Can be high	Can be high	Can be high

macro environment, the competitive environment and the internal business environment of every horticultural firm.

Globalization

Over the last few decades, the barriers to trade in food between most countries in the world have gradually fallen away, spearheaded by the efforts of the World Trade Organization to achieve freer global trade. Under these initiatives, many governments have agreed to reduce tariffs that had been used mainly to protect their domestic food producers. At the same time, new technologies for storage and transport have allowed food products to access distant markets. The physical location of food production and processing facilities is longer a guarantee of market access, and many food companies, including some dealing in fresh produce, see the world as their marketplace, as they have both the access and the technology to reach distant markets.

Global competition means that firms are no longer competing against other local firms for a share of their own domestic market. Many are competing in distant markets against firms from other countries who are also not "locals" to that market, or they are competing in their own domestic markets against firms from overseas. While this global marketplace for food has quite understandably attracted the biggest processors (e.g., Nestlé) and retailers (e.g., Wal-Mart), small firms have not been shut out. There are many examples of small food companies that have identified profitable opportunities in distant markets. It has been shown that the ability of a firm to profit from the globalization of markets is not a function of its size, but of how well the firm understands that it is the "total competitiveness along the value chain which determines whether they can export successfully" (Instate Pty Ltd, 2000, p. 3).

The opening of global markets has also resulted in increasing concentration of supermarket and food service operators. A small number of large food retailers have expanded their operations across the globe and they have been especially active in countries where they can introduce more highly developed retail systems that streamline logistics and distribution, widen the choice of products to consumers and provide new shopping experiences (Regmi and Gehlhar, 2005).

In extending their reach to new and distant markets, one of the biggest challenges for global food retailers has been to take their supply chains with them so that they can guarantee a supply of products that reliably meet quality specifications at competitive prices. What was already a complex and at times difficult process in their own domestic markets becomes far more complex and difficult in markets that are far away and whose consumers are not as well understood. Retailers have realized that sourcing the right products and having a supply chain that is capable of delivering those products, often from one hemisphere to another, is a major challenge in the global marketplace for food.

Technological advances

It is not difficult to see how advances in science and technology have radically shaped the food business environment at every stage; from production through to processing, storage, transport and retail. Hewett (2006, p. 39) refers to genetic technology, nanotechnology and information technology as a "triad of technologies driving change in supply chains world wide". These technologies have spawned innovations in products (genetically modified products, bioactives) as well as processes (radio frequency identification, irradiation, active packaging). At the same time, the technology that allows firms to gather, store, manipulate and communicate information is developing exponentially.

In combination, technological advances of all kinds have opened up new possibilities for firms to deliver new food products, more efficiently, to more distant consumers, and to send and receive information in real time along the complete chain from production to consumption. Not surprisingly, a food industry firm's ability to capture and use newly emerging technologies is closely associated with is ability to compete (Hewett, 2006).

Consumerism – the power of consumers

Consumers have more power than ever before, and they are prepared to exercise that power. As many more suppliers achieve the capacity to target many more markets, some markets become "saturated", giving retailers and consumers the ability to exert considerable power in discerning among the many offers from would-be suppliers. The food industry is quoted as one example where markets are saturated with product offers and suppliers are having to become more and more sophisticated in developing new products to attract and retain customers, a process that has been described as "mass individualization" (Linnemann et al., 2006).

Broadly speaking, consumers of food products exert their influence in two different ways. One the one hand they influence the outputs of food production systems (the kind of food produced); on the other hand they influence the systems themselves.

Food and lifestyle are inextricably linked. Consumers want food that is nutritious, safe and healthy, but they also want it in a convenient form, they want variety and new experiences, and they want to be able to find food that fits all these needs without having to work too hard to find it. Milstein (2007) identified the megatrends that consumers are responding to as including products and services made "just for me", a growing interest in health and well-being and an increasing belief that quality is better than quantity. Milstein also notes that debate will continue to revolve around issues such as obesity, nutrition labeling, absolute traceability along the food chain and the role of "authenticity" in food production. Consumers are expressing a deepening understanding of the relationships between food and quality of life in their consumption habits and buying behavior.

How food is produced is an increasing concern for consumers world wide. Of particular interest is how food production systems affect the environment.

Here, too, consumers are expressing their concerns through their purchasing decisions. This has given rise to food certified as being produced in environmentally responsible ways, food that has been produced by systems with a low carbon footprint, or food that has traveled a low number of "food miles". Companies are responding to these consumer-driven concerns by adopting more sustainable business practices such as sourcing products locally, using less water or power in production, producing less waste or reducing unnecessary packaging. In the developed world, every food company, whether farmers, packers, processors, transport operators or wholesalers, could point to some part if its business that is a direct response to increasing consumer concern for the impact of food production systems on the environment.

In an increasingly crowded global marketplace for food products, the ability for firms to make profits by responding to what consumers need is related to their ability to differentiate themselves from one another. Differentiation is virtually impossible unless firms play an active role in the chains that create and deliver what consumers need. In a global marketplace, independent firms, even with the world's best new product development ideas and technologies, simply cannot guarantee consumers that their products are safe, healthy, environmentally responsible, available all year round and represent value for money unless they collaborate with the other firms that make up the chain from production to consumption of those products.

B VCM as a setting for postharvest horticulture

Understanding VCM as a model for being competitive in the rapidly changing agri-food business environment provides the background for exploring how VCM and postharvest horticulture are linked. This section argues that postharvest practices are value adding activities, thus VCM can enhance a firm's ability to profitably deliver postharvest processes, outcomes and outputs to those parts of the chain where they represent value. For example, downstream in the chain when postharvest practices create value for a retailer, incentive is generated to continue these practices. Upstream, when a primary producer sees value in the postharvest performance of a potential customer, there is incentive for the primary producer to become a preferred supplier to that customer.

Why horticultural firms become involved in VCM

Boehlje et al. (1998) note that firms collaborate to form value chains for three reasons: to be able to respond better to consumers, to improve efficiency and to reduce risks.

As mentioned above, consumers are becoming more discerning about the food they consume and they tend to direct their business towards those chains that can anticipate and service these needs. The value created through postharvest activities such as grading, processing, packaging, storage and transport is targeted at meeting specific consumer requirements. The more precisely, reliably and economically those requirements are met, the more value is created. When a chain of collaborating firms is able to create value in this way, it not only strengthens the relationships among the collaborating firms, but it also builds relationships between the chain and its consumers. This is VCM at work, and chains of firms operating in this way become extremely difficult for competitors to emulate because they have to compete against not only the technical value-creating abilities of the chain, but also against the strength of the relationships that have been formed through collaborating to meet consumers' needs.

The second motivator behind value chain formation relates to efficiency. Chains must deliver food products to particular specifications, including conformance with mandatory requirements such as food safety standards. Collaboration among firms in a value chain not only ensures that specifications have been met at every point in the chain, but it also allows efficiencies and cost savings to be identified within firms as well as between firms. Examples include the ability to hold less inventory through made-to-order systems, sharing of infrastructure such as storage and transport between firms, integrating IT systems between firms, and the adoption of technologies and systems that are unavailable or uneconomic for single firms. The ability to reduce costs through improved efficiency represents value created through collaboration. This value may be retained by the firm(s) responsible, or passed along the chain so that it becomes value for other chain members, and ultimately the consumer.

Finally, firms form value chains to reduce risks. Individual firms can lower their exposure to influences such as the unavailability or rising prices of inputs, the impact of seasonal variation on product quality and availability, or the need to ensure that a whole chain can guarantee food safety through the adoption of a certified food safety management system. On their own, most firms would be far more exposed to these risks and could make few guarantees beyond their own boundaries.

All three examples demonstrate how postharvest systems and practices can create value for collaborating firms along a chain. Put another way, those same postharvest systems and practices in the hands of independent horticultural firms aiming to maximize their individual profitability are far less able to:

1. Monitor, respond to and influence consumer needs;
2. Ensure that product is delivered to the retailer as cost efficiently as possible; and
3. Guarantee the safety of the product delivered to consumers.

How horticultural firms become involved in VCM

The most common pathway to VCM begins when two firms decide to collaborate, then based on positive results they extend their reach to other chain members. A value chain is formed when firms involved in a collaborative relationship share a common objective of targeting a specific market or market segment. The more successful they are, the more difficult it becomes for competitors to copy their value chain, as shown in the example below.

AN EXAMPLE (BASED ON AN ACTUAL CASE)

A large vegetable grower successfully negotiates with a processor to supply higher quality inputs at a slightly higher price. Customers of the processor respond to the higher quality output and business expands until more inputs are required than can be supplied by the original grower. With the support of the processor, the original grower invites a small group of new growers to become high-quality suppliers to the processor. These new growers are in different regions and they can extend supply over a much longer season. Growing across more regions also spreads environmental risks. These growers are trained to meet the same higher standards and they prove to be reliable and committed. Business continues to expand. Now the supplier group looks to genetics as a source of even higher quality, and they form an alliance with a supplier of superior genetics. The genetics supplier sees enough business, and has enough trust, to give exclusive rights to the grower alliance for certain of its seed products. The seed supplier's company name also appears on the packaged product that consumers buy. Business continues to expand; retailers are happy with the results and ask for a wider range of products. This represents an opportunity for both the growers and the processor to diversify and spread their risks. Collaboratively, a small number of new products are identified for which high-quality genetics are available, and that require only minimal investment in new processing and growing capacity. These products are also successful and a small portfolio of products under a common brand becomes established. The genetics—grower—processor value chain adopts a strategy of reinvesting a share of each partner's returns into consumer research. The objective is to stay in touch with how consumers are responding to their products so the value chain can assist retailers to promote and merchandize their brand. Over time, and based on consumer feedback, the group is able to incorporate world class environmental standards into its production and processing systems. At this point, with exclusive genetics, dedicated and capable growers across a number of regions, an innovative processor and satisfied retailers and consumers, the value chain has put itself in a position where competitors were struggling to keep up.

It is important to note from the example above that it is not necessary for every firm in a value chain to collaborate. Retailers and wholesalers, for example, may not be directly involved but may be willing to co-operate as customers of the main value chain partners. In fact, in practice it is rare to find a value chain that is able to achieve high levels of collaboration and value creation involving *every* member of the chain (Collins et al., 2002; Bollen, 2004). What is always needed, however, is a chain champion who initiates value chain formation and takes oversight of the early stages of formation. These principles, and those illustrated in the example above, have been discussed by van Roekel et al. (2002).

In horticulture, as individual producers are small scale in relation to their ability to service a market segment, it is common for producers to form alliances among themselves, sometimes referred to as horizontal alliances (Agriculture and Food Council, 2002). Through their involvement with downstream chain members, these alliances may initiate the formation of value chains in horticultural industries. Collins (2004) describes the kind of activities that firms become capable of through alliance and value chain formation. They include:

- co-investing in research to better understand consumers' needs;
- actively influencing consumer behavior;
- exploring for new products, technologies or markets; and
- providing proof of authenticity such as country of origin or environmental credentials.

These kinds of activities confer competitive advantage on a whole value chain because each of them is difficult to achieve by individual producers or other chain members acting alone.

C Postharvest horticulture as a value creation domain

Defining the domain

Postharvest horticulture can be defined at various scales and in various ways. At its widest scale it begins when the product is separated from the plant or growing medium and ends with consumption by the final consumer. More narrowly, it might be defined as extending from harvest until the product is in the form in which it will be retailed. By any definition, postharvest horticulture involves transformation of a product from its state at harvest to its ready-to-consume state. This may be a simple transformation, e.g., for a fresh whole lettuce that will be retailed within a few days, or a complex transformation, e.g., for a potato processed into frozen French fries sold many months later in another country. The chain along which the product flows may be very short and involve no or few other firms, e.g., product sold at the farm gate; or it may be long and involve many other firms, e.g., potatoes in the frozen French fries example given above. Regardless of their scale or complexity, postharvest activities have two features in common: they add value and they involve members of the chain.

The ways in which postharvest activities can involve other chain members have been addressed earlier in this chapter. At sophisticated levels of involvement, these activities are elements of a business model known as VCM. At minimal levels of involvement, they may simply represent the various stages at which product changes hands from one firm to another along a traditional supply chain, for example from a grower to a packer, a packer to a wholesaler or a wholesaler to a retailer. This chapter concentrates on the higher levels of involvement that are associated with VCM because they have been shown to improve the competitiveness of businesses at all stages of the horticultural supply chain.

Adding value through postharvest science and technology

Postharvest horticulture has been defined as having the potential to add value through four interconnected areas of activity. They are food safety, traceability, information systems and consumer response to quality (Bollen, 2004). Each is discussed below.

Food safety

The need for food safety is beyond question. Research has shown that general consumer confidence in the motives of food producers and retailers has decreased (Knox, 2013; Frewer, 2003), fueled by publicity surrounding outbreaks such as BSE, *E. coli*, bird flu and foot and mouth disease. Horticulture has not been immune from this public concern about its systems and their outputs. Recent publicity has highlighted *E. coli* contamination of leafy vegetables in the US in 2011 and 2012 and Europe in 2011, and serious cases of agricultural chemical contamination of vegetables in China in 2012 and 2013.

Hurst (2004) reports that the incidence of human foodborne illnesses related to horticultural produce is low but increasing. He suggests that this may be because of better microbial detection methods, higher per capita consumption of fruit and vegetables, global sourcing and the evolution of more virulent strains of pathogens (see also Chapter 11). Hurst goes on to argue that every horticultural supply chain needs a Food Safety Plan, and in many countries this is a mandatory requirement.

Postharvest practices that ensure food safety add value through the consumer confidence they instill. When consumers believe that a horticultural product is "risky" they engage in the following behaviors, all of which directly impact on the profitability of the chains that delivered the product to the consumer (Frewer, 2003):

- they move to another product category, e.g., from fresh cut product to fresh whole product;
- they change to another brand or origin of the product, e.g., away from product produced in a particular country;
- they move to another retailer or type of retailer, e.g., away from supermarkets, or away from local markets;
- they move towards product produced in a particular way, e.g., towards low chemical usage produce; or
- they reduce consumption altogether, e.g., they stop consuming products in that broad category.

In summary, one objective of postharvest horticulture is to create value based on its ability to ensure food safety. Ultimately this is achieved through building trust with consumers that a particular product, brand, retailer and production method is safe, time after time. From a technical point of view, food safety means avoiding microbiological contamination that exceeds defined limits. From a management point of view it means implementing and enforcing food safety standards and management systems that deliver value 100% of the time. While individual firms can, and must, carry responsibility for their part of the chain, integrated value chains can give much higher level food safety assurances to consumers because the whole chain is managed as a system whose responsibility is to deliver food safety. Despite occasional scares, consumers take food safety for granted in developed countries, but the situation is very different in developing countries where research has shown willingness to pay, even among the poorest consumers, for better food safety (Macharia and Collins, 2011).

Traceability

Bollen (2004) lists four functions of traceability in a supply chain. They are:

- so that product can be traced back as part of a food safety system;
- to allow tracking of product from farm to market to give evidence of Good Agricultural Practice or Good Manufacturing Practice;
- to be able to track and trace shipments by air or sea, especially given current international security concerns; and
- to improve segregation of product so that specific market segments may be targeted.

Each of these functions involves postharvest activities and technologies, and each adds value for one or more members of a value chain. As all of them rely on documentation produced as part of a codified management system, it is therefore impossible to achieve traceability without at least some co-operation from every chain member. At one end of the spectrum is the minimum acceptable functional level of traceability, or base-level traceability. At the other end of the spectrum, when chain members make a collective decision to invest in traceability systems as part of a VCM business strategy, very high levels of performance become possible. This may be because of improved inventory management, higher levels of security, guaranteed best practice or more highly differentiated offers to consumers. In each of these cases, postharvest systems and technologies have a critical role to play in adding value.

Information systems

The globalization of horticultural markets has brought with it a manifold increase in logistical complexity. Because of the perishability of horticultural products, supply chains have time-critical dimensions, thus any improvements in the ability to store and transport horticultural products have significant commercial value. At the same time, the storage and transport of products is meaningless without information exchange, and the timing and quality of information exchanged often determines the value that can be created by the storage and transport functions themselves.

Information systems may not always be thought of as part of the postharvest system, yet without them the flow of product within and between firms is impossible. Information is needed to capture the quantity and quality characteristics of the product, its location in the value chain at any time, the state of the processes that transform the product and the value of the product at each stage of the chain. Postharvest activities not only directly add value to the product along the chain, they also create information that is needed to inform decisions about the product as it flows along the chain. The integration of postharvest technologies with information management systems has received relatively little research attention. However, in the VCM business model, the value added by improved postharvest technologies is only translated into profits when information about that value is communicated to those to whom it is commercially significant. Bollen (2004, p. 48) has suggested that information systems are "the major opportunity for the logistics supply chain to progress to become a value chain".

Consumers and quality

The role of postharvest research and development in assuring that consumers get the quality they demand has been the central orientation of the discipline. A review by the author of 180 published papers in the field of postharvest science since 2003 revealed 155 that made direct reference to consumer satisfaction or meeting the needs of markets as the rationale for the research. The significance of this orientation is captured by Shewfelt (2006, p. 31) in stating "the success or failure of any food is determined by the consumer".

In defining quality using simple and practical terms, Prussia (2004) defined low quality as not meeting consumer expectations; acceptable quality as satisfying consumer expectations; and high quality as exceeding consumer expectations. This definition is consistent with Shewfelt's (2006) view of the primacy of the consumer in determining what constitutes quality. Prussia (2004) also separated purchase quality from consumption quality. Purchase quality related to those attributes that could be assessed at the time of purchase, such as size, color, blemish, firmness and aroma. Consumption quality related to attributes that could only be assessed destructively, such as flavor, texture, flesh color, juiciness and mouth-feel.

Understanding what constitutes quality of a product as defined by the consumer and being able to deliver that quality is the main business of a horticultural value chain. The ability to deliver purchase quality attracts consumers to make purchases, but being able to deliver consumption quality drives repeat purchases and builds consumer loyalty – and these form the basis of sustained profitability for a value chain.

While some quality attributes are determined pre-harvest, many are determined after harvest. Ripening and storage conditions after harvest, for example, have direct effects on quality attributes such as flavor, texture, color, blemish and perceptions of freshness. For processed horticultural products, every aspect of the postharvest system creates value in the finished product, for example, by grading, slicing, mixing ingredients, sanitation treatments, packaging and labeling. Collectively, these activities create value through flavor, color and texture profiles, portion or pack size and attractiveness for the consumer.

The goal of VCM is to deliver value to consumers at an acceptable price, i.e., to deliver value for money. Quality as perceived by the consumer is central in determining what represents value for money. The orientation of postharvest R&D towards quality for the consumer is in fact an orientation towards value creation, which is the basis of VCM.

The future

The future for VCM and its interaction with postharvest horticultural systems will be shaped by the three forces of change discussed earlier: globalization, technology and consumerism.

Globalization will continue to give access to new markets, and will bring more competition to domestic markets. Both large and small players will stand to benefit, but whatever the scale, the ability to capture new markets will be determined by the quality of the whole value chain, not the quality of any individual firm. At the same time, food security will be a counterbalancing force. Nations will not want to become wholly reliant on imported foods, and local production to ensure food security will be a strategic issue for some nations. Horticultural industries will figure prominently in these strategies due to their ability to produce large volumes of fresh, nutritious food quickly and flexibly for local communities.

Advances in postharvest technologies will be used to create new food products, new processes and new ways of managing information. Only those that represent value, either to members of value chains or to consumers, will survive. New technologies associated with the intersection of food, health and well-being will be especially valued, along with those that help to ensure the security of supply chains.

Consumers in the future will be even more discerning than they are now. The ability to anticipate, understand and influence consumers will confer competitive advantage on value chains, the members of which will invest more and more in consumer research. Shewfelt and Henderson (2003) list six consumer trends related to horticultural produce that are relevant to this chapter. They are:

1. More emphasis on quality: fruits and vegetables will become more of a high-value speciality item; safety may be associated with total absence of pesticides.
2. More emphasis on local production: more incentive to produce horticultural food locally to avoid dependence on imported produce.
3. Less emphasis on shelf life and more emphasis on consumption quality: long shelf life will be considered a negative attribute; a true appreciation of flavor will supersede the importance of purchase quality attributes such as size and color.
4. Less concern about price and more emphasis on value: consumers will pay higher prices for fruit and vegetables as a speciality item; consumers will be less forgiving of unreliability of quality and will demand more information
5. More emphasis on technological solutions: campaigns against technologies such as irradiation and genetic modification will be less effective; technologies that can deliver consumption quality, especially those that maximize flavor, will be accepted (see also Chapter 19).
6. More emphasis on sustainable production: governments will require accounting for environmental impacts; inputs such as power and water will become more expensive; higher costs will be passed on to the consumer.

Broadly speaking, the forces of globalization, changing technology and consumerism will exert their influence on postharvest horticulture in two ways. They will define what constitutes consumer value; and they will therefore influence R&D priorities in the domain of postharvest R&D. Perhaps most importantly, more firms will adopt VCM strategies that are based on delivering value to consumers based on these R&D outputs.

Bibliography

Agriculture and Food Council, 2002. Value Chain Handbook. Alberta Agriculture, Food and Rural Development, Alberta, Canada.

Anderson, D., Britt, F., Favre, D., 2007. The 7 principles of supply chain management. Supply Chain Manag. Rev. 11, 41–46.

Beers, G., Beulens, A., van Dalen, J., 1997. Chain science as an emerging discipline. Proceedings of the Third International Conference on Chain Management in Agribusiness and the Food Industry. Wageningen Agricultural University, The Netherlands, pp. 295–308.

Boehlje, M., Schrader, L., Akridge, J., 1998. Observations on the formation of chains. In: Ziggers, G., Trienekens, G., Zuurbier, J. (Eds.), Proceedings of the Third International Conference on Chain Management in Agribusiness and the Food Industry. Wageningen Agricultural University, The Netherlands, pp. 393–403.

Bollen, F., 2004. Logistics in supply chains for fresh produce. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 47–56.

Bonney, L., Clark, R., Collins, R., Fearne, A., 2007. From serendipity to sustainable competitive advantage: insights from Houston's farm and their journey of co-innovation. Supply Chain Manag. 12, 395–399.

Bowersox, D., 1990. The strategic benefits of logistics alliances. Harv. Bus. Rev. 68, 36–43.

Christopher, M., 2010. Logistics and Supply Chain Management, fourth ed. Prentice Hall.

Collins, R., 2006. The functions and consequences of alternative fresh produce supply chain models. Acta Hortic. 712, 67–73.

Collins, R., 2004. Whole-of-chain quality management: an emerging perspective for postharvest science. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 15–23.

Collins, R., Dunne, A., O'Keeffe, M., 2002. The locus of value: a hallmark of chains that learn. Supply Chain Manag. 7, 318–321.

Cooper, M., Ellram, L., 1990. Supply chain management, partnerships, and the shipper-third party relationship. Int. J. Logist. Manag. 1, 1–10.

Fearne, A., Hughes, D., 1999. Success factors in the fresh produce supply chain: insights from the UK. Supply Chain Manag. 4, 120–128.

Frewer, L., 2003. Quality in chains: consumers and risk. Acta Hortic. 604, 233–237.

Gifford, D., Hall, E., Collins, R. (Eds.), 1997. Competitive Performance. Australian Government Publishing Service, Canberra.

Gunasekaran, A., Patel, C., Tirtiroglou, E., 2001. Performance measures and metrics in a supply chain environment. Int. J. Oper. Prod. Manag. 21, 71–87.

Halldorsson, A., Kotzab, H., Mikkola, J., Skjott-Larsen, T., 2007. Complementary theories to supply chain management. Supply Chain Manag. 12, 284–296.

Hewett, E., 2006. Progressive challenges in horticultural supply chains: some future challenges. Acta Hortic. 712, 39–49.

Hugos, M., 2003. Essentials of Supply Chain Management. John Wiley & Sons Ltd, New Jersey, US.
Hurst, W., 2004. GAPs/GMPs/HACCP: food safety systems for handling fresh produce. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 129−136.
Instate Pty Ltd, 2000. Exporting Australian Processed Foods: Are We Competitive? Agriculture, Fisheries and Forestry Australia, Canberra.
Jackson, M., 2003. Systems Thinking. Creative Holism for Managers. John Wiley & Sons Ltd., West Sussex, England.
Knox, B., 2013. Consumer perception and understanding of risk from food. Br. Med. Bull. 56, 97−109.
Kouvelis, P., Chambers, C., Wang, H., 2006. Supply chain management research and production and operations management: review, trends, and opportunities. Prod. Oper. Manag. 15, 449−469.
Lambert, D., Cooper, M., 2000. Issues in supply chain management. Ind. Market. Manag. 29, 65−83.
Linnemann, A., Benner, M., Verkerk, R., van Boekel, M., 2006. Consumer driven food product development. Trends Food Sci. Technol. 17, 184−190.
Macharia, J., Collins, R., 2011. Consumer value preferences: a pre-requisite for sustainable performance improvement in agri-food supply chains. Proceedings of the Fifth International Consumer Science Research Conference. University of Bonn, Germany.
Martinez, V., Bititci, U., 2006. Aligning value propositions in supply chains. Int. J. Value Chain Manag. 1, 6−18.
Mentzer, J., DeWitt, W., Keebler, J., Min, S., Nix, N., Smith, C., et al., 2001. Defining supply chain management. J. Bus. Logist. 22, 1−25.
Milstein, D., 2007. What's Hot in Food? Sixth ed. David Milstein and Associates, Brisbane, Update.
Morgan, R., Hunt, S., 1994. The Commitment−Trust theory of relationship marketing. J. Market. 58, 41−55.
Mudimigh, A., Zairi, M., Ahmed, A., 2004. Extending the concept of supply chain: the effective management of value chains. Int. J. Prod. Econ. 87, 309−320.
O'Keeffe, M., 1998. Establishing supply chain partnerships. Supply Chain Manag. 3, 5−9.
Porter, M., 1980. Competitive Strategy. The Free Press, New York.
Prussia, S., 2004. Systems thinking for improving modern quality management systems. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 39−46.
Regmi, A., Gehlhar, M. (Eds.), 2005. Information Bulletin No. 794. USDA.
Shewfelt, R., Henderson, J., 2003. The future of quality. Acta Hortic. 604, 49−59.
Shewfelt, R., 2006. Defining and meeting consumer requirements. Acta Hortic. 712, 31−38.
Simons, D., Francis, M., Jones, D., 2002. Food value chain analysis. In: Doukidis, G., Vrechopolous, A. (Eds.), Consumer Driven Electronic Transformation. Springer, Berlin, pp. 179−192.
Spekman, R., Spear, J., Kamauff, J., 2002. Supply chain competency: learning as a key component. Supply Chain Manag. 7, 41−55.
Taylor, D., 2005. Supply chain analysis: an approach to value chain improvement in agri-food chains. Int. J. Phys. Distrib. Logist. Manag. 35, 744−761.

van Roekel, J., Kopicki, C., Broekmans, C., Boselie, D., 2002. Building Agri Supply Chains: Issues and Guidelines. World Bank, Washington, D.C.

Wernerfelt, B., 1984. The resource-based view of the firm. Strat. Manag. J. 14, 415–423.

Williamson, O., 1971. The integration of production: market failure considerations. Am. Econ. Rev. 23, 335–345.

This page intentionally left blank

CHAPTER

7 Consumer Expenditures on Fresh Fruit and Vegetables

Wojciech J. Florkowski[a], Anna M. Klepacka[b], Padmanand Madhavan Nambiar[a], Ting Meng[a], Shengfei Fu[a], Ghanna Sheremenko[a] and Daniel B. Sarpong[c]

[a]*Department of Agricultural and Applied Economics, The University of Georgia*

[b]*Faculty of Production Engineering, Warsaw University of Life Sciences-SGGW, Warsaw, Poland*

[c]*University of Ghana-Legon, Ghana*

I Introduction

The sustained demand for fresh fruit and vegetables is reflected in consumer expenditures on this food category. Expenditures are a function of income and prices and vary across countries, reflecting their level of economic development and disposable incomes. The general relationship between income and expenditure on various foods has been captured by the Engle curve (for some new applications, see Chai and Moneta, 2010). Empirical verification of the general relationships depicted in the Engle curve indicates a fairly steady growth in expenditure on fruits and vegetables as incomes increase. The objectives of this chapter are to: discern differences between expenditures on fruits and vegetables as separate categories, illustrate preferences for specific fruits and vegetables and evidence the differences in choices of various fruits and vegetables across countries with different income levels and climatic zones. The information will demonstrate similarities and opportunities for international trade and the challenges to postharvest handling. Insights from this exercise provide an additional justification for using the systems approach to effectively meet consumer expectations across various income strata on a global scale in the delivery of fresh produce.

Expenditures on fruits and vegetables, along with fresh produce preferences are illustrated using data collected by the Central Statistical Office (CSO; in the case of Poland) or data collected via household surveys from urban consumers (in the cases of the Republic of Korea, Ghana and Uganda). The countries studied represent a diversity of consumers in the contemporary world in terms of disposable income, preferences, consumption and natural resource endowment conditioning the supply of domestic fresh produce and indirectly determining the potential for trade. Incomes in these countries have been growing in recent times and fruit trade has been increasing. In comparison to some post-industrial economies, the consumption of fruits and vegetables in these countries shows a tendency to increase. For example, fruit consumption in the United States has been

Postharvest Handling.

fairly steady and changes affect the type but not the total volume of consumed fruits and vegetables, while in countries with growing incomes the drivers of consumer purchases are preferences for fruit variety, convenience and novelty (see Chapter 2). All three features create opportunities for increased trade in fresh produce, but require that produce retain its quality and are safe, traceable, accessible and affordable.

II Recommended daily fruit and vegetable consumption

The World Health Organization recommends a daily intake of about 400–500 g of fresh fruits and vegetables (WHO, 2003; p. 89). Few countries actually meet that level. Various consumer education and food programs have been developed by national governments to encourage greater fruit and vegetable consumption (EUFIC Review, 2012). In the United States, a food pyramid was presented in 1992 to promote the desired eating patterns and make fruits and vegetables a sizable part of the healthy diet (Neuman, 2011). It was modified in 2005 and has been recently replaced by a logo in the shape of a dinner plate. Other countries adapted graphic guidelines to promote proper nutrition, emphasizing the importance of fruits and vegetables familiar to their societies (Figure 7.1). Such efforts to emphasize the importance of fresh fruit and vegetable consumption coincided with the systems approach for delivering quality fresh produce to satisfy consumer expectations. Yet, the differences in fresh produce consumption across countries reflect a multitude of factors including demographic and socio-economic status, personal factors (e.g., perceived time constraints) and social environments (e.g., meal patterns, attitudes towards fruit and vegetables) (EUFIC Review, 2012). The lack of a standardized data collection methodology for fruit and vegetable intake across countries is a major obstacle for cross-country comparisons (EUFIC Review, 2012) and should be kept in mind when reading this chapter.

The average consumer in the Republic of Korea consumes about 197.5 g of fruits and 283.5 g of vegetables, giving a total of 481 g daily. This level is one of the highest amounts of consumption in the world. But among Asian countries the average consumption varies widely and a number of countries do not meet the WHO standard. In Europe, the average Polish consumer eats 577 g of both fresh and prepared fruits and vegetables per day (EUFIC Review, 2012). This amount is higher than the average in many other European countries, where the most fruits and vegetables are eaten in countries of the European Union (EU). Among countries outside the EU, for example in Ukraine, the average consumption of fruits and vegetables in 2005 and 2006 decreased by 3.2% and increased by 3.3%, respectively (based on State Statistical Service of Ukraine, 2007) and does not meet the WHO recommendation. In Sub-Saharan Africa, the average consumption of fruits and vegetables is also relatively low as compared to the WHO recommended daily volume.

FIGURE 7.1

An example of the "food pyramid" concept adjusted to improve communicating the message about fruit and vegetable consumption to Chinese consumers (poster placed at Shanghai Academy of Agricultural Sciences, China).

Photo: Zweling Kong.

In the two countries representing East and West Africa in this chapter, the consumption is quite different and illustrates the differences not so much in terms of location, but ability to purchase fruits and vegetables and their relative importance in daily diets. Ghana, a West African country, reports the daily fruit and vegetable consumption level close to the WHO recommendations at 400–500 g per day. Using per capita consumption of fruits and vegetables converted from the FAO statistics (FAO, 2013) to daily per capita consumption in grams, an average person in Ghana consumed 456 g of fruit and 88 g of vegetables per day in 2009 (excluding roots and tubers such as sweet potato; calculations made for this chapter are by the authors). However, one has to recognize that spoilage and waste (including peel) lower the volume, as most vegetables are cooked rather than eaten raw because preparation lowers microbial contamination (Wright et al., 2009) and increases the availability of nutrients (Wrangham and Conklin-Britain, 2003). In Uganda, the daily per capita consumption of fruits and vegetables is estimated at 425 g and 77 g, respectively, using the same calculation method as in the case of Ghana.

However, the figures seem to be much higher than the observed consumption, and figures from the household survey support the view that the calculated figures are far too high and, because of the calculation method, ignore the waste from preparation and spoilage. More importantly, casual observations suggest that daily consumption is highly variable across regions and between seasons. Regional differences reflect the variation in household incomes in Uganda. As is the case in many lesser-developed countries, the highest per capita income is enjoyed by residents of the capital city, making that urban market particularly attractive for fruit and vegetable sellers. In all countries considered in this chapter, there is a wide variability in the variety of consumed fresh fruit and vegetables, and to a varying extent it includes fruit and vegetables that are obtained outside the formal distribution channels. However, all countries considered in this chapter are experiencing an increasing presence of formal retail outlets, including supermarket chains.

A Income growth

In the case of all four countries, the growth of per capita income has been a prerequisite for the growth of fruit and vegetable consumption. In the Republic of Korea (South Korea), incomes grew substantially between 1990 and 2011 and the per capita income (measured as Gross National Income, GNI, in current $) increased by 360.3% during that period (KOSIS, 2013). The economy in Poland, after its transition to a market economy, has been steadily growing (Florkowski, 2013). Similarly, the Ghanaian and Ugandan economies have been expanding. From 2003 to 2012, the average GNI per capita (in current $) increased 20% annually in Ghana (calculation based on World Bank, 2013), while Uganda maintained an average real Gross Domestic Product, GDP, growth of 7.48% from 2003 to 2011 (World Bank, 2012).

Increasing incomes have been reflected in fruit and vegetable expenditures and consumption. For example, in Poland the average per person monthly expenditure on fruit increased by 26.8% between 2006 and 2011, while the corresponding expenditure on fresh vegetables grew by 14.7% during the same period. Vegetables are a main or side dish of many meals and are ingrained in culinary traditions. Fruit is often consumed as a snack or dessert. Given the place of fruits and vegetables in the diets of many countries, the consumption of vegetables tends to be more stable than that of fruit. The essential role of vegetables in the diet means the expenditure on fresh vegetables tends to be more important for countries or households with lower incomes than expenditure on fresh fruit. Fruit expenditure is more responsive to increasing incomes (assuming prices remain constant) because it is viewed as less essential to the diet and weakening household budget constraint allows more free choice by consumers. A recent study of consumer demand for fruit in Scotland supports the influence of prices on both short- and long-term demand for fruit (Revoredo-Giha and Florkowski, 2013).

B Average expenditure on fruits and vegetables

Average expenditure on fruits and vegetables are illustrated with figures from four countries. In the case of Poland, the figures refer to the average monthly per capita expenditure on all fruit and vegetables and are based on time-series data for the period 2007−2011 obtained from Główny Urząd Statystyczny (GUS) (CSO). Fresh fruit and vegetable expenditure in case of the Republic of Korea and Uganda refers to weekly household expenditure in the week preceding the interview with a respondent. The figures are cross-sectional data obtained from a survey of urban residents in selected large cities in each of the three countries, seven in the Republic of Korea, three in Ghana and five in Uganda. The figures illustrate the relative importance of fruit and vegetable expenditure in different countries and contrast with the figures by income quantiles or groups discussed in the next section.

In the Republic of Korea, based on responses from 1100 urban women, the average expenditure in a week preceding the survey amounted to $109.8 on fresh vegetables and $157.4 on fresh fruit. The data from the survey of Polish households suggested the average monthly per capita expenditure on vegetables amounted to 26.67 zlotys ($8.33 at the exchange rate $1 = 3.20 zlotys) and fruit expenditure was 13.60 zlotys ($4.25) (at current prices) for the period from 2007 to 2011 (Central Statistical Office, CSO; Polish acronym: GUS, various issues). Among the 1076 consumers in three urban centers surveyed in Ghana in the first half of 2011, the average weekly household fresh vegetable expenditure amounted to 12.90 cedis ($8.31), while the household fresh fruit expenditure was 5.71 cedis ($3.68). Another survey among 1646 consumers from five cities (Kampala, Gulu, Lira, Soroti and Mbale) in Uganda implemented in 2011 shows the average per person weekly expenditure of fresh vegetables and fruits as UGX 952.82 ($0.42) and UGX 694.49 ($0.31), respectively.

III Expenditure by income quantile in selected countries

Preferences for fresh fruit and vegetables vary, but from the produce marketer's standpoint, the ability to purchase is the key indicator in stimulating the delivery of preferred quality. The analysis of consumer purchases based on income quantiles leads to insights that distinguish various segments of the population. In general, the quantile analysis shows markedly different consumption or expenditure pattern as income increases. Often, consumers in the highest income quantile, whose expenditure is constrained little by income, display a distinctly different choice of fruits and vegetables. In other words, the highest income group presents market segmentation opportunities for special quality fresh produce that differ from consumers classified in other income quantiles in a given country. This pattern will be illustrated in this section using data from four countries from three different continents and from different climatic zones, income levels and dietary

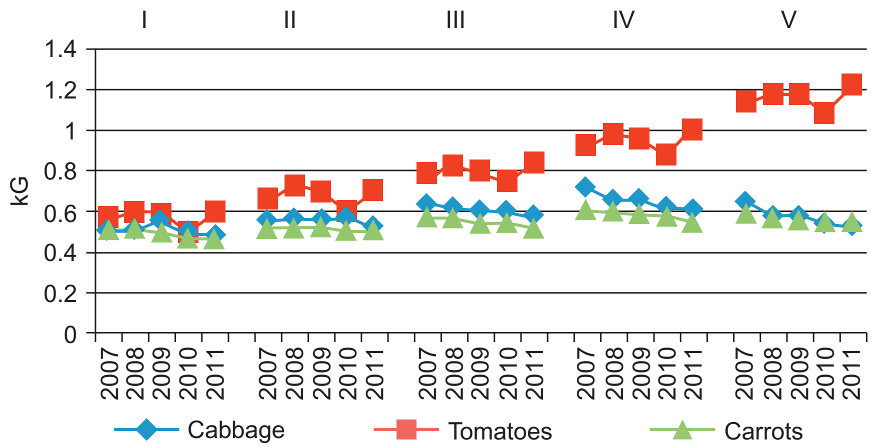

FIGURE 7.2

Per capita consumption of selected vegetables by five income quintiles in Poland, 2007–2011. Note: GUS defined per person income levels for each quintile in 2010 as: I – 644.88 zł ($195.4) or less, II – from 645.00 zł to 898.57 zł ($195.4–$272.3), III – from 899.00 zł to 1182.61 zł ($272.4–$358.4), IV – from 1182.65 zł to 1600.64 zł ($358.5–$485.1), V – 1601.67 zł ($485.2) or more; the applied exchange rate: $1 = 3,3 zł.

Source: GUS, Budżety Gospodarstw Domowych w: 2007, 2008, 2009, 2010, 2011, Warsaw, Poland. 2008; 2009; 2010; 2011; 2012.

patterns, namely Ghana, Poland, the Republic of Korea and Uganda. The similarities and differences have implications for the supply of specific quality produce to specific consumer groups and highlight the benefits for a systems approach to the postharvest handling of fresh fruit and vegetables.

The CSO in Poland provides details on per capita consumption only for a limited number of fruits and vegetables. However, the data are reported in various configurations. For the purpose of illustration, three fruit and three vegetable categories have been selected. The vegetables are tomatoes, cabbage and carrots because they are commonly consumed not only in Poland, but also in other European and non-European countries. The selected fruits include apples (the most commonly eaten fresh fruit internationally, although some argue that mango is eaten by a larger number of people across the globe), berries (which include several varieties including strawberries, blueberries, and red and black currants), and a broad category of exotic fruits. The name of the latter category was assigned by the CSO and includes citrus, bananas (two main types of imported fruit), as well as other sub-tropical or tropical fruit (e.g., pineapple, pomegranate, persimmon and kiwi). Therefore, the term "exotic fruit" refers to the interpretation of the data-collecting agency and this interpretation should be kept in mind while reading this chapter.

Figure 7.2 shows per capita consumption of three vegetables by five income quintiles in Poland between 2007 and 2011. Consequently, each plotted line shows the amount and changes in the amount consumed over the period of five years. Each vegetable is eaten both fresh and cooked although, traditionally, carrots tend to be eaten cooked in larger quantities than fresh, while cabbage is eaten both cooked or pickled (sauerkraut) in larger volumes than fresh. Tomatoes are eaten fresh and processed, because fresh, high quality tomatoes have become readily accessible year-round through the expanding supermarket chains in larger quantities than in the past. All quintiles show very similar tendencies in consumption. In terms of quantity consumed, tomatoes are eaten in larger volumes than cabbage, which is consumed in larger amounts than carrots (except for the lowest and the highest quintile in some years). Moreover, the volume of tomatoes increases rapidly across the four lower quintiles, but the increase in volume consumed in each quantile does not show a steadily increasing tendency. The volume of the other two vegetables increases from quantile to quantile, but at a much lower rate than tomatoes and in the highest quantile it is not much different from that of the middle quantile (Figure 7.2). It appears also that the per capita consumption of cabbage and carrots has been declining in all quintiles. Such a decline is not necessarily desired from the standpoint of nutrition and disease prevention (see also Chapters 3 and 5), but consumers have an increasingly wide selection of fresh vegetables – a manifested success of proper postharvest handling procedures.

The strong preference for tomatoes among households as their income increases is likely the effect of a combination of factors, which vary in importance to different quantiles. The factors include progress in postharvest handling of good-tasting tomatoes (variety selection and postharvest efforts), tomato suitability to the forms of consumption (sandwiches, salads), convenience (ready-to-eat food with little waste), storability under home conditions and little, if any, waste. For example, for the highest quantile, the taste and convenience could be relatively important factors, while lack of waste and storability matter relatively more to lower quantile income groups. Tomato attributes and accessibility resulting from increased density of food retail outlets also encourages consumption growth.

Per capita consumption of fruit (Figure 7.3) also shows an interesting pattern of differences across quintiles and over time. As could be expected, per capita volume consumed of all fruits increases across quantiles reflecting income increase and the weakening budget constraint. However, year to year fluctuation in the consumed volume within a quantile show that households remain price sensitive. The consumption volume of berries increases across quintiles, but is lower than that of exotic fruits and apples. Because berries include a variety of fruits, the change in consumption between 2007 and 2011 shows that the berry consumption was declining in the second half of that period and the decline was more pronounced in higher quantiles. However, berry consumption was considerably higher in the highest income quantile.

The volume of exotic fruit consumed shows a big difference between the lowest and the highest quintile – the amount in the highest quintile is roughly 2.5 times higher than in the lowest quintile. The volume of exotic fruit consumed seems to show less variability than that of apples. This tendency reflects the smaller variability

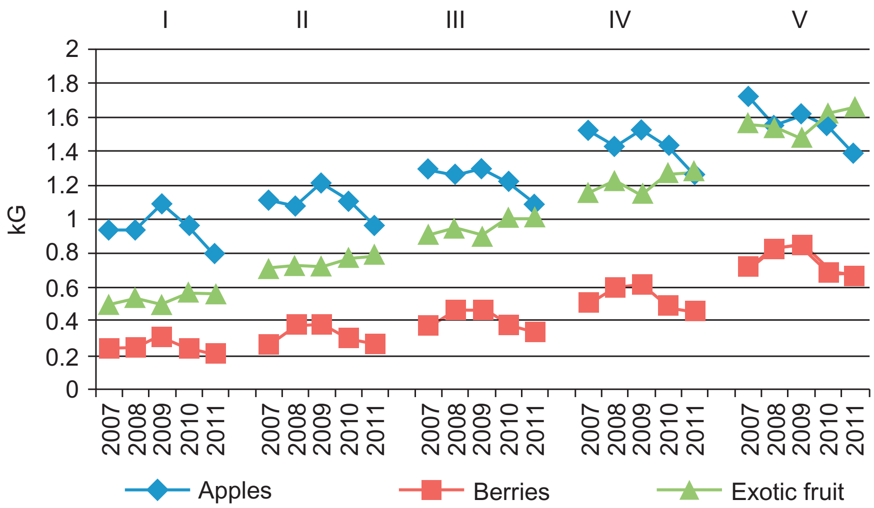

FIGURE 7.3

Per capita consumption of selected fruit by five income quintiles in Poland, 2007–2011. Note: GUS defined per person income levels for each quintile in 2010 as: I – 644.88 zł ($195.4) or less, II – from 645.00 zł to 898.57 zł ($195.4–$272.3), III – from 899.00 zł to 1182.61 zł ($272.4–$358.4), IV – from 1182.65 zł to 1600.64 zł ($358.5–$485.1), V – 1601.67 zł ($485.2) or more; the applied exchange rate: $1 = 3,3 zł.

Source: GUS, Budżety Gospodarstw Domowych w: 2007, 2008, 2009, 2010, 2011, Warsaw, Poland. 2008; 2009; 2010; 2011; 2012.

in the retail prices of exotic fruit than primarily domestic apples. Apple prices respond to domestic supply conditions, and the supply is determined by annual crop affected by weather, primarily any late spring frost. More importantly, the consumption of exotic fruit exceeds the apple consumption in the highest quintile, suggesting a particularly strong preference for this fruit type among well-off households.

Still, per capita consumption of apples by households in the highest income quintile is larger than in the other four quintiles suggesting that these households remain important apple buyers. But the consumed apple volume shows a decline in each quantile during the period under consideration. The pattern of the consumed volume also shows that apples tend to be more important to households in the lowest quantile, where the increase in the consumed volume is the largest (in 2009) in response to the price decline that year. The increases in other quantiles were lower and in the highest income quantile virtually muted. Florkowski (2013) showed that apples are a much more important fruit for low income households than for well-off households when measured by expenditure.

In the Republic of Korea, the expenditure on fresh fruits and vegetables in a week preceding the interview with the respondents during the 2007 survey shows the expected pattern of accelerated fresh fruit expenditure increase as income increases (Figure 7.4). The increase in expenditure on fresh vegetables across six categories suggests that households in the two lowest categories spent about a

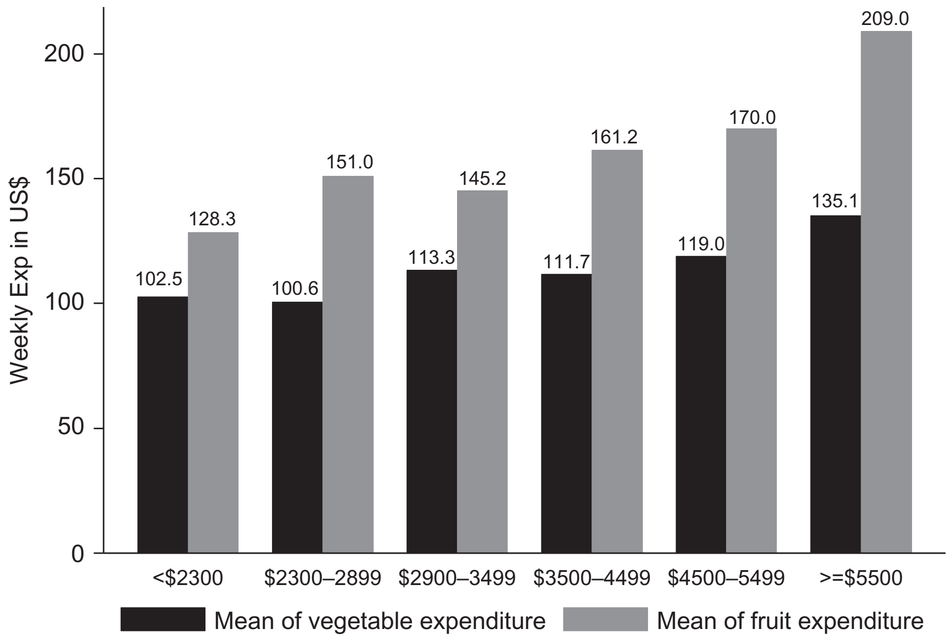

FIGURE 7.4

Weekly fruit and vegetable expenditures in urban households in the Republic of Korea by six income categories based on the 2007 survey data, in $. Note: currency converted at the exchange rate $1 = 929 Korean won as of September, 2007.

fourth more on fresh vegetables than the highest income category. The observation is important from the fresh vegetable marketing point of view, providing insights about spending in terms of household income. In the case of the Republic of Korea, it does not imply that households in the lowest income groups eat an inadequate amount of fresh vegetables because the household size is not taken into account and figures are measured in terms of money. In developed economies, the lowest income households contain a sizable number of one-person households comprising individuals who are living on pensions. Therefore, it is important to pay attention to the details of presented tendencies. Despite this possible household size confounding effect, households in the highest income group clearly outspend all other shown groups (Figure 7.4) although the fifth income group also spends more than other income groups. Because the traditional Korean diet is heavily dependent on vegetables and the average person eats the WHO recommended daily amount of fresh fruit and vegetables, the opportunities for an increased intake of fresh vegetables probably depend on innovative forms of preparation, eating occasions, or changes in the shares of individual vegetables or vegetable categories, which is likely to demand innovative postharvest handling to ensure high quality.

The increase in fresh fruit expenditure is more pronounced across the six income categories (Figure 7.4) than is vegetable expenditure, suggesting a very

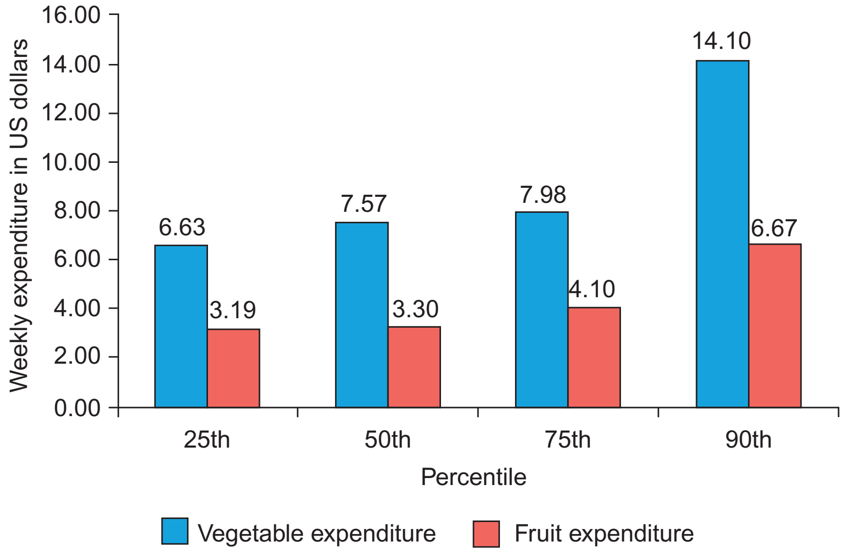

FIGURE 7.5

The weekly fresh fruit and vegetable expenditures corresponding to income quantiles in Ghana (in $; converted at the exchange rate $1 = 1.52212 Ghanaian cedi as of June 1st, 2011).

high association between expenditure and household income in the Republic of Korea. All households spend more on fresh fruit than on fresh vegetables. Although the results could have been affected by the generally higher fresh fruit prices as compared to fresh vegetables prices, the increase in expenditure on fresh fruit is much more strongly pronounced across the six income categories. First, households in the lowest income category spent much more (28%) on fresh fruit than on fresh vegetables. This is interesting because, as shown later in this chapter, households from lowest income groups in less developed economies spend very little on fresh fruit purchases. The strong preference for fresh fruit among Korean households is reflected in the rapid increase in per capita intake of fruit in recent decades, which contrasts with the rather slow to stagnant growth in per capita vegetable intake. The second, third and fourth income categories (Figure 7.4) spend a similar amount on fresh fruit (expenditure ranged from $145 to $161) and about 30–40% more than they do on vegetables at the time the survey was taken. The fifth income category spend somewhat more than the middle three income categories and considerably more than they do on fresh vegetables (43% more on fresh fruit). The highest income category (Figure 7.4) reported much higher fresh fruit expenditure than any other category, $209 or about 63% more than the lowest income category. Interestingly, a strong growth in fresh fruit expenditure can also be observed among the surveyed Ghanaian households (Figure 7.5), suggesting that in this particular income group, the budget constraint weakens and allows more choice in fruit purchases. Consumers in the highest income category may be open to trying a wider variety of fruit, but also may be willing to spend more if the fresh fruit meets their quality expectations, an

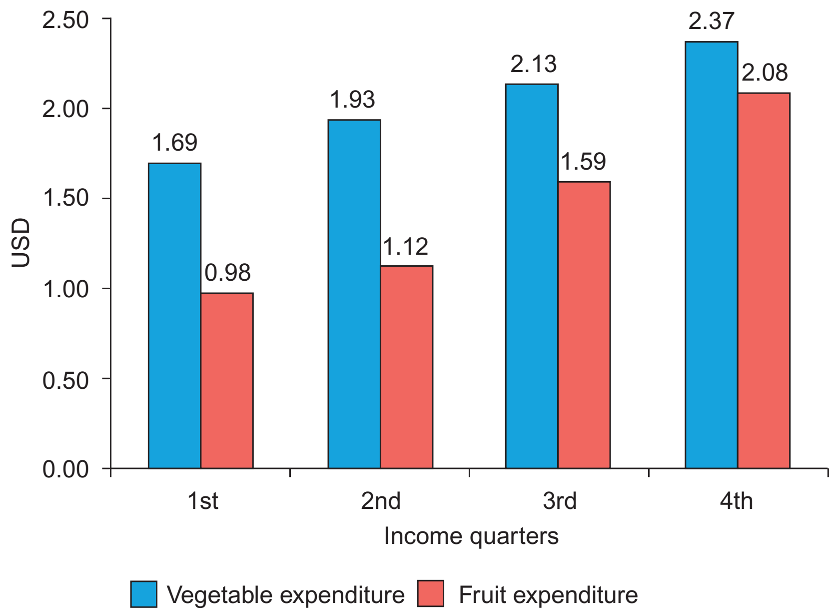

FIGURE 7.6

The weekly fresh fruit and vegetable expenditures by income quarter in Uganda (in $, converted at the exchange rate $1 = 2273.7495 UGX as of June 2011).

implicit requirement of proper postharvest handling. The highest income category spends more than other categories on fresh fruit (Figure 7.4) in the Republic of Korea, and the amount was larger than that spent on fresh vegetables. It outspends the fifth category by 23%, a considerable increase that should not escape the attention of fruit marketers.

The expenditure on fresh fruit and vegetables by urban households in Ghana refers to respondents surveyed in three large cities: Accra, Takoradi and Tamale. For the purpose of evaluating fruit expenditure tendencies, the focus on major urban centers is useful because such cities represent the largest domestic markets for domestic suppliers and fresh fruit traders. Figure 7.5 shows fresh fruit and vegetable expenditure based on the responses of 1076 households. Fresh vegetable expenditure continues to grow as income increases from the first to the third quartile, then the expenditure doubles for households with incomes in the 90th percentile. The relative increase in fresh fruit expenditure is largest between the lowest and the middle quartile, and the rate of expenditure growth decelerates in the two highest quartiles. Overall, the expenditure on fresh vegetables increases more rapidly than that on fresh fruit.

In Uganda, the average fresh vegetable expenditure is higher than the average expenditures on fresh fruit across all income quarters (Figure 7.6). However fresh fruit expenditure has increased faster for the higher income quarters; average vegetable expenditure increases by about 10% from the second to the third quarter, and by about 14% from the third to the fourth quarter. But the corresponding increases in average fruit expenditure are 31% and 42%, respectively. The pattern of faster increase in expenditure on fresh fruit than on fresh vegetables is similar to that observed across income categories in the other countries considered in this chapter.

When calculated in terms of expenditure per household member (children under four years old excluded; also, household size is highly variable especially across Africa), the pattern of higher average expenditure associated with higher income persists for fruit expenditure. This indicates that the income elasticity in fruit expenditure is strictly positive across all four income quarters. However, the pattern of vegetable expenditure is different. Compared to the lowest income quarter, higher income quarters are, generally, associated with higher vegetable expenditure. But the second quarter has the highest average vegetable expenditure of the four groups considered in this study. Such a result seems reasonable because higher income groups are less budget constrained and thus are more likely to purchase other foods, for example, fresh fruits, in addition to a certain amount of vegetables. This is also reflected in the purchase pattern of the households in the top 10% income group (not shown in Figure 7.6). The highest income households have the highest weekly total and per capita expenditure on fruits (UGX 5437.1 or $2.39 and UGX 1034.2 or $0.45, respectively), although their vegetable expenditure is slightly lower than the calculated expenditure in the third quarter. The average weekly household total and per capita vegetable expenditures by the top 10% income group are UGX 5191.4 and UGX 976.9 ($2.28 and $0.43), respectively. It is important to note that the fruit expenditure in the first income quarter is substantially lower than in the highest income quarter. The average weekly household total and per capita fruit expenditures in the first income quarter are only about half (47% and 55%, respectively) of their counterparts in the highest income quarter.

An important overall pattern to consider is that the share of expenditure on fresh fruits and vegetables, although increasing from the lowest to the highest quantile or income category, is decreasing in total household expenditures. That relative decrease has potentially important implications for quality and purchase. Consumers from well-off households may pay less attention to a single purchase of fresh produce with a quality below expectations. The less well-off households, in turn, may put up with lower quality if the price reflects the quality defects. The effects of the relative share of fresh produce expenditure in total expenditure may have different implications for consumer choices and purchase in countries with varying per capita income. Quality is placed in the context of affordability, allowing for different marketing strategies, which could have implications for postharvest handling.

A Examples of other factors which influence the choice of fresh produce

Consumption of fresh fruits and vegetables is conditioned not only by economic factors, especially income, but also by socio-demographic factors, household location, access to fresh produce and perceptions, including perceived health benefits.

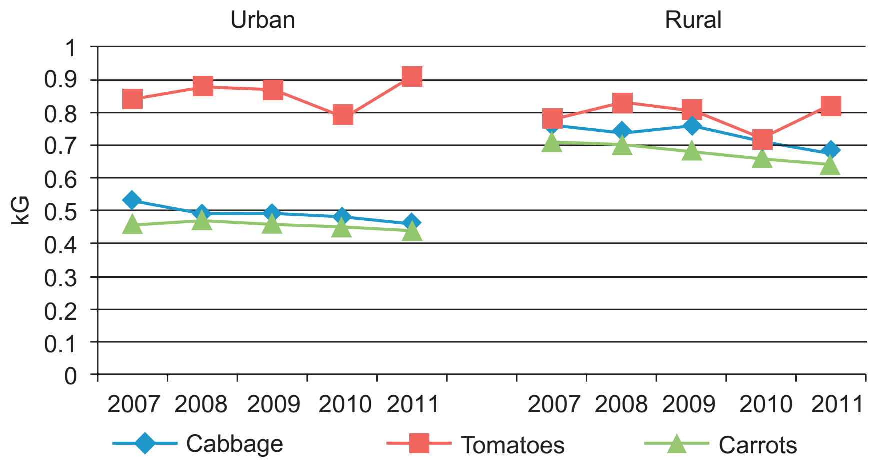

FIGURE 7.7

Per capita consumption of three vegetables by urban and rural residents in Poland, 2007–2011.

Cultural factors further condition fresh produce choices. The following subsections illustrate the relevance of various factors other than income to the consumption or purchase of fresh fruits and vegetables. It is assumed throughout the chapter that the purchase of fresh produce implies its consumption, although at household level, spoilage constricts the actually consumed volume.

Education

The data from the survey in Ghana reveal a strong association between secondary or higher education level and the reported fruit-eating frequency. The number of households with at least secondary education level and the number of households with primary and lower education are roughly equal, however, two-thirds of households reporting eating an apple weekly are from higher education groups and only a third are from the lower education group.

Urban versus rural household location

The available data also provide insights into differences in fruit and vegetable consumption between urban and rural consumers in Poland between 2007 and 2011. Figure 7.7 shows that urban consumers ate more tomatoes than rural residents in per capita terms between 2007 and 2011. The difference was relatively small in the case of tomatoes, but was much more pronounced in the case of per capita consumption of cabbage and carrots. Rural residents ate only slightly more cabbage per capita than carrots and the per capita volume of both was smaller than that of tomatoes. Urban consumers ate carrots and cabbage in very similar volumes in per capita terms during the period under consideration, but the consumption level was considerably below that of rural residents. For both urban and

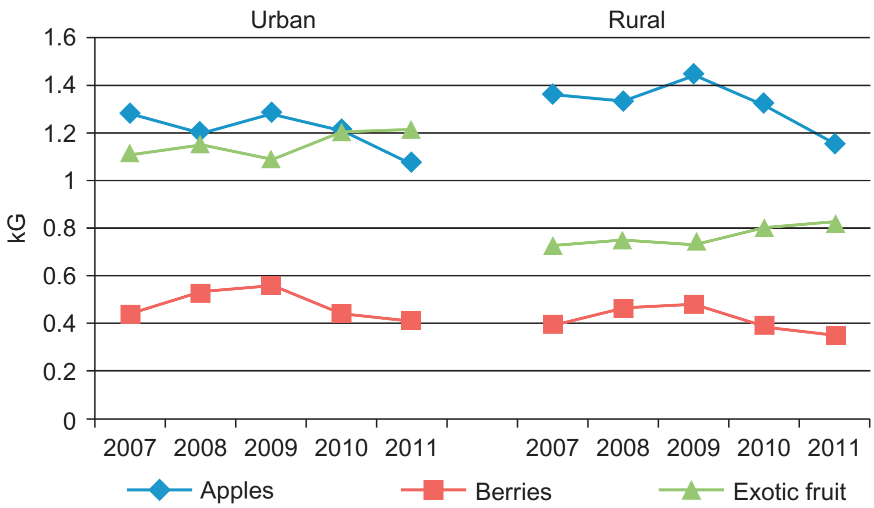

FIGURE 7.8

Per capita consumption of two fruit and a fruit category by urban and rural residents in Poland, 2007–2011.

rural residents, the per capita consumption has been steadily declining, with the rural per capita carrot consumption showing the most pronounced decrease.

Apples are the most popular fruit among rural residents and they are consumed in quantities that are larger per capita than for urban consumers in Poland (Figure 7.8); even so, their consumption is declining over time. The most noticeable per capita consumption difference between urban and rural consumers is the exotic fruit category and the fact that its consumption per capita is growing for both groups. Per capita berry consumption shows similar patterns among urban and rural residents during the period 2007–2011. Overall, the pattern of differences in per capita consumption of major fruits between urban and rural consumers reflects, among other things differences in accessibility and preferences.

City size and vegetable consumption

Urban consumers may have been offered a wider selection of fresh vegetables than rural residents because of higher density and competition among retail outlets offering fresh produce. Figure 7.9 shows the per capita consumption of three vegetables by residents in five town sizes in Poland in the period 2007–2011. Cabbage and carrot consumption steadily declines as the town size increases. Although the per capita consumption of cabbage is higher than carrot consumption in the three smaller town sizes, the opposite is true for residents of the two large sized cities. The importance of cabbage and carrot consumption for residents of smaller sized cities is quite evident, and may also reflect different densities of large retail outlets and shopping habits. The per capita tomato consumption is relatively stable with town size, except for the higher consumption in the largest city category (over 500,000 residents). This is an example of the influence of logistics and

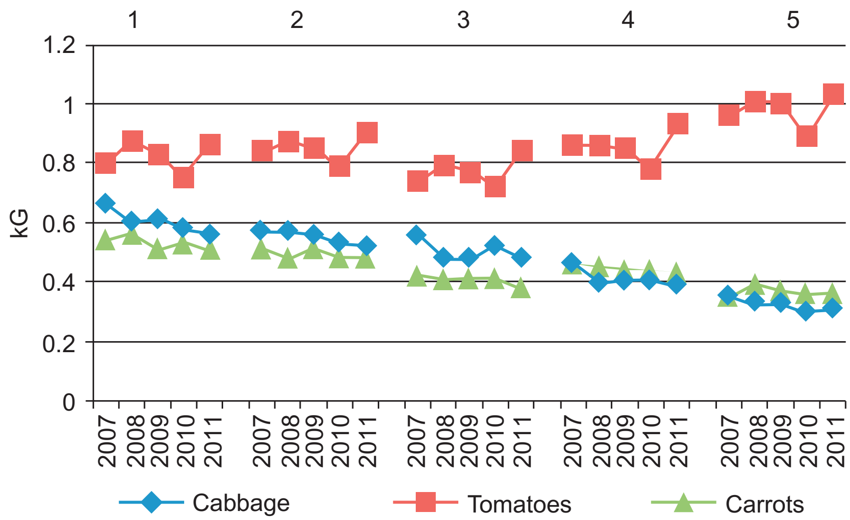

FIGURE 7.9

Urban resident per capita consumption of three vegetables by five town size categories in Poland, 2007–2011. Note: the plotted lines range from the smallest size on the left to the largest on the right; the city categories are: 1 = less than 20,000 residents; 2 = 20,000–99,000 residents; 3 = 100,000–199,000 residents; 4 = 200,000–499,000 residents; 5 = 500,000 or more residents.

postharvest handling tailored to supplying large urban centers where supermarket chains dominate the retail landscape. Tomatoes, well liked, versatile, and easier to handle than many other fresh vegetables, are the most frequent choice of consumers, especially residents of the largest cities who also tend to differ in lifestyle from residents of other locations.

Accessibility

Differences have been confirmed by results from the household survey in Ghana in terms of distance from the potential supply source. The already mentioned example of the weekly eating frequency regarding the domestic orange and imported apple shows markedly different frequencies across the three large cities. Accra and Takoradi respondents consumed oranges with similar frequency (the proportions of households eating an orange weekly in these two cities are both about 35%), while Tamale respondents ate oranges more often (45% of Tamale households ate an orange weekly). Apple consumption frequency was the highest in Accra, where 15% of households reported eating an apple weekly, followed by Takoradi, 9%, and Tamale, 7%, respectively. The distance from the port of entry (most likely Greater Accra or Takoradi) could influence the accessibility of imported fruit and, eventually, the consumption frequency. It takes up to 12 h for a truck to travel the distance from Accra to Tamale. Nevertheless, it also has to be recognized that incomes and locally available fruit selection differ across the three cities and could influence the choice of fruit.

Regional differences

The review of urban Korean household survey data reveals that the weekly expenditure on fresh fruit and vegetables varies widely. The weekly fresh vegetable expenditure in the surveyed seven urban areas in September 2007 were $129 in Busan, $121 in Ulsan, $116 in Inchon, $114 in Seoul, $102 in Daejeon, $93 in Daegu and $87 in Kwangju. Busan and Ulsan are located in the industrialized southeastern part of the country and are densely populated, though relatively far from domestic supply sources. The observed differences could reflect the possible local supply and demand conditions at the time of survey implementation. The weekly fresh fruit expenditure shows a very different pattern. Weekly expenditures were $176 in Inchon, $170 in Seoul, $168 in Ulsan, $165 in Daegu, $142 in Busan, $127 in Daejeon and $83 in Kwangju. Clearly, fresh fruit expenditure shows a different pattern suggesting that the largest agglomeration of the capital city and Inchon are likely to represent a highly concentrated demand area. This illustration serves as a reminder that fresh produce marketing must recognize regional differences, and that shipped fresh produce must be appropriately handled.

IV Most commonly eaten fruits and vegetables

This section is based on household survey data from Ghana and Uganda. The data illustrate similarities in vegetable consumption. The most frequently eaten fruit shows larger differences than the most frequently eaten vegetables between the two countries (and across countries overall).

A Vegetables

Figure 7.10 shows the percentage of surveyed households reporting weekly consumption of the 10 most often named vegetables in Ghana. More than 44% of households named yam, which outdistanced all other vegetables. Yams are very popular and well liked and they are also domestically produced in Ghana. Moreover, the country also exports yams, primarily to the European Union. Exported yams are selected from the domestic supply to meet size and quality requirements in the destination markets. The yams remaining in the domestic market are highly variable in size and quality, but areaten boiled or roasted, not fresh. Cabbage and carrots were also reported to be eaten weekly by 31% and 25% of households, respectively. The share of households reporting weekly consumption of the next six vegetables ranged from 14% for cucumbers to 10% for avocado. Only about 7% of households reported eating the Irish potato on a weekly basis. The variety of fresh vegetables is affected by the season, but for many of them, there is a nearly continuous domestic supply since there is usually a region with suitable growing conditions.

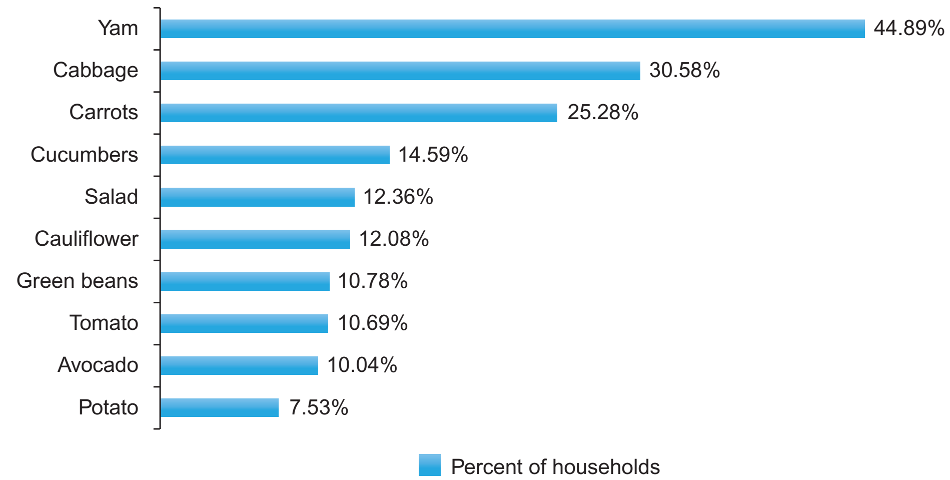

FIGURE 7.10

The proportion of surveyed households reporting eating weekly the 10 most-often-selected vegetables in Ghana, in percentages.

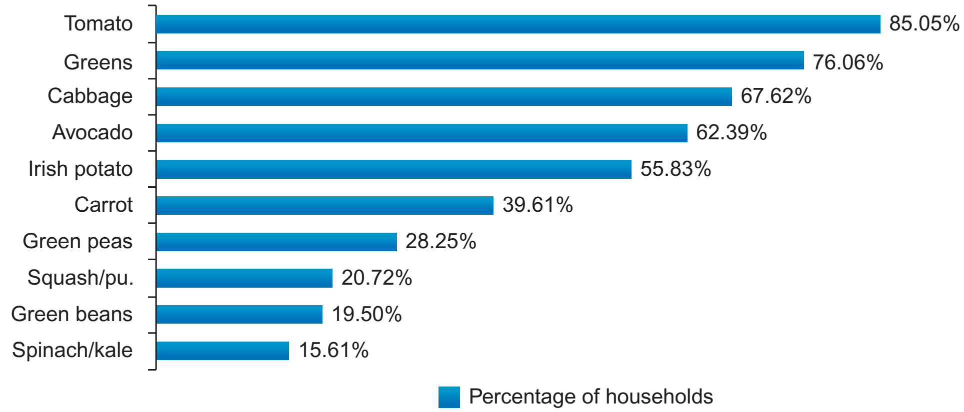

FIGURE 7.11

The proportion of surveyed households reporting eating regularly the ten most often selected vegetables in Uganda in percentages.

The survey data from urban households in Uganda reveal that the largest share of households reported "regularly" eating tomatoes among the 10 top vegetables (Figure 7.11). This result is consistent with vegetable consumption frequency in many countries of the world regardless of their level of per capita income. The tomato is a versatile vegetable (botanically it is a fruit, however) and is universally liked, therefore it finds an almost unending number of uses. The high share of households reporting eating greens supports casual observations and the reported forms of eating selected foods. Greens are typically cooked and eaten with rice or beans and peanut sauce. Meat is added to such a meal if it is

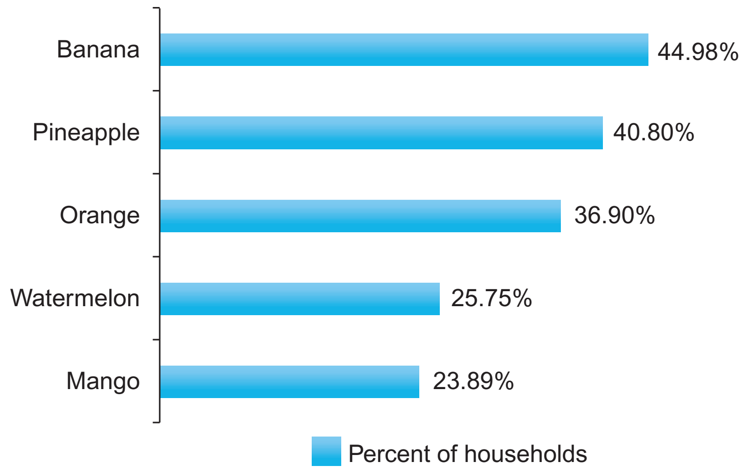

FIGURE 7.12

The proportion of surveyed households reporting eating weekly the five most often selected fruit in Ghana, in percentages.

available. Other popular vegetables are cabbage, avocados, carrots and green beans, which were named among the top 10 vegetables eaten on a weekly basis by urban households across Ghana (Figure 7.10).

B Fruit

In Ghana, bananas and pineapples were the most frequently eaten fresh fruit (Figure 7.12). The southern parts of the country are suitable for growing bananas, which require little effort to produce a crop. Pineapples have traditionally been the major exported fruit from Ghana. Oranges are commonly grown and supplied in large volumes to the open-air markets. However, a large portion of oranges spoil before they can be eaten or processed. Oranges are competitively priced and available throughout the country. Watermelons, followed by mangoes, are also among the top five eaten fresh fruits, but the reported consumption frequency is considerably less than that of pineapples or bananas. It is possible that the time period of survey implementation influenced the observed frequencies, but, in general, they reflect the availability of fresh, domestically produced fruit. In terms of the postharvest handling system, the pineapple sector has developed a well-functioning system stimulated by the export market. Other fruit is mostly consumed domestically, and postharvest handling procedures vary widely from supplier to supplier.

The Ugandan urban respondents provided answers about the "regular" consumption of fresh fruits or vegetables (Figure 7.13). The phrasing of the question was finalized after the pilot test, which suggested that the initially requested information about consumption frequency measured on a daily, weekly, or monthly basis caused difficulty in providing answers. In Uganda, the five most often consumed fresh fruits, with the exception of passion fruit, are the same as in Ghana (Figure 7.12),

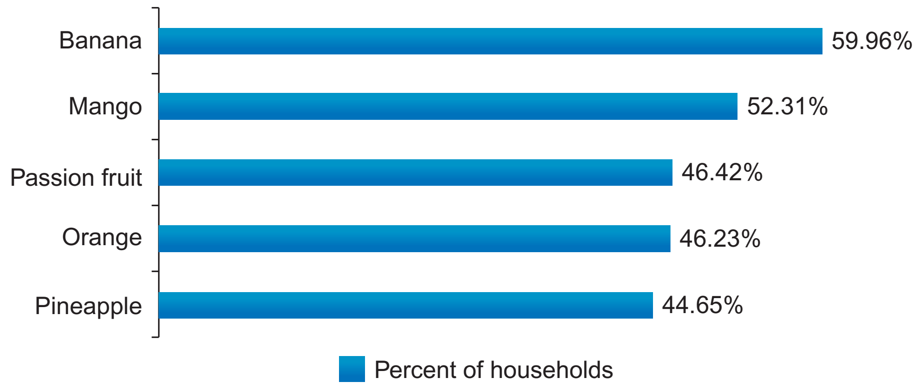

FIGURE 7.13

The proportion of surveyed households reporting eating regularly the five most often selected fruit in Uganda, as percentages.

but the order of frequency is somewhat different. Not surprisingly, bananas are consumed regularly by the largest percentage of households, 60%. Banana plants grow unimpeded in Uganda due to favorable conditions in large parts of the country. The plant bears fruit without any special care. Mangoes have been reported as being eaten regularly by 55% of the surveyed urban households, while the three other fruits have been eaten on a regular basis by 45–46% of the households, implying little variation in regular consumption of passion fruit, oranges, or pineapples.

V Concluding comments

Huge discrepancies in fresh fruit and vegetable consumption across countries and within countries across economic strata, socio-demographic groups and locations create tremendous opportunities for fresh produce suppliers. Many countries are far from reaching the goal of eating the recommended 400–500 g of fresh produce per day. Reaching various groups and consumer segments with quality fresh produce they can afford poses postharvest challenges, many of which still have not been addressed.

Globally, for the time being, consumer disposable incomes will continue to drive the purchase and, subsequently, trade direction and consumption of fresh vegetables and fruit. As the variety in the market place increases, competition among various produce types will increase. To deliver the quality expected by consumers will require cooperation among various players of the distribution system and value chain. Consumer education will be increasingly necessary to encourage sustained consumption because of the many choices even if price and quality expectations are fulfilled.

A factor not considered in detail in this chapter is the fragmentation of motives behind purchasing and eating fresh produce. Relatively more affluent societies, but aging and experiencing declining health, will demand fresh produce in expectation of disease prevention and health maintenance. Affluent households across all countries will seek fresh produce as a tool to manage weight as the problem of overweight and obesity becomes a global scourge inflicting increasing costs on economies. The less affluent, as their incomes increase, will rapidly increase fresh produce consumption simply because they want to eat more of it if their budget constraints weaken. The interpretation of what is an exotic fruit or vegetable will be defined locally, but it will remain an influential factor driving purchase and consumption, requiring adjustment of postharvest handling for various climates, cultures and distribution systems.

Bibliography

Chai, A., Moneta, A., 2010. Retrospectives engels curves. J. Econ. Perspect. 24 (1), 225−240.

EUFIC Review, 2012. Fruit and Vegetable Consumption in Europe − Do Europeans Get Enough? Available online at <http://www.eufic.org/article/en/expid/Fruit-vegetable-consumption> (accessed 07.10.13).

FAO, 2013. Available online at <http://faostat.fao.org/site/368/default.aspx#ancor> (accessed 30.09.13).

Florkowski, W.J., 2012. Evidence of household consumption changes associated with the global economic slowdown. Poznan Univ. Econ. Rev. 12 (3), 42−80.

GUS, Various issues. Budżety Gospodarstw Domowych w 2007; 2008; 2009; 2010; 2011, Warsaw, Poland.

KOSIS, 2013. Per Capita GNI of South Korea from 1990−2012 (at current prices). Available online at <http://kosis.kr/eng/> (accessed 01.10.13).

Neuman, W., 2011. Goodbye to the food pyramid, hello to the dinner plate. New York Times, May 28, Late edition. Available online at <http://www.nytimes.com> (accessed 04.10.13).

Revoredo-Giha, C., Florkowski, W.J., 2013. An analysis of the demand for fresh fruit in Scotland. Roczniki Naukowe SERiA 15 (3), 279−287.

State Statistical Service of Ukraine, 2007. Available online at <http://www.ukrstat.gov.ua/> (accessed June, 2013).

WHO, 2003. Diet, Nutrition and the Prevention of Chronic Diseases. WHO Technical Report Series 916, Geneva, Switzerland, pp. 160.

World Bank, 2012. Indicators Database. Available online at http://data.worldbank.org/indicator (accessed 10.09.12).

World Bank, 2013. GNI per capita, Atlas method (current US$). Available online at <http://data.worldbank.org/country/ghana> (accessed 26.09.13).

Wrangham, R., Conklin-Britain, N.L., 2003. Cooking as a biological trait. Comp. Biochem. Physiol. Part A 136, 35−46.

Wright, A.C., Danyluk, M.D., Otwell, W.S., 2009. Pathogens in raw foods: what the salad bar could learn from the raw bar. Curr. Opin. Biotechnol. 20, 172−177.

CHAPTER

8 Postharvest Regulation and Quality Standards on Fresh Produce

Kerry B. Walsh

Plant Sciences Group, Central Queensland University, Rockhampton, Queensland, Australia

Setting the task

The orchard has been irrigated, fertilized and pruned. Disease, insect and weed problems have been addressed. The crop is mature, the yield set and the picking crews can be set to work. The postharvest phase of the crop begins. By this stage the producer should have decided which supply chains to participate in, and thus the intended market for the crop. The final value achieved for the crop will depend on the marketing and technical nous of this chain to present and manage "quality" in the product.

So we are led to the hoary issue of a definition for "quality". Of course, there is no single answer, and the term "product quality" has as many definitions as there are participants in the supply chain. For example, to the product supply manager and to the retailer, a major component of "quality" is product shelf life. To the government regulator, quality is often primarily conceived in terms of public risk. But, typically, there is more than one government regulator. For example, that branch concerned with quarantine risk will cast "quality" in terms of entomological and microbiological issues. Another branch of government concerned with human health risk (food safety) will cast "quality" in terms of the presence of chemical residues and microbial contaminants. To the retail client, "quality" is often viewed in terms of issues related to the remaining shelf life of the product and aesthetic issues which affect consumer purchase decisions (fruit color, size, shape, blemish size and frequency). To the end consumer, fruit "quality" is best described in terms of both shelf life and the eating experience. The latter is a function of fruit firmness, sugar content, organic acid content and tissue juiciness. As with all stages in the supply chain, though, the consumer is not a single entity, and many fractions exist. For example, different ethnic or age groups may have different taste preferences. Further, some consumers link "quality" to the issue of local production, or to organic production practices. Such consumers often implicitly link these production aspects to eating quality. Other consumers place value

Postharvest Handling.

on larger environmental issues, such as "production without destruction" (e.g., use of crop netting rather than killing of flying foxes or birds), or on issues related to CO_2 emissions (e.g., food miles).

This chapter summarizes regulation which exists to enforce "quality" in fresh produce, postharvest. These regulations may be imposed within any step in the value chain, and may impact broadly (e.g., a microbiological standard), or may pertain to a narrow market segment (e.g., organic product). The particular issue of eating quality is considered further, in terms of the drivers for adoption of standards.

II Regulation modifies value chain behavior

A value chain is a commercial construct and, as such, is driven by issues extending beyond the biology of the commodity. Certainly production and postharvest technical issues are fundamental considerations to a supply chain, but the commercial viability of a value chain is also determined, in substantive measure, by the social and regulative milieu in which it is set.

A "Supraregulations"

The broad social milieu can often be relatively static, changing "slower than the eye can see". Further, this milieu is effectively beyond the influence of any individual business, and so the influence of this "supraregulation" on value chain viability is often ignored. At other times, an abrupt change in social or regulative conditions occurs, with corresponding abrupt change in trading conditions. Consider the following examples of broad issues that affect the postharvest viability of a given value chain:

Global trade environment

It is technically possible to grow horticultural crops in harsh environments through the creation of protected environments. Conversely, in an era of cheap transport, it is possible to air- and sea-freight produce across the world. The economic viability of such activities is not an "absolute", but is a function of broader economic and political settings.

As an undergraduate, I was greatly impressed on a tour of a local (Australian) Department of Primary Industries postharvest physiology laboratory. It was explained that insurance premiums on shipments of citrus to the UK were effectively unaffordable because of the high incidence of physiological disorders and disease, but that after a range of technical postharvest "fixes", it was not necessary to insure the loads! But the entry of the UK into the (then) European Common Market fundamentally altered trade between Australia and the UK, and citrus exports to the UK withered as Europe raised a trade tariff barrier. The "technical fix" was overwhelmed by changes in the terms of trade. The overriding "quality" criterion became country of origin.

National policy – infrastructure

The viability, or even possibility, of a supply chain depends on the national infrastructure available for use – on the quality of the electricity supply to the cold rooms of the pack-house, of the roads and railways, the availability of refrigerated transport, the efficiency of the sea and air ports and the frequency of scheduled services, the quality of communication systems (telephone, broadband) and the size of the domestic market. All of these items are influenced by government policy.

China has provided spectacular examples of national infrastructure development in the last decades (Figure 8.1). Special development zones have been designated and supported with land reform, transport, power, water and civil infrastructure. Where horticultural production is a focus, areas suited to production in terms of soil type have been identified, water allocations provided and postharvest facilities provided (e.g., improved market facilities). Land reform has split the communal farms for individual use, and then allowed consolidation of land parcels for agribusiness activity. Large production units and associated packing facilities are private, but are often supported by state capital.

National policy – labor market and immigration

Farm viability is highly influenced by the cost of harvest labor. This cost is high in developed countries relative to that in developing nations, and regulated by a government imposed minimum labor cost.

Immigration regulations favor different solutions in different countries. In Israel, the horticultural sector effectively lost the use of Palestinian labor, but has been supported by south-east Asian (particularly Thai) labor, present on two-year working visas. The southern United States horticultural industry traditionally utilized Mexican labor. Changes in government policy relevant to the labor market or immigration can thus have rapid impact on horticultural operations, both pre- and postharvest. The Australian horticultural industry relies to a surprising degree on "backpackers". Such workers are allowed into the country on short-term working visa schemes, but have a high turnover on-farm and a low (horticultural) skill level. More recently the Pacific Seasonal Worker scheme was introduced, with groups of Pacific Islanders working for 4–6 months each year in harvest operations (e.g., Firth, 2006). Further, if immigration policy supports population growth, and contributes to ethnic diversity in the population, new domestic markets for horticultural produce that are larger but also more diverse in taste preferences are created.

Intellectual property rights

Successful marketing requires a point of differentiation for the product. With Plant Variety Rights, a tool exists to enforce differentiation. A new variety may be released under exclusive production and marketing arrangements (Figure 8.2). Such a marketing arrangement allows for "easy" implementation of a quality standard and of standard (pre- and) postharvest practices. Similarly, the intellectual property of new technologies for postharvest storage or sorting may be protected and thus commercially controlled. There is increasing incidence of exclusive

No.	Item	Constructing Contents	Total Investment
1	Apple deep processing and integrated utilization	It is planned to construct an airconditioning storage with a capacity of 5000 tons, a 2000,000 tons/h processing line with grading, polishing and packaging, apple dehydrating processing line with a capacity of 5000 tons, pectic processing line with an annual processing capacity of 600 tons, protein beverage processing line with an annual capacity of 20,000 tons and a set of apple fragrance equipment with an annual capacity of 12 tons	185.07 million RMB Yuan
2	12,000 ha green fruits base and apple commercial processing line with a capacity of 50,000 tons	It is planned to construct 12,000 ha green fruits production base in Baishui, Pucheng, heyang and Hancheng counties;. It is planned to construct 10 pre-cooling cold storages with a capacity of 300 tons; one apple processing line with an annual capacity of 50,000 tons, two vehicles with a freezing system	65 million RMB Yuan
7	Construction on 5000 tons C.A. storage	To construct 5000 tons C.A. storage	40.79 million RMB Yuan
11	Construction on 5000 tons C.A. storage	To construct 5000 tons CA storage, to facilitate refrigeration equipment, computer lab and auxiliary equipment	40 million RMB Yuan
12	Construction on Pink Lady apple production base	To construct 33.3 ha demonstration apple orchard, to renovate 333.3 ha old fashioned apple orchard into organic Pink Lady apple orchard, to construct one apple photoemission selecting line and one fruit quality inspection center	51.55 million RMB Yuan

(B)

FIGURE 8.1

(A) New pack-house and administrative building in Shandong province, China, dependent on infrastructure developments of a Special Development Zone. (B) Excerpt from a Shaanxi province Department of Agriculture brochure, extolling 12 horticultural investment opportunities (Shaanxi fruit Industry; Shaanxi Provincial fruit Administrative Bureau; http://www.sxfruit.com).

FIGURE 8.2

"Calypso" mango fruit, a variety available under exclusive production and marketing arrangements. Fruit have been sorted non-destructively (using near infrared spectroscopy) on dry matter content at the time of harvest. After two days of ripening, low dry matter fruit remain green relative to high dry matter fruit. Dry matter at harvest is related to fruit maturity and thus to subsequent rate of ripening, and also to fruit eating quality as indexed by TSS of ripened fruit.

marketing arrangements for postharvest technologies (e.g., Maxtend, a modified atmosphere control system for shipping containers is licensed to Mitsubishi, see www.maxtend.com.au).

National policy – taxation policy

Taxation policy influences investment activity, and thus can influence horticultural supply chains. For example, in Australia, Managed Investment Schemes in forestry and perennial crop horticulture offered a tax effective treatment of funds for urban professionals on higher marginal tax rates. Large amounts of capital were accessed by these schemes, with funds invested into "corporate farming" exercises (i.e., large, professionally managed operations rather than family farms), often with distinct marketing arrangements. However, in 2007, the Australian Taxation Office removed tax concessions for Managed Investment Schemes operating horticultural enterprises, dramatically curbing the level of investment in this sector.

A carbon tax?

Given current political uncertainties, we can only begin to speculate about the impact of C trading schemes on horticultural pricing structures (e.g., through the cost of fertilizer and transport) and, thus, on market positioning. Horticultural value chains may be impacted by costs associated with C emissions tagged to land clearing, soil organic matter loss, fertilizer, fuels or cool room use. Conversely they may benefit from payments associated with C sequestration, e.g., use of biochar. But such projections are tenuous, and rely on an interaction of national and international regulations.

Summary

Directly or indirectly, "supraregulations" impact the horticultural sector. Although these issues are basically beyond control of a given supply chain, it is useful to acknowledge their impact. "Watershed" changes in such regulation, e.g., in immigration policy or C trading, require businesses to formulate a strategic position in the new trading environment.

A CASE STUDY: NEPAL

Following a defeat in battles with the British Raj, the Kingdom of Nepal isolated itself from foreign contact from 1816 until 1951. Hilary ascended Mt Everest in 1954, and the Tribhuvan Highway between Kathmandu and the Indian border was started in 1956. Despite large campaigns to extend the electrical grid and road network, infrastructure remains poorly developed, with load shedding for up to 20 h a day, and much of the population remains several hours' walk from a road. Traffic behavior is erratic, such that a 180 km trip between the main cities of Kathmandu and Pokhara can easily take 8 h. As such, much horticultural production remains at a subsistence or local level. The Kingdom of Nepal became the 147th member of the World Trade Organization (WTO) on 23 April 2004, but this has little significance to the horticultural industry. The border with India is porous to labor and goods into India, with horticultural produce from India often dominating segments of the Kathmandu market, yet corruption issues seem to effectively block export of Nepalese produce to India. With improved rail infrastructure from China to Tibet, Chinese apples are penetrating deep into Nepalese markets (Figure 8.3). China allows the export of

FIGURE 8.3

Apples from China, transported through Tibet and being unloaded in Pokhara, Nepal. November, 2012.

> Nepalese mandarins to Tibet for product meeting phytosanitary standards, but Nepalese producers and government agencies have yet to achieve the level of organization required (for in field and in pack-house disease and insect checking, and produce labeling). In short, the national infrastructure and business environment is not yet conducive to the development of a horticultural value chain of any size.

For the remainder of this chapter, we examine issues of regulation with more focus on horticulture, and that have a shorter-term impact.

III The goals of regulation directed at the horticultural sector

As a broad generalization, regulation targeted to the horticultural sector is enacted in an attempt to benefit either the consumer or the producer. Occasionally, the two aims are intertwined! Such regulation can come either from "outside" the value chain, with the regulation imposed on the entire product sector, or from "within" a value chain.

In the not-so-distant past, agricultural industries in many western countries were regulated in terms of marketing arrangements, often with the effect of limiting production. These practices were aimed at providing a benefit to the producer, based on an ethic of "rural socialism". These practices belong to an era of large rural populations in democratic systems in which the rural vote was important. Marketing boards with quasi-government agency status were given authority to require all growers to market through a single desk. Such exclusivity improved the marketing clout of that body, albeit at the loss of individual freedom. These arrangements typically served to preserve a pricing level and to maintain quality control.

As marketing boards curtail individual activity, they are considered to stifle entrepreneurial activity, and, thus, to run counter to free trade principles. Such arrangements are, therefore, targeted in international trade negotiations under the World Trade Organization (WTO). For example, the South African "state ordained" horticultural marketing body was dismantled following the passing of the Agricultural Marketing Act 1996, with over 60 export licenses granted for deciduous fruit alone in the first season following deregulation (Scrimgeour and Sheppard, 1998).

However, a similar result can often be achieved by a very dominant, if not exclusive, private marketing entity. In the South African example, the original marketing board morphed into the internationally active fruit marketing company, Capespan, with annual sales of around R 5.6 billion and profit of R 185 million (Capespan, 2013).

Another "evolutionary path" is illustrated by the New Zealand based Zespri (kiwifruit) group, with a centralized marketing function retained due to support from growers. In the 1950s and 1960s, kiwifruit grower groups in New Zealand were very fragmented in their approach to the export of fruit. The Kiwifruit Marketing Licensing Authority was created in the 1970s to regulate the activities of exporters, and grade standards and a coordinated marketing strategy was established across the industry. However, a rapid increase in production and a rising value of the NZ$ led to a collapse in fruit prices, leading to "cannibalistic" competition in export, and the exodus of many growers from the industry. The NZ government established the New Zealand Kiwifruit Marketing Board in 1988 as a single desk exporter under grower control. The single export entity concept was endorsed by growers across New Zealand, and legislated within the Kiwifruit Industry Restructuring Act (1999) (www.legislation.govt.nz/act/public/1999/0095/latest/DLM38169.html, accessed 10 August, 2013). The public company ZESPRI International Limited was then formed to act for the export of New Zealand grown kiwifruit (Zespri, 2013). The key to the continuation of a centralized export marketing function was the formal agreement of growers.

Other involuntary "producer-centric" regulation is being eliminated. For example, the Australian producer group Queensland Fruit and Vegetable Growers once maintained a program of research, marketing and political advocacy, supported by a compulsory levy on all horticultural products sold. However, the right to collect this levy was lost. The group re-incarnated in August 2004 as "Growcom", but now must seek voluntary support from growers (Growcom, 2013).

Current attempts to regulate the fresh produce sector typically aim for a gain to wider society, or for a gain in "quality" for one or more elements of the supply chain. Examples include:

1. Fair trading. Most countries regulate all commerce in terms of fair trading provisions. In the horticultural area this includes enforcement of product identity and content labeling (e.g., accuracy of weight or count labels). In the United States, traders of fresh produce must obtain a license under the Perishable Agricultural Commodities Act (1930). This Act allows the enforcement of contracts between buyers and sellers (Agricultural Marketing Service – USDA, 2013a). Similarly, the Australian Horticulture Code of Conduct (enacted 14 May 2007, but poorly implemented) requires written agreements between buyers and sellers, ensuring that the parties define and document the level of any required quality attributes (DAFF, 2013a);
2. Product origin. There is an increasing requirement for traceability, from the broad level of labeling country of origin to the specific level of traceability of every lot from orchard to retail outlet – e.g., Dole Organic incorporates a three digit number on the fruit label visible in store that allows a link to a website displaying information on the growing site;
3. Biosecurity issues, typically entomological or microbiological. In responding to quarantine regulations, fruit consignments may be required to be subject to treatments such as vapor heat or gamma radiation, with potential impact on shelf life (i.e., loss of "quality").

4. Food safety, typically heavy metal and organic chemical residues and microbiological contamination. Regulations typically favor supply chains that can provide records of chemical usage and practices undertaken, and that are amenable to inspection (e.g., central packinghouses rather than dispersed packing, under a formal certification process);
5. "Local food", e.g., in Europe, the use of geographic names in labeling is regulated (European Commission – Agriculture and Rural Development, 2013). In Japan, consumers identify specific product qualities by region and retailers may label product with locality and even the identity of the farmer (Figure 8.4);
6. Product size, color and appearance. Retailers usually set product specification in terms of these aesthetic issues; also, many national standards for grades define size and the color typical to a particular variety as well as the presence of blemishes or malformation (examples given in Section VII);

FIGURE 8.4

Advertising material from the Japanese retail chain Diaea (2004), with inclusion of information on production locality and a photograph of the grower. The 'stamp' indicates fruit has been 'light sorted', i.e., graded to a sweetness level using near infrared spectroscopy.

7. Eating quality. Uncommonly, a retail client may also enforce product specifications on this aspect of quality, generally enforced only in extreme cases; more commonly, grower groups may offer specific level of measurable attributes such as Brix in an attempt to capture retailer interest (e.g., use of the Washington Apple brand requires Red Delicious apples harvested before October to have a minimum Brix of 11, http://www.bestapples.com/facts/facts_grades2.aspx; the Californian FreshSense "Ripe 'n' Ready" stonefruit program also provides a "taste guarantee" based on Brix and firmness standards to retailers http://www.goodfruit.com/Good-Fruit-Grower/July-2008/Taste-guarantee/, accessed 6 Oct 2013; also see examples given in Sections VIII and IX);
8. Organic production. Specific supply chains may require organic production, vetted by various certification schemes (see example in Section VII);
9. Other environmental issues. Some consumers/supply chains/governments weight production issues such as water use and wildlife "friendliness" (e.g., netting to exclude flying foxes), and postharvest issues such as type of packaging and "food miles"(see example in Section VII).

Of the above examples, the first four are government regulated, while the remaining five are usually value chain regulated.

A Does regulation of product quality evolve with an economy?

Developed economies have often passed through a period of government regulated (single desk) marketing and quality control before the export industry was well established, followed by a withdrawal of government function to that of regulating food safety, biosecurity and fair trading. Should developing economies evolve through stages of regulation, or has the global environment changed such that this is not necessary, or possible under WTO provisions? Could a developing economy move straight to a voluntary agreement of all growers to participate in a single desk arrangement comparable to Zespri?

IV Levels and examples of regulation

Regulation of the postharvest handling of horticultural produce exists at an international level, a national level and at the level of the individual supply chain. Indeed, there is a web of intergovernmental and non-government (NGO) organizations, national and sub-national (state) government agencies and various supply chains involved in the setting of regulations and standards. Fortunately, there is a trend towards standardization and rationalization among these various organizations [e.g., working from The United Nations Economic Commission for Europe (UNECE) and Codex, see Section VII].

In this text we are not directly concerned with the economic regulators of the horticultural industry, such as import tariffs or import volume limits, set by national governments. However, the reality is that global horticultural trade is constantly shifting in response to the "real-politik" of trading disputes between countries, with phytosanitary standards and research used as ammunition in this tussle. For example, Asia Fruit Magazine reports the following issues within a one-month period within 2013 (www.fruitnet.com/asiafruit):

1. M. Jones (15 July 2013). A small plant for vapor heat treatment of fruit has been established in Karachi and the first consignment of mango sent to Japan. The Japanese government lifted an 18-year ban on Pakistani mangoes three years ago, on the condition that fruit was sterilized before shipment.
2. M. Jones (19 July 2013). Pakistan and China have signed an import protocol that will allow Pakistan mangoes into China. The protocol involves certain quarantine and phytosanitary procedures.
3. E. French (29 July 2013). Fruit fly has been discovered in 2.8% of the 1652 lots of Pakistani mango arriving into the UK in the first half of 2013. The leading mango exporter was quoted as saying, "It's not more than 5% of exports, so it's not a big issue".
4. E. French (18 August 2013). Australia has granted market access for Pakistan mangoes, following a monitoring of quality standards over several years. The decision may have been prompted by a hot water treatment technology which is reported to ensure that mango pulp is free from "nine varieties of bacteria and can keep mangoes fresh for up to 42 d". It was reported that Australia market capacity for Pakastani mangoes is approx. 5000 tonnes, and that Pakistan's 2013 production is 1.8 M tonnes, with 40% lost due to poor storage and 175,000 tonnes exported.
5. E. French (26 July 2013). The Indian government is considering temporarily banning exports of onions, in response to a domestic shortage and escalating prices.
6. M. Jones (6 August 2013). The Indian government released revised regulations on foreign investment in retail − foreign investment in a retail entity is capped at 51% ownership, with the foreign partner required to invest US$100 M upon entry into the market, with 50% of these funds to be in "back-end infrastructure", and also required to source 30% of stock from small Indian firms. Further, State Governments have been given power to restrict retail stores to cities of their choice, as opposed to cities with a population of more than 1 M residents (in the prior regulation).
7. M. Jones (16 August 2013). The NZ apple industry is seeking a "more welcoming" environment in trade negotiations between NZ and India.
8. G. McShane (29 July 2013). The draft USA Food Safety Modernization Act, a set of regulations aimed at ensuring imported food meets the same safety standards as that produced domestically, is open for comment within 2013. This Act will legislate a verification process for foreign suppliers and an

accreditation process for third party auditors. Accredited bodies could be foreign governments or private companies, which in turn could accredit third party auditors to audit and issue certifications on foreign food facilities. It was noted that food from 150 countries is imported into the US, representing about 15% of US food supply.

9. E. French (12 August 2013). Biosecurity Australia has accepted an import protocol to allow entry of Californian stonefruit into the Australian market in May. Californian peaches and nectarines will be in Australian stores until mid October, when the Californian season closes.
10. M. Jones (13 August 2013). An Australian senator called for market access overhaul, noting that although South Australian citrus industry was free of fruit fly, with South Australian taxpayers contributing close to US$4.5M pa to maintain this status, and this status recognized in almost all markets. China requires South Australian fruit to undergo cold sterilization prior to entry, at a cost of up to US$6835 per shipping container.
11. M. Jones (15 August 2013). Market access for Californian grapes was granted by the Dept. of Agriculture and Food for Western Australia, despite opposition of Western Australian grape growers, concerned about the spread of the fungal disease *Phomopsis viticola* as a result of the imports.

Global horticultural trade is also influenced by "private" regulations, viz. regulations within a supply chain. For example, the same issues of *Asia Fruit Magazine* record the following issues:

1. G. McShane (2 April 2013). Chilean growers have established a national set of guidelines aimed at establishing the nations' export credentials in the area of sustainability.
2. C. Collen (20 March 2013). Maersk Line reported reaching an energy efficiency target of a 25% reduction in CO_2 emission per container kilometer "eight years early", and that it now targets a 40% reduction by 2020.

V International trade regulation

The following section briefly describes the framework in which regulation of fresh produce quality operates.

A The World Trade Organization (WTO)

The WTO acts in the field of regulation related to free trade. Support programs that stimulate production directly and import tariffs on imported product must be reduced for a nation to participate in the WTO (Agriculture Agreement) framework, on the basis that such policies advantage domestic production over imports or result in "dumping" of product on world markets (World Trade Organization, 2007). The strengthening of the New Zealand horticultural sector following deregulation represents an apparent success story for this thesis (Bell and Elliott, 1993).

WTO members were required to estimate the annual value of agricultural production support ("total aggregate measurement of support") for the base years of 1986–88. Developed countries agreed to a 20% reduction of the support level over six years from 1995, while developing countries agreed to a 13% reduction over 10 years, and least-developed countries were not required to make any reduction.

Programs that are not considered to have a direct effect on production (e.g., a nationally funded R&D program, an infrastructure program or a food security program) are exempt from this process. Certain other payments made directly to farmers that do not directly stimulate production, such as drought support, industry restructuring programs, payments to limit production and environmental and regional assistance programs, are also exempted. Qualified government assistance programs to encourage agricultural and rural development in developing countries are also exempt, as is other small scale support (5% or less of the total value of the product in the case of developed countries and 10% or less for developing countries).

The inherent expectation is that developed countries should have no import restriction on, or production support for, horticultural produce. The major barrier to trade, then, becomes quarantine or food safety issues. Of course, there are always gray areas, with good scope for legal maneuvering between trading nations! Sound science on the underlying quarantine issues is required to achieve a rational outcome. However, incomplete or bad science may be used to justify trade restrictions. Resolution of such issues typically involves diplomatic trade-offs, involving a compromise on one trade issue in order to achieve success on another. The resolution process is effectively beyond the capacity of a marketing or industry group, and relies upon government support, and, thus, on political lobbying by industry groups for allocation of resources. For example, in the 1990s, the export of Philippine grown mangoes to Australia was blocked on the basis of the potential to import mango seed weevil into Australia. The Philippines subsequently blocked importation of live cattle from Australia, a likely retaliatory measure. Australian aid funds were sourced to assist in the development of processes to disinfest mango shipments of seed weevil. Fresh mango fruit may now be imported into Australia from the Philippines (DAFF, 2013b).

To resolve trade disputes the WTO provides a forum (court) for "independent arbitration". For phytosanitary related disputes, such decisions come down to a risk analysis on the possibility of transfer of a pest or pathogen. For example, the United States and New Zealand have long sought to export apples to Japan and Australia, respectively, but in both cases have been blocked on the basis that the apple disease fireblight exists in the United States and New Zealand, but not in Japan and Australia. Controversy exists on the technical side as to whether fireblight can be transmitted via the fruit alone. The mechanism in such actions is that a trading body will propose to market fruit, in this case from the United States or

New Zealand to Japan or Australia. This proposal will be vetted by the quarantine service and production associations of the importing nation and may be opposed on scientific grounds (e.g., the risk of introducing fireblight disease). The technical merits of this objection may be argued against by, typically, a government-supported research agency from the country of origin (the USDA and Plant and Food Research NZ in this case). If the matter is not resolved between the parties, the case may be taken to the WTO for a ruling. Such rulings may be appealed, so the process typically takes many years to resolve. Responding to a 2003 WTO ruling, Japan allowed for import of mature symptomless fruit from fireblight affected areas, but required field inspections of United States orchards by Japanese inspectors three times a year. Compliance complexity and cost effectively prevented any trade. This requirement was removed by a WTO ruling in 2005. Following challenges through the WTO, New Zealand achieved access to the Australian market in 2011.

B International bilateral trade agreements

Governments may negotiate trade agreements outside of the general WTO framework. Typically this involves a compromise between the parties, with reduction in regulatory and tariff barriers in various commodity classes. For example, in the 2004 United States–Australia free trade agreement (Australian Government – Department of Foreign Affairs and Trade, 2013), Australia agreed to provide immediate duty free tariff treatment on all incoming United States fruit imports, removing a 5% tariff, and to resolve outstanding phytosanitary issues, e.g., for apples, Florida citrus and stone fruits. The United States agreed to grant duty free access for over half of the listed fruit, including oranges, tree nuts, mandarins and strawberries, and to phase out import tariffs (from rates as high as 30%) on the remaining fruit products, including pecans, dried apricots, peaches, pears and canned fruit over the next 4–18 years, while maintaining phytosanitary restrictions on many fruits, such as avocados and tropical fruit. Presumably, the seeming imbalance in this agreement with respect to trade in fruit was balanced by the terms of other areas.

VI A language for regulation

The success of a regulation exercise rests on the ability of participants to understand the intended requirements. As noted earlier, many countries have entered free trade agreements reducing tariff barriers to trade, but quality and food safety standards have served to moderate the flow of imported product. Obviously, the resolution of disputes between trading partners is likely to be less contentious if all parties are using a "common language".

Grade standards can improve marketing efficiency by providing a common language for the understanding of the product to both sellers and buyers

(Florkowski, 1999). This comment is valid for communication both "up" and "down" the value chain. For example, the producer must be able to interpret and effectively measure the standards set by a retailer, while the retailer must set meaningful standards and adjust these standards according to production limits. However, the value chain effectively consists of a series of tribes trading with each other, with each of these tribes varying in dialect or language. As well as being literally true in international trade, the metaphor here is in the "language" used by each group to describe their product, and, in particular, to describe quality in their product.

Production description languages are an attempt to use a common set of descriptors across the supply chain. Such documentation exercises may be simple and visual (e.g., a poster produced by a marketing organization detailing quality characteristics), through to complete manuals. The languages may be produced for use within a single value chain, for use at a national level (e.g., Story and Martyine, 1996), or for international use (e.g., OECD, 2013a).

In the context of mutual understanding for readers of this section, let us distinguish between a standard, a specification and certification. A standard is an agreed specification used as a "rule" for a level of performance. The significance of a standard is linked to the mechanism of its enforcement, a mechanism by which produce is certified to conform to the standard. A standard-setting body may also act in certification, or the two functions may be separated.

A Codex

The Codex Alimentarius Commission (CAC) was created in 1963 by FAO, the World Health Organization (WHO) and other bodies to develop food standards, guidelines and codes of practice, with the aim of protecting the health of consumers, ensuring fair trade practices in the food trade and promoting co-ordination of work on food standards (Codex Alimentarius Commission, 2013a). In these activities, the CAC acts as an aide to the WTO, allowing for the minimization of "the negative effects of technical regulations on international trade". The CAC aims to act as the internationally recognized body for food standards, with its norms being applied to the widest extent possible by all members as a basis for domestic regulation and international trade. The CAC has created a set of internationally agreed standards which are available for use in domestic regulation and international trade. Guidance is also provided to member countries on labeling and import/export inspection and certification systems. The CAC also offers advice on food safety management systems (e.g., Pineiro and Diaz, 2007).

The CAC does not conduct any direct technical work on standards, but rather it relies on expert Committees convened by FAO and WHO, and upon the technical work of member nations. For example, the Joint FAO/WHO Meetings on Pesticide Residues and the Joint FAO/WHO Expert Meeting on Microbiological Risk Assessments are independent of the CAC (Codex Alimentarius Commission 2013b).

The growth in global food trade has resulted in a substantial growth in membership of the CAC, with developing countries now accounting for a majority of total membership. To achieve agreement across all members, however, CAC product specifications can be a case of the lowest common denominator. The CAC has been successful, however, in the setting of maximum heavy metal, chemical residue and microbiological contamination criteria. Otherwise, Codex specifications generally relate to issues such as labeling of country of origin, fruit size and aesthetic issues, with attributes related to eating quality rarely included (table grapes being one exception, see Figure 8.5). Codex specifications exist for many processed (frozen, canned, dried, etc.) fruit and vegetables, and for pineapple, papaya, mango, prickly pear, carambola, litchi, avocado, limes, pummelos, guavas, chayotas, ginger, grapefruit, longan, asparagus, cape gooseberry, pitahayas, oranges, rambutan and table grapes (in order of appearance on the Codex web page) as fresh fruit. A focus, to date, on tropical fruit is obvious.

B The Organization for Economic Co-operation and Development (OECD)

The Organization for Economic Co-operation and Development (OECD) is a group of 34 countries (http://www.oecd.org/general/listofoecdmembercountries-ratificationoftheconventionontheoecd.htm, accessed 6 Oct 2013) committed to "democracy and the market economy" which acts to "facilitate international trade through the harmonization, implementation and interpretation of marketing standards". The OECD claims to be the "main reference for the certification and standardization of certain agricultural commodities". The OECD is active in developing standards in collaboration with the UNECE and Codex, offering a range of explanatory brochures of the standards, and in promoting uniform quality assurance and inspection systems, under its "Scheme for the Application of International Standards for Fruit and Vegetables" (including a methods manual on testing fruit and vegetable eating quality; OECD, 2013b). The OECD and UNECE standards on fresh fruit and vegetables are identical, with the OECD website on these standards (OECD, 2013a) linked to that of UNECE (2013a).

C The United Nations Economic Commission for Europe (UNECE)

The UNECE was established in 1947 and includes the countries of North America, Europe and Russia. UNECE reports to the United Nations Economic and Social Council. Within UNECE, the "Specialized Section on the Standardization of Fresh Fruit and Vegetables" is part of the Working Party on Agricultural Quality Standards. This body sets standards on fresh fruits and vegetables intended for application at the point of export, and so informs the CAC (United Nations Economic Commission for Europe, 2013b).

The function of this body is illustrated by summarizing the outcomes of one of its meetings (United Nations Economic Commission for Europe, 2013c).

CODEX STANDARD FOR TABLE GRAPES (CODEX STAN 255-2007)
1. DEFINITION OF PRODUCE
2. PROVISIONS CONCERNING QUALITY
2.1 MINIMUM REQUIREMENTS: the bunches and berries must be practically free of pests and damage caused by them.
2.1.2 Maturity Requirements
Table grapes must display satisfactory ripeness. In order to satisfy this requirement, the fruit must have obtained a refractometric index of at least 16° Brix. Fruit with a lower refractometric index are accepted provided the sugar/acid ratio is at least equal to:
(a) 20 : 1 if the Brix level is greater than or equal to 12.5° and less than 14°° Brix,
(b) 18 : 1 if the Brix level is greater than or equal to 14° and less than 16°° Brix.
2.2 CLASSIFICATION
2.2.1 “Extra” Class: Table grapes in this class must be of superior quality.
2.2.2 Class I: Table grapes in this class must be of good quality.
2.2.3 Class II: Table grapes which do not qualify for inclusion in the higher classes.
3. PROVISIONS CONCERNING SIZING: Size is determined by the weight of the bunch.
3.1 MINIMUM BUNCH WEIGHT: The minimum bunch weight shall be 75 g.
4. PROVISIONS CONCERNING TOLERANCES
4.1 QUALITY TOLERANCES
4.1.1 “Extra” Class: Five percent by weight of bunches not satisfying the class requirements,
4.1.2 Class I: Ten percent by weight of bunches not satisfying the class requirements,
4.1.3 Class II: Ten percent by weight of bunches satisfying neither the class or minimum requirements.
4.2 SIZE TOLERANCES: Ten percent by weight of bunches not satisfying the size requirements as specified in Section 3.
5. PROVISIONS CONCERNING PRESENTATION
5.1 UNIFORMITY: Packages of a net weight not exceeding 1 kg may contain mixtures of table grapes of different varieties, provided they are uniform in quality, degree of ripeness and, for each variety concerned, in origin.
5.2 PACKAGING: Grapes shall be packed in each container in compliance with the Recommended International Code of Practice for Packaging and Transport of Fresh Fruits and Vegetables (CAC/RCP 44-1995)
6. MARKING OR LABELING
6.1 CONSUMER PACKAGES
6.1.1 Nature of Produce: If the produce is not visible from the outside, each package shall be labeled as to the name of the produce and may be labeled as to name of the variety.
6.2 NON-RETAIL CONTAINERS
6.2.1 Identification : Name and address of exporter, packer and/or dispatcher. Identification code (optional).
6.2.2 Nature of Produce: Name of the variety or, where applicable, names of varieties
6.2.3 Origin of Produce: Country of origin, optionally, district .
6.2.4 Commercial Identification: Class, net weight (optional).
6.2.5 Official Inspection Mark (optional).
7. CONTAMINANTS: Produce shall comply with the maximum levels of the Codex General Standard for Contaminants and Toxins in Food and Feed (CODEX STAN 193-1995).
8. HYGIENE
8.1 Recommended International Code of Practice – General Principles of Food Hygiene (CAC/RCP 1-1969).
8.2 Comply with Microbiological Criteria for Foods (CAC/GL 21-1997).

FIGURE 8.5

Summary of the Codex specification for Table Grapes (www.codexalimenatrius.net, accessed August 2013).

The fifty-second session of the Specialized Section on the Standardization of Fresh Fruit and Vegetable was held in Geneva between May 16 and 19, 2006, attended by representatives of 16 European nations, Morocco, New Zealand, South Africa, Turkey and the United States (i.e., exporters of horticultural produce to Europe). The meeting considered modifications on UNECE standards on potatoes, melons, bilberries and blueberries, cherries, peaches and nectarines, table grapes, truffles and apples. For example, the "minimum maturity requirement" for peaches and nectarines was defined by the following criteria: "the refractometric index of the pulp measured at the middle point of the fruit flesh at the equatorial section must be greater than or equal to 8° Brix and the firmness must be lower than 6.5 kg measured with a plunger of 8 mm diameter (0.5 cm^2) at two points of the equatorial section of the fruit, with skin intact, except for fruits with Brix values greater than 10.5°, in which case firmness must be lower than 8 kg measured with an 8 mm diameter plunger".

Standards recommended by this group inform the OECD, Codex and GlobalGAP standards (see discussion below).

D National standards

Every trading country should maintain standards on the quality of traded horticultural produce. The standards should be, at a minimum, those of the Codex Alimentarius, and are likely to be informed by the OECD-UNECE standards. Each nation will differ in its mechanism of enforcing quarantine and food safety standards, with the Australian structure presented by way of example in this section. Going beyond these issues, the example of the national grade standards and inspection service offered within the United States and the additional regulation criterion of locality offered within Europe are also presented in this section. Finally, the specifications required in the national standards of a developing economy, the Philippines, are considered. Over time, all countries are likely to adopt similar standards.

Australia

Fresh fruit and vegetable quality is regulated in terms of quarantine and food safety issues by several federal government agencies, notably the Australian Quarantine Inspection Service (AQIS) and Food Safety Australia and New Zealand (FSANZ), respectively. Codex standards apply to all imported fresh fruit and vegetable, but Government based regulation of eating quality, per se, does not exist.

Food Standards Australia and New Zealand (FSANZ, 2013) is a regulatory body that defines maximum allowable chemical residue and microbial loads in fruits and vegetables. FSANZ does not monitor these levels, leaving this to state agencies or commercial practices. However, it can be involved in dispute resolution. This body is also responsible for the registration of chemicals for use on a given crop. As the cost of preparing a case for registration is high, this process is a major issue for horticultural crops of relatively low total farmgate value. An international standard on chemical registration would be very useful.

The Australian Quarantine Inspection Service (AQIS) is charged with the responsibility of preventing entry of unwanted fruit and vegetable pests and diseases into the country (Australian Quarantine Inspection Service, 2013a). The service also issues statements of compliance with specified treatments (e.g., vapor heat treatment) of produce destined for export markets. Within the country, quarantine issues are dealt with by State Agriculture Departments. For example, papaya fruit fly is a serious pest of tropical fruit that entered Australia through Cairns airport, presumably via a passenger carrying infected fruit and despite AQIS inspection. The state agriculture agency enforced bans on fruit transport through road blocks in concentric rings around Cairns until the pest was eliminated. Similarly, when citrus canker appeared on a mandarin farm in Emerald, Central Queensland, despite AQIS inspection of all imported equipment and budwood, the state agriculture agency enforced bans on fruit and equipment movement, and oversaw destruction of all citrus trees in a 200 km radius (Australian Quarantine Inspection Service, 2013b).

Other state and federal agencies maintain a watching brief on other issues. For example, frogs are frequently transported from tropical to temperate areas in banana shipments. The Melbourne markets are estimated to import around 6000 frogs of four species per year. It is believed that the fungus *Mucor amphibiorum* was introduced to Tasmanian platypii from "banana" frogs (Tasmania – Department of Primary Industries and Water, 2013).

As mentioned earlier, developed economy governments have largely exited from the enforcement of eating quality standards. However, this is not universal. For example, the Western Australia government (through its Citrus Fruits Grading Code, legislated in 2008) regulates maturity standards on citrus in terms of minimum Brix, Brix acid ratios and juice content (http://www.apcwa.org.au/committees/fruit-west-committee, accessed 29 August 2013).

The United States

The Agricultural Marketing Service (AMS) of the United States Department of Agriculture (USDA) began in 1915 with the aim of providing market information and common terminology for quality and the development of grade standards (Agricultural Marketing Service – USDA, 2007b). Given their experience and technical capacity, the AMS has contributed significantly to the development of international produce standards, e.g., Codex and UNECE.

The United States Inspection Service acts to apply these fruit and vegetable standards, and was established in 10 of the largest wholesale markets in 1917. The Service arranges the domestic inspection of fruit and vegetables, both for sellers and for buyers, to ensure that products meet specific grade standards. There are 158 grade standards for 85 fresh fruits, vegetables and nuts. Inspections are generally voluntary, made at the discretion of either the seller or buyer, and paid for by user fees. However, inspections are mandatory for fruit purchased by government agencies. Clients can request a quality and condition inspection, a condition only inspection, or a container weight/count only inspection. A quality and condition inspection of a product "in quantities of 51 or more packages... unloaded from the same land or air conveyance, over half a carlot equivalent product" is priced at US$114 (Agricultural Marketing Service – USDA, 2013b).

The European Union

Pascale (1992) reviewed the wider issue of the impact of EEC regulations on quality on trade in fresh fruit and vegetables. The European Food Safety Authority is the primary source of regulations on fruits and vegetables, e.g., maximum residue limits and for health claims. The European Community has also regulated the labeling of food by geographic or traditional origin (European Commission, 2013). Three categories are recognized: Protected Designation of Origin (PDO), Protected Geographic Indication (PGI) and Traditional Speciality Guaranteed (TSG). PDO describes foodstuffs produced, processed and prepared in a given geographical area using recognized know-how. For PGI, a geographical link to one of the three stages of preparation must be demonstrated. To achieve designation, a case must be supported by the relevant national government and approved by the European Commission, Agriculture/Food quality section. Well over 100 PDO/TSG assignments have been granted for fruit and vegetables (European Commission, 2013).

The Philippines

As a horticultural trading country, the Philippines maintains national standards on a range of fruit and vegetables. For example, The Philippine National Standard on Mandarin (Philippine National Standards, 2013) details specifications on fruit diameter, defects, packaging, color, juice total soluble solids (or Brix), juice total acidity, juice Brix to total acidity ratio and minimum percentage juice content as a maturity requirement. These standards are informed by existing standards (e.g., USDA-AMS and UNECE). Allowable levels of heavy metal and pesticide residues are directly referred to those set by the Codex Alimentarius Commission.

VII Regulation within a supply chain

A given supply chain must adapt to suit the trading environment set by governmental and value chain regulations. In a free market, there will be constant "evolutionary pressure" between rival value chains to capture market share. Large retailers will often engage at least two "produce supply managers" for each commodity. The resulting competition involves differentiation of product in terms of price, quality or some other aspect of the "offer". The successful supply chain will be disciplined in adherence to standards and robust in its ability to deliver quantity and quality of fruit. To achieve this, a successful supply chain will impose "regulations" on its members, seeking to distinguish itself in some way.

For example, exclusive marketing rights to a variety that promises increased market share or premium price may be acquired. Participants agree to be bound by rules that may include the window and volume of production, the production and postharvest methods, and the marketing path. Alternately, a distinguishing technology may be (exclusively) acquired. For example, the SmartFresh™ quality system, developed in the United States, has been effectively and widely used by Australian producers participating in export programs to maintain consistent fruit quality (Good Fruit and Vegetables, 2007). In this system, fruit are treated with a chemical (1-methylcyclopropene, MCP) to delay the ripening process and improve shelf life.

Another component of fresh fruit and vegetable supply chain "self" regulation involves the reduction of risk associated with chemical safety and hygiene to consumers. Proactive action by the large retailers in this area also reduces the risk of provoking government imposed regulation. Supply chain members are required to participate in food safety management program schemes, which typically vary somewhat between retailers. Such programs become an important feature in the import/export process if they are recognized by supply chain participants and government regulators in both source and destination countries.

There are several food safety management programs utilized within the fresh fruit and vegetable sector. Ahold, Carrefour, Delhaize, Metro, Migros, Tesco and Wal-Mart, seven of the worlds' largest retailers, were reported to have agreed to use four global Food Safety Initiative schemes: BRC (British Retail Consortium Global Food Standard); IFS (International Food Standard); SQF 2000 (Safe Quality Food Scheme); and the Hazard Analysis and Critical Control Point (HACCP) Scheme (Asia Fruit Magazine, 2007). To take the HACCP program as an example: this program is used in the United States, Europe, East Asia and Australasia and is accessed through a project management company which designs, implements and manages the food safety program (e.g., HACCP Australia, 2013). In these programs, an analysis of what and where hazards can occur is made, and systems and procedures are implemented to minimize the risk of failure. Subsystems such as pest control, recall protocols, hygiene and sanitation are also implemented. For example, an analysis of a packinghouse operation might consider the risk of use of contaminated water in the fruit washing process, or the possibility of contamination of fruit from the breakage of a glass component in the pack-line. On-site operators and management are trained, and a maintenance/audit program involving HACCP personnel is implemented.

Such food safety programs need to consider likely sources of contamination. French (31 July 2013, www.asiafruit.com) reported a case in China in which 15 of 16 samples of PVC plastic wrap used on fresh fruit contained bis(2-ethylhexyl) adipate, some at "alarming" levels (23%). The contaminant may cause fertility problems and can migrate into wrapped food, particularly products with high fat levels. A Tongxiang company admitted using DEHA due to the price of raw materials to manufacture the wrap, reported at US$1305 per tonne for wrap using DEHA, compared with US$1957 for wrap using the permitted dioctyl adipate.

Another component of supply chain "self" regulation takes the form of a specification sheet (Figure 8.6), against which produce can be assessed. Generally, this specification is written for fruit and vegetables arriving at the retailer distribution center.

Typically, assessment of fruit against at least some of the specified criteria (e.g., juice Brix) at a retailer distribution center is haphazard. This is a function of

'The Fresh Food People' WOOLWORTHS

Produce Specifications

PRODUCT : **PEACH**

TYPE : **White Flesh**

VARIETY : **Donut®**

GRADE : **One**

	GENERAL APPEARANCE CRITERIA
COLOUR	*With cream-pink to red blush covering 20-80% of surface, background skin to be creamy green, internal flesh to be creamy white..*
VISUAL APPEARANCE	*Flat irregular surface donut shape with a thin skin and minimum fuzz level; no foreign matter.*
SENSORY	*Firm to touch, sprung not soft; min 11% TSS, not dry and woody; free of foreign smells and taints.*
	With need for stickers with PLU and product/variety name, or bar code when available, per Woolworths requirements.
SHAPE	*Flattened irregular distinctive Donut® saucer shape.*
SIZE	*In pre-ordered size per Woolworths requirements; uniform per tray. Diameter 57-80 mm*
MATURITY	*Harvested as the background surface changes to a creamy dull green and the surface colour brightens with sufficient maturity to achieve good development of sweet, juicy flavour and the required level of red blush at receival.*
	MAJOR DEFECTS
INSECTS	*With evidence of live insects.*
DISEASES	*With fungal or bacterial rots/scabs; no core rots/mouldy coreor signs of fungal infection (botyrtis).*
PHYSICAL / PEST DAMAGE	*With cuts, holes, punctures, cracks or wounds (that break the skin)*
	With deep, soft watersoaked bruises or discolouration (browning).
	With unhealed damaged stem ends due to stem pull.
TEMPERATURE INJURY	*With tissue shrivelling, softening; and browning of the stem cavity (heat damage).*
	With water-soaked, translucent areas (freezing damage).
PHYSIOLOGICAL DISORDERS	*With suture or stem end splits; no 'splitstone' with open stem end*
	With scalded, discoloured skin, which slips easily from the flesh (condensation injury).
	With dark discolouration of skin and flesh and skin shrivelling (cool storage breakdown).
	MINOR DEFECTS
PHYSICAL / PEST DAMAGE	*With slight depression/flattening of skin >2 sq cm.*
	With dry, healed skin scarring due to insect, bird or major hail damage affecting in aggregate >0.5 sq cm; no broken skin or unhealed scars.
	With bacterial spot >3 dry spots (1mm); not sunken & watersoaked.
SKIN MARKS / BLEMISHES	*With dark superficial skin marks/blemish, eg. limb rub, dipping injury (black lesions, mostly on red skin areas) affecting in aggregate >0.5 sq cm of surface.*
	With light superficial marks/blemish (not dark against background skin colour), eg. russet, affecting in aggregate >1sq cm.
	CONSIGNMENT CRITERIA
TOLERANCE PER CONSIGNMENT	*Total minor defects (within allowance limit) to be < 2 defects per item Total minor defects (outside allowance limit) must not exceed 10% of consignment. Total major defects must not exceed 2 % of consignment. Combined Total not to exceed 10%.*
PACKAGING & LABELLING	*Packaging as per Woolworths requirements. Labelling to identify grower or agents name/brand (plus growers name/code if via an agent), address, contents, grade/class, size and minimum net weight. Bulk Loose Product to identify 'Packed On' date (eg. Pkd DD/MM/YY) on outer carton and Pre Packed Product to identify 'Best Before' date on retail unit and outer pack. 'Best Before' date not to exceed 16 days from date of packing while providing not less than 12 days clear shelf life prior to expiry date.*
RECEIVAL CONDITIONS	*Compliance with Quarantine Treatments (if required) for Interstate Consignment. Stacked to Ti Hi specifications onto a stabilised pallet as pre-ordered. Refrigerated van with air bag suspension, unless otherwise approved. Pulp Temperature 6 – 13 °C for Receival.*
CHEMICAL & CONTAMINANT RESIDUES	*All chemicals used pre/postharvest must be registered and approved for use in accordance with the requirements of the NRA regulatory system. Contaminants and Heavy Metals to comply to the FSANZ Food Standards Code A 12 – A 14 MPC's and MRL's.*
	Specifications reviewable: eg. to account for specific regional effects or adverse seasonal impacts on quality or early or late seasonal variances as agreed with each state operation and communicated formally in writing by Woolworths.

FIGURE 8.6

Specification sheet for peaches from an Australian retailer, as available from http://www.wowlink.com.au/wps/portal (Topic Center).

the effort required to effect a representative sample and to measure the desired criteria of a statistically significant number of samples. Unfortunately, enforcement of specification criteria may be used within a supply chain to regulate supply, i.e., the specification may only be enforced when product is in over-supply. If enforcement is sporadic, the supply chain will largely ignore the criterion. If enforcement is consistent, a strong incentive exists for the grower/packer/supply chain agent to adopt systems to ensure that the criterion is addressed.

Valero and Riuz-Altisent (2000) describe a quality control system for fruit quality intended for implementation at the retailer distribution center which involves statistical sampling protocols and quantitative measures of quality attributes, including fruit firmness, temperature, skin color, juice total soluble solids content and juice total titratable acidity. This system represents an “ideal” – the reality at a retailer receival warehouse is more likely to be a small table at which a few fruit are sporadically cut and visually assessed.

A GlobalGAP (EurepGAP)

EurepGAP, now known as GlobalGAP, was initiated by European retailers as a means of ensuring that a product was safe, of high quality and produced in a humane and environmentally sound way. It is also required that product be traceable from its point of origin in terms of all treatments. The specifications set in this scheme are thus tighter (extending to eating quality determinants) and broader (extending to social and environmental issues) than those set by the CAC.

The GlobalGAP certification requirement was originally imposed onto producers wishing to access the large European retailers, but GAP certification now serves a wider purpose. The commonality of the GAP programs in different countries allows it to act as an international standard. Thus, this certification scheme is becoming a global market requirement in the fresh produce trade. GAP certification can be a tool to ensure access to global markets.

GlobalGAP certifiers can inspect conditions and product in the country of origin, or a local version of GlobalGAP can be certified by GlobalGAP, with the standard adapted to local conditions. Implementation of a local version of the standard, with certification of product undertaken by local bodies, reduces the cost of audit and inspection. For example, ChinaGAP, J-GAP and ThaiGAP have been established in China, Japan and Thailand, respectively (e.g., www.thaigap.org).

To achieve GAP certification for products, farmers must invest in systems to comply with the standard and pay for independent verification of compliance. The processes and documentation required by GlobalGAP thus factors against the involvement of small producers. Hey (2007) reported that GlobalGAP accreditation in Thailand was driven by a few large private export companies and involved only 300 agricultural suppliers, but that, through ThaiGAP, the Thai government intended to provide support to eight clusters of growers across five regions, with certification documentation services supplied to poorly educated grower groups.

In 2011, Thailand halted export of 16 vegetable types after quarantine pests were frequently found in exports to the EU, in a bid to avoid a complete ban, which proved to be an incentive for the uptake of ThaiGAP. ThaiGAP was benchmarked for GlobalGAP Integrated Farm Assurance Standard Version 4 in early 2013 (http://www.globalgap.org/uk_en/media-events/news/articles/, accessed 4 October 2013).

B Organic certification

Another area of differentiation is in organic certification. Both production and postharvest practices must be certified as "organic". Thus organic produce loses this status if quarantine provisions require it to be fumigated.

Certification agencies confirm compliance to organic standard requirements. However, there is more than one standard – a situation that has arisen as the organic industry has developed "from grass roots", forming several industry associations which have established their own standards and certifying bodies. A useful list of standards and certifying bodies can be found at http://organic.com.au/standards/, although this list is likely to be very incomplete. Multiple standards (Figure 8.7) are confusing to the marketplace and there is a trend towards

Fresh Herbs

Item		Size	Price	Quantity Required	Certification
Organic parsley - curly		Bunch	$2.90		ACO 3114A
Organic rosemary	*local*	Bunch	$2.00		NASAA 4069A
Organic coriander		Bunch	$2.90		
Organic basil	*local*	Bunch	$2.00		ACO 10071A
Organic lemongrass	*local*	Bunch	$2.00		NASAA 4069A
Organic garlic chives	*local*	Bunch	$2.00		ACO 10071A
Organic thyme	*local*	Bunch	$2.00		ACO 10071A
Organic garden mint	*local*	Bunch	$2.00		ACO 10071A
Organic oregano	*local*	Bunch	$2.00		ACO 10071A
Organic ginger		1kg	$12.90		NA 4013A
Organic Russian garlic		1kg	$29		NA 4013A

Fresh Fruit

Item		Size	Price	Quantity Required	Certification
Organic apples – gala		1kg	$6.90		ACO 4552A
Organic apples – pink lady	**New season!**	1kg	$7.90		ACO 4552A
Organic apples – granny smith		1kg	$6.90		ACO 4552A
Organic apples – red delicious		1kg	$5.50		ACO 4552A
Organic bananas – Cavendish		1kg	$5.20		OGA 731A

FIGURE 8.7

Excerpt from order form of "Mary's Home Delivered Organic Fresh Food, Product Price List and Order Form, 5 June 2007" (Yeppoon, Australia), now trading as LillyPilly Organics (http://lillypillyorganics.com.au/why-organic/, accessed 23 August 2013). Certification column refers to organic certification.

standard consolidation (Lockie et al., 2006; also see the useful review at http://en.wikipedia.org/wiki/Organic_certification).

This consolidation of standards is coming from two directions — (i) through the organic "movement", e.g., through the International Federation of Organic Agricultural Movements, a German-based international NGO, with the setting of a private standard that is recognized by all major trading blocs, and (ii) through governmental agencies within and between countries.

IFOAM introduced the IFOAM Family of Standards in 2011 in an attempt to simplify harmonization. This action was intended to establish the use of a single global reference (the Common Objectives and Requirements of Organic Standards, COROS), rather than focusing on bilateral agreements (http://www.ifoam.org/en/ifoam-norms).

Some countries have consolidated certification at a national level. For example, the United States, the European Union, Canada and Japan all have organic standards which are formulated and overseen by the government, and the term "organic" may be used only by certified producers. In the USA, these organic standards are implemented by the USDA (USDA Certified Organic), and the common standard allows interstate trade under an "organic" label. A fine of $11,000 per instance is levied on a product carrying the label "organic" that is not certified.

Thus the major trading blocs are segregated by their use of different standards, such as the USDA Certified Organic (developing from the National Organic Program, NOP) in the United States, the EU standard (regulation 2092/91) and the Japanese Agricultural Standard (JAS) (Lockie et al., 2006). For example, the JAS organic certification system requires that no chemicals be used on-farm for three years prior to the start of organic production, in common with most standards. But, the JAS standard extends the definition of "chemical" to alkali humic acid, lignin sulfonate and potassium bicarbonate, items allowed in the US NOP organic certification. To export products to Japan as "certified organic", a certified United States producer must, therefore, arrange for a JAS certification of his operation. However, bilateral arrangements are developing. For example, a US–Japan mutual recognition of organic standards is set to come into play from 1 Jan 2014 (recognizing products produced in Japan and USA only, not recognizing the respective certifications per se). Other arrangements for bilateral recognition of the USDA organic standard are given at http://www.ams.usda.gov/NOP. If there is no agreement between two countries, exported organic product is usually certified by agencies from the importing country.

Biodynamic agriculture involves a more "fastidious" form of organic farming. The term *Biodynamic* is a trademark held by the Demeter association of biodynamic farmers and the biodynamic certification "Demeter", created in 1924, was the first certification and labeling system for organic production. The movement involves a network of national associations. As such, this production system has long enjoyed clear branding.

C Tesco – greenhouse friendly?

The past half century has seen the rise of the global retailers. These retailers dominate their supply chains and, therefore, can drive (regulate) change. In driving change, the retailers often seek to reflect rather than influence public attitudes, with the timing of the change linked to a judgment of when a specific value client group appears sufficiently large and cohesive. For example, when public attention swung to the issue of greenhouse gases and global warming, Tesco, the UK based trans-national retailer, announced their intent to label air freighted produce with an aeroplane symbol in 2007, and ramped up to a commitment to introduce a carbon labeling system on all products (with this calculation to include emissions due to production, transportation, storage and packaging) in 2008 (Tesco, 2013). However, the data and assumptions required for such an exercise are not trivial, and in 2013 Tesco announced in would discontinue the program, perhaps in parallel with a decrease in public focus on this issue.

VIII On the regulation of eating quality

A Setting and maintaining eating quality standards on fresh produce

We have seen that national and international standards on fresh fruit and vegetables focus on issues of food safety and external appearance. In contrast, standards on eating quality have been sporadically enforced. Indeed, eating quality is often not considered within discussions of "fruit quality" or "vegetable quality". For example, in the specific context of citrus, Fellars (1985) concedes that the words "flavor" and "flavor quality" often appear in the literature without associated sensory ratings for quality or palatability. Similarly the text, "Quality Factors of Fruits and Vegetables" (1989), edited by Jen, features a broad range of topics relating to the processing of fruit and vegetables, but offers little on quantitative levels of components related to eating experience, and does not report any minimum standards. The text "Fruit and Vegetable Quality" (2000), edited by Shewfelt and Bruckner, details a range of concepts, from breeding to economics, but again does not address the issue of measurement of internal eating quality or the setting of minimum standards. This situation is addressed by the more recent text "Fruit and Vegetable Flavours" (2008), edited by Bruckner and Grant Wyllie, in which attempts to define and set flavor standards are documented.

B Defining eating quality

Setting a quality standard to deliver eating quality in a consistent fashion requires the use of quantitative, but easily measurable, characters that can be correlated to eating quality. The primary measurable attributes of a fruit that can be related to taste are texture (commonly indexed as firmness), total sugar content (measured as percent total soluble solids, TSS, or Brix, in juice extracted from the fruit), type of sugar present (fructose elicits a greater sweetness sensation than sucrose), and in certain fruit, acidity (sourness sensation). Volatile and semi-volatile organic compounds also impact the flavor and aroma of foods. However, analysis of volatiles can be a “daunting task, and obtaining useful information from such measurements can be even more challenging” (Marsili, 1997). In some fruit, starch is accumulated during maturation and converts to sugar during ripening. For these fruit, starch (or dry matter content, DM) at fruit maturity is a useful guide to fruit sugar content at ripeness, and, thus, to potential eating quality. In other fruit, other parameters are of importance (e.g., oil content in avocado fruit).

The importance of these various parameters will vary by fruit, but firmness and TSS and/or DM content are arguably the most important general criteria. TSS and/or DM are easily measured attributes and, therefore, the logical criteria upon which to establish a quality control (QC) procedure. A “layman’s guide” to the value of fruit Brix testing has been given by Harrill (http://www.crossroads.ws/brixbook/BBook.htm, accessed 29 August 2013).

C Who enforces eating quality standards?

Historically, the advent of the central marketing system allowed the imposition of a more formal (often government sponsored) regulatory system. For example, Fellers (1988) reported that early in the pineapple industry, Queensland government inspectors attempted to enforce a minimum flesh TSS standard (of 12% for summer harvested fruit and 10% for winter harvested fruit), through random inspections of fruit in the Brisbane Central Market. Similarly, Greer (1990) detailed Queensland’s then current legal requirement for lychee fruit, being a minimum TSS to acid ratio of 35:1. Fruit could be destroyed if they did not meet this grade. We discussed the advent in 1915 of the voluntary AMS grade standards in the United States earlier.

The emergence of “super” retailers, with direct purchasing from producers, has worked to weaken the central market system and associated broad regulatory structures. For example, current Queensland Department of Primary Industries (QDPI) recommendations (Menzel et al., 2001) for these fruit exclude internal quality grade standards, and only describe external attributes. As noted earlier, however, supply chains, driven by the large retailers, have developed their own formalized quality control systems that extend to the setting of standards on eating quality criteria.

However, it is an observation that, except in Japan, retailers inconsistently, even rarely, enforce their internal quality specifications. Enforcement occurs only when a sufficiently large proportion of the consignment is affected by a disorder that would provoke severe consumer dissatisfaction (e.g., brown core in apples), or when the supply chain is oversupplied. In large measure this behavior can be ascribed to the relative difficulty of assessing fruit for internal attributes. Advances in technologies that allow for sorting of internal parameters (particularly defects such as internal browning) will likely lead to the setting of relevant specifications by retailers.

In the following sections specification levels for a range of commodities are considered, and issues related to enforcement of such specifications are discussed.

D Setting the eating quality standard

There exists a considerable body of published work on the relationship of fruit eating quality to measurable attributes such as TSS. This literature covers factors such as market differentiation (different grade standards for different market segments) and the influence of flesh firmness and acidity on perceived sweetness. However, it is possible to summarize this literature in terms of a minimum level for various attributes, by commodity, to achieve an acceptable eating quality (Table 8.1).

The human palate is able to differentiate between fruit varying by 1−2% TSS. To generalize hopelessly, a TSS level of at least 10 is required for the fruit to taste sweet, but this value does vary by commodity. As noted above, this value can also vary by consumer group (e.g., Crisosto, 1994; Crisosto et al., 2007).

The setting of official and product supply chain specifications on eating quality attributes should be informed by the scientific literature. For example, the specifications of a national body, the Australian United Fresh Fruit and Vegetable Association (AUF), and those of two international bodies, the Codex Alimentarius Commission and UNECE, show general agreement (Table 8.2). There is, however, room for greater consistency between these bodies. In particular, the Codex specifications need to be expanded as they generally do not cover internal (eating) quality attributes.

A given distribution channel may also specify attributes associated with eating quality. Typically such specifications are set by the retailers on advice from the value chain manager, and by reference to the official standards. A typical product specification used in horticultural trade covers a range of features (e.g., Figure 8.6). For example, a product specification from the retailer Woolworths for peach and nectarine covers size, pack count per box, firmness (as measured with an 8 mm diameter probe), sugar (percent TSS of extracted juice), pulp temperature, blemish incidence, skin color, skin shriveling, flesh color, split stones and foreign taints or odor. Of these 11 features, only two relate directly to internal eating quality (firmness and percent TSS).

The general level of agreement between specifications set on eating quality attributes by three major Australian retailers (Table 8.3) indicates that these retailers are not seeking differentiation on the basis of product eating quality.

Table 8.1 Examples of Specifications on Eating Quality Attributes, as Recommended in the Scientific Literature

Fruit	Climacteric	Attribute	Level	Reference
Avocado	+	DM (at harvest)	21	Agrilink (2001)
		Oil	8% FW	Seymour and Tucker (1993)
Banana	+	TSS	6.7–12.7 (unripe) 23.0–31.0 (ripe)	Choon and Choo (1972)
		Fullness index	Variable per cultivar	Samson (1989)
Citrus	–	TSS : acid	8 : 1–10 : 1	Baldwin (1993)
		Limonin	≤ 6 ppm	Davies (1986)
(Grapefruit)		TSS : acid	6 : 1	Kader (2002)
(Mandarin)		TSS : acid	8 : 1	Kader (2002)
(Orange)		TSS : acid	8 : 1	Kader (2002)
			10 : 1–16 : 1	Samson (1989)
			Navels: 7.5 : 1–9.0 : 1	Davies (1986)
		Juice content	50% FW	Samson (1989)
Grape – table	–	TSS	Ribier, Red malaga, Emperor 16; other 17	Weaver (1976)
		TSS : acid	Thompson seedless, Malaga, Ribier 25 : 1	Weaver (1976)
			Muscat, Emperor, Cornichon, O'Hanez 30 : 1	Weaver (1976)
Kiwifruit	+	TSS (at harvest)	6.2	Given (1993)
		TSS (ripe)	14	Kader (2002)
			15	Mitchell et al. (1991)
		TSS (for long-term storage)	7–9	Sale (1985)
		Firmness (8-mm probe)	0.71	Cheah and Irving (1997)

(*Continued*)

Table 8.1 (Continued)

Fruit	Climacteric	Attribute	Level	Reference
Lychee	−	TSS : acid	35 : 1	Greer (1990)
			30 : 1–40 : 1	Underhill and Wong (1990)
		TA	4.4 cmoH^+/Kg	Batten (1989)
Mango	+	TSS	15	Yamashita (2000)
			16	Satyan and Chaplin (1986)
			12	Samson (1989)
		DM (at harvest)	14	Bally et al. (2000)
		Specific gravity	1.01–1.02	Samson (1989)
		Firmness	1.75–2 kg/cm^2	Samson (1989)
Melon	+	TSS	10	Mutton et al. (1981)
		Firmness (8-mm probe)	1–2	Mutton et al. (1981)
Papaya	+	TSS	11.5	Sankat and Maharaj (2001)
Pineapple	−	TSS	14	Smith (1988b)
			12	Bartholomew (2003)
		TA	≤ 1.0%	Kader (2002)
		TSS : acid	20 : 1–40 : 1	Bartholomew (2003)
		TSS : citric acid	19 : 1	Bartholomew (2003)
		Translucency	Optimum 50–60% cross-sectional area	Bowden (1969)
		Specific gravity	0.960–1.004	Smith (1984)

Pome fruit	+			
(Apple)		TSS	Jonathan 11; Delicious and Red Delicious 10	Australian Horticultural Corporation (AHC, 1999)
			12–14 (ripe)	Harker et al. (1997)
			Starking and Delicious 10.8–12.2	Truter and Hurndall (1988)
			High quality dessert 14–16, cooking 11–13, Delicious and Spartan: 9–11	Goodenough and Atkins (1981)
		TSS (storage)	Delicious 10; Bonza 13; Golden Delicious 12; Gala 12.5; Granny Smith 12; Fuji 13; Pink Lady 15; Sundowner 14.5; Lady Williams 14.5	AHC (1999)
		pH	High quality dessert 3.2–3.5, cooking 2.8–3.2, Delicious and Spartan 3.5-3.7	Goodenough and Atkins (1981)
		Firmness	5.5 at sale, 6.5 storage	AHC (1999)
(Pear)		TSS	12 (at optimal firmness, suitable TSS : acid ratio)	Harker et al. (1997)
			13	Kader (2002)
		Firmness	Highly liked at 0.6–1.5; optimum at sale 1.3–1.5	Harker et al. (1997)
		TSS : acid	2.85 : 1–3.31 : 1	Kappel et al. (1995)
Stone fruit	+			
(Apricot)		TSS	10	Kader (2002)
		TA	0.8	Kader (2002)
(Cherry)	–	TSS	14–16 depending on cv.	Kader (2002)
(Nectarine)		TSS	10	Brady (1993)
			11	McGlasson (2001)
		TA	0.6	Kader (2002)
		Firmness	0.9–1.4	Crisosto (1994)

(*Continued*)

Table 8.1 (Continued)

Fruit	Climacteric	Attribute	Level	Reference
(Peach)		TSS	10	Brady (1993)
			11	McGlasson (2001)
		TA	0.6	Kader (2002)
		Firmness	0.9–1.4	Crisosto (1994)
(Plum)		TSS	11	McGlasson (2001)
			12	Kader (2002)
		Internal breakdown/ TSS	Amber jewel 17% TSS for less internal breakdown)	Ward and Melvin-Carter (2001)
		TA	0.8	Kader (2002)
		Firmness	0.9–1.4	Crisosto (1994)
Strawberry	–	TSS	7	Kader (2002)
		TA (citric)	0.8	Kader (2002)
Tomato	+	Moisture content	>94% w/w	Hobson and Davies (1971)
		Firmness	1.0–1.5	Kader and Morris (1976)

Attributes of dry matter (DM), juice content, total soluble solids (TSS), total acidity (TA), moisture content and firmness are reported. DM, juice content and TSS are minimum specifications; TA and firmness are maximum specifications. Units on DM, juice content, TSS and TA as %w/w, %w/w; %w/v of extracted juice, mg/l in extracted juice, and kg/f with an 8-mm diameter plunger, respectively, except where otherwise stated.

Table 8.2 Official Grade Standards on Eating Quality

Fruit	Attribute	UNECE/OECD	Codex	AUF (1996)	US (California)
Avocado	DM at harvest	Hass 21 other 19	–	<21; 21–23; >23	≥ 18.4–21.9 depending on cv.
Banana	–	–	–	–	–
Citrus					
(Grapefruit)	Juice content	–	35	–	–
(Lemon)	Juice content	25	–	30	≥ 28–30 depending on cv.
(Lime)	Juice content	–	42	–	–
(Mandarin)	TSS	–	–	8	–
	TSS : acid	–	–	8 : 1	6.5 : 1
	Juice content	33	–	28	–
(Orange)	TSS	–	–	7–9; 10–11; >11	–
	TSS : acid	Israeli market: pigmented 5.5 : 1 other 6 : 1; European market 6.5 : 1	–	Navel 8 : 1; other 8.1; 8 : 1–10.1; >10 : 1	8 : 1
	Juice content	Israeli market: Navel ≥ 30; other ≥ 35; European market: ≥ 38	Navel ≥ 33; other ≥ 35	Navel ≥ 30; other ≥ 33	–
Custard Apple	–	–	–	–	–
Grape – table	TSS	–	–	–	14.0–17.5 depending on cv.
(Seedless)	TSS	14	–	≤14; 15–16; 17; ≥18	
(Seedless)	TSS : acid	–	–		≥ 20 : 1
(Seeded)	TSS	13 (12 some cv.)	–	≤14; 15–16; 18; >18	
Kiwifruit	TSS (at harvest)	6.2	–	6	6.5
	Firmness	–	–	1.0; 1.5; 2.0; 2.5	–

(Continued)

Table 8.2 (Continued)

Fruit	Attribute	UNECE/OECD	Codex	AUF (1996)	US (California)
Lychee	–	–	–	–	–
Mango	DM	–	–	14	–
Melon	TSS	10 Charentais; 8 other	–	Honeydew ≤10; 10–12; >12	Cantaloupe >8.0, >9.0
				Rockmelon ≤ 9; 9–12; >12	Honeydew 10
Papaya	–	–	–	–	–
Pineapple	TSS	12	12	<10; <12; >12	–
Pome Fruit					
(Apple)	TSS	–	–	Fruit for storage ≤10; 11; 12; ≥13	Jonathan 12
		–	–	Immediate sale <10; 10; 11; ≥12	Red Delicious 11.0
	Firmness	–	–	Fruit for storage ≤ 5.5; 6.0; ≥ 6.5	Jonathan 8.6
				Immediate sale ≤ 5.5; 6.0; ≥ 6.5	Red Delicious 8.2
(Pear)	TSS	–	–	–	13
	Firmness	–	–	–	10.4
Stone Fruit					
(Cherry)	TSS	–	–	–	≤14–16 dep cv.
Strawberry	–	–	–	–	–
Tomato	–	–	–	–	–

Attributes and units as for Table 8.1. Where a single value is presented, only two grades exist (unacceptable/acceptable). Where further values are presented, a number of grades are possible.
Sources: UNECE (www.unece.org/trade/agr/standard/fresh/fresh_e.htm); Codex (www.codexalimentarius.net); AUF (Story and Martyine, 1996).

Table 8.3 Specifications on Eating Quality Attributes of Fresh Fruit, Except Apple, as Set by Three Australian Retailers (in 2004)

Fruit	Attribute	Australia i.	Australia ii.	Australia iii.
Avocado	DM	Hass 22–26; Shepard 23	21–35	–
	Firmness	–	–	–
Banana	Dry matter	–	–	–
	TSS	–	–	–
Blueberry	TSS	–	10	–
Citrus				
(Grape fruit)	TSS	9	9	–
	TSS : acid	–	4.8 : 1	–
	Juice content	35	33	–
(Lemon)	Juice content	30	10	–
(Lime)	Juice content	20	10	–
(Mandarin)	TSS	Ellendale 8; Honey Murcott, Imperial 10	9	10
	TSS : acid	Ellendales 7 : 1, Honey Murcott, Imperial 10 : 1	8 : 1; Clementine 7 : 1	–
	Juice content	33	33	–
(Orange)	TSS	Navel 11; Valencia 7	9	10
	TSS : acid	Navel 8 : 1; Valencia 7.5 : 1	8 : 1; Valencia 7 : 1	–
	Juice content	33	33; Navelina, Sevile 25	–
Custard apple		–	–	–
Grape – table	TSS	16; Thompson 18; Sweet White seedless 15; Muscatel White 20	16; Calmenia, Red Gum, Ribier 15; Cardmal, Italia, Marro seedless 17	15
	TSS : acid	Seedless: Sweet White 20 : 1; Crimson, Thompson 19 : 1; Stanley, Flame 18 : 1	18 : 1; Thompson 19 : 1	–

Attributes and units as for Table 8.1.

E Examples of eating quality standards

In the following section, specifications related to eating quality standards are considered for two widely traded commodities, apple and stonefruit, in terms of the scientific literature, intergovernmental and NGO standards and retailer specifications.

Pome fruit – apple

It is generally accepted that fruit total acidity (TA), TSS and firmness of flesh are important eating quality factors for apples (e.g., Chen and De Baerdemaeker, 1993; Yahia, 1994; Harker, 2001; Harker et al., 2003). Malic acid is responsible for the sour and acid taste in apples (Yahia, 1994). Harker (2001) reported a close relationship between TA and acid taste in apples, although the relationship between TA and consumer acceptability was cultivar specific.

Sweetness in apples is related to sucrose, glucose and fructose content, with 50% of the sugar present being fructose (Yahia, 1994). Eating quality specifications have historically been set in terms of TSS of extracted juice of ripened fruit. For example, Goodenough and Atkin (1981) recommend that high quality dessert apples should have a high TSS (14–16%) relative to "Delicious" and "Spartan" cultivars (9–11%). Harker (2001), however, contended that, while TSS is a good sweetness indicator for juices and other fruits, it is not for apple fruit. This contention is based on sensory research in which the relationship between perceived sweetness and TSS was poorer than the relationships between perceived texture and puncture force, or perceived acid taste and TA, in apple. This result is suggested to be due to the level of flavor volatiles that alter the perception of sweetness. Returning to the importance of carbohydrate levels to flavor development, Palmer et al. (2010) recommend fruit dry matter concentration as a new quality metric for apples. Nonetheless, apple TSS is widely specified in both official (Table 8.2) and supply chain (Table 8.4) standards, with greater differentiation by cultivar than seen for any other commodity. The minimum suggested TSS for apples ranges between 12–14% (Tables 8.1–8.4).

Apple crispness and juiciness are key attributes in determining consumer preferences. Harker et al. (2002) reports that penetrometer measurements are good predictors of such textural perceptions. Further, Harker et al. (2002) report that apples with a firmness level < 5.0 kgf (11 mm diameter probe) are more susceptible to the development of the mealiness (texture) disorder, while fruit with a firmness value > 7 kgf are effectively free of the disorder.

The Australian Horticultural Corporation (Table 8.2) recommends different flesh firmness and TSS levels depending on cultivar and whether the fruit is at point of sale or intended for long-term controlled atmosphere storage. For example, flesh firmness (measured using an 11 mm diameter plunger) of no less than 6.5 kgf was recommended for apples for long-term storage, and less than 5.5 kgf for fruit at point of sale. A Californian standard on "Jonathan" and "Red

Table 8.4 Specifications on Eating Quality Attributes for Apple Fruit as Set by Three Australian Retailers in 2004

Retailer	TSS			Firmness		
	i	ii In season (CA)	iii	i	ii In season (CA)	iii Feb–Aug (Sept–Jan)
Apple						
Abas	–	13	–	–	5.8–6.0	–
Akane	11.5	13	–	5.6	5.8–6.0	–
Bonza	12.6	12	12	5.6	5.3–5.5	5.5 (5)
Braeburn	14	15	11.5	6.5	5.8–6.0	6 (5)
Cameo	12	12	–	–	6.8	–
Cox Orange	–	14	–	–	5.8–6.0	–
Crofton	–	14	–	–	5.8–5.8	–
Firmgold	–	12.8	–	–	5.8–6.0	–
Fuji	13	14	13	5.6	5.6–5.8	6 (5)
Golden	12.5	–	12	5.5	–	6 (5)
Golden delicious	–	12.8	–	–	5.8–6.0	–
Granny Smith	–	11	12.5	–	6.3–6.5	6.5 (5.5)
Gravensten	–	12	–	–	5.8–6.0	–
Johnagold	13.6	14	13	6	5.8–6.0	6 (5)
Johnathan	12.6	11.5	13	5.6	5.6–5.8	6 (5)
Lady William	14	12.5	14.5	6.5	6.2–6.4	6.5 (6)
Matsu	–	11	–	–	6.8–7.0	–
Pink Lady	14	13.5	14	6.3	5.8–6.0	6 (5)
Red Delicious	12	12	10	6	5.8–6.0	6.5 (6)
Royal Gala	12.6	12	12	6.5	5.8–6.0	6 (5)
Stark Blushing Gold	–	12	–	–	5.8–6.0	–
Sundowner	13	12.8	14.5	6.5	5.9–6.1	6 (5.5)
Toffee Apple	–	11	–	–	–	–
Pear						
Buerre Bosc	13	11 (12)	–	6.3–8.0	6.0–9.0 (4.0–8.0)	–
Packham	11	–	–	6.0–8.0	–	–
Packham Ripe and Ready	13	12	–	4.0–4.5	4.0–6.0 (3.0–5.0)	–

(*Continued*)

Table 8.4 (Continued)

Retailer	TSS			Firmness		
	i	ii In season (CA)	iii	i	ii In season (CA)	iii Feb–Aug (Sept–Jan)
Red Sensation	11.5	–	–	6.0–8.0	–	–
Sensation	–	11	–	–	5.0–9.0 (4.5–8.0)	–
Sirrera	–	12	–	–	8.0–10.0 (5.0–10.0)	–
Sophia Pride	–	11 (12)	–	–	6.0–9.0 (4.0–8.0)	–
William	11	–	–	6.3–9.0	–	–
Ya	9	–	–	6.0–8.0	–	–
Other	–	11 (12)	–	–	6.0–9.0 (4.0–8.0)	–

Attributes and units as for Table 8.1. Retailer ii specified standards for fruit in season and for fruit going into controlled atmosphere storage (values in parentheses).

Delicious" apples sets a minimum TSS of 12 and 11%, respectively, and a maximum firmness of 8.6 and 8.2 kgf, respectively. Indeed, the specifications for Brix and firmness, by variety and stage of ripeness by a single producer/marketer are revealing (http://www.riveridgeproduce.com/FreshApples/Varieties/PressuresandBrix/tabid/69/Default.aspx, accessed 4 October 2013).

No specifications are set on eating quality related attributes in the UNECE or Codex guidelines. Arguably, these guidelines should contain such information, at least in the specification of premium grade fruit.

In contrast, Australian retail stores specify internal quality standards for over 20 cultivars of apples (Table 8.4). These specifications vary slightly between retail chains. For example, the minimum TSS standard required for "Akane" apples is 11.5% with one retailer, and 13% with another retailer (Table 8.4). However, in practice, there is no evidence that the retailers are attempting to differentiate their standard product on the basis of eating quality.

Stonefruit – peaches, nectarines and plums

The eating quality of peaches, nectarines and plums is usually described in terms of flesh texture and firmness, TSS and acidity. Sucrose is the dominant sugar in peach, nectarine and plum fruit, accounting for at least 80% of total sugars (Lill et al., 1989). The predominant organic acid in peaches and nectarines is malic acid (Lill et al., 1989).

Lill et al. (1989) suggested that flesh firmness in conjunction with background color was a reliable indicator of the picking maturity for peaches and nectarines, with a firmness of 5−7 kgf (11 mm plunger) recommended. Further, Crisosto (1994) reported that for peach, nectarine and plum, flesh firmness was a useful indicator of postharvest ripening. Peaches with a firmness rating of 2.7−3.6 kgf were "ready to buy", and "ready to eat" at a flesh firmness of 0.9−1.4 kgf.

As a specification of eating quality, McGlasson (2001) recommended a minimum of 11% TSS for peach, nectarine and plum fruit produced in Australia, while Kader (2002) suggested a minimum TSS of 10% for apricot and peach, 14−16% (depending on cultivar) for cherry and 12% for plum fruit. As noted earlier, Crisosto et al. (2007) has further differentiated consumer groups in terms of preferred TSS levels.

The commercial release of low acid lines of fruit, complimenting the traditional high acid varieties, represents a comment on consumer sweetness preference as much as a preference for low acidity. For fruit of a given TSS level, a lower acidity level increases the perceived sweetness.

Internal breakdown is a physiological disorder of stone fruit that negatively impacts eating quality. The disorder results from the abnormal ripening and early senescence of the fruit, with symptoms usually occurring during cold storage or during ripening after cold storage. Ward and Melvin-Carter (2001) reported that symptoms in plums appear as internal browning and gel breakdown. Fruit with TSS ≥ 17% were noted to have a significantly reduced risk of developing internal breakdown symptoms. They found that for "Amber Jewel" plums, the incidence of internal breakdown was minimized if the fruit were packed and appropriately cooled on the day of harvest.

UNECE stonefruit specifications (Table 8.2) are subjective, e.g., "they must be sufficiently developed and display satisfactory ripeness", and have not adopted any quantitative standards for internal eating quality factors. Similarly, Codex and AUF maturity grades are based on firmness descriptors ("hard", "firm," etc.), with infrequent mention of internal quantitative measures or recommendations (Table 8.2). Thus, comprehensive official specifications on eating quality do not exist, as yet.

Of the retailers surveyed, one provided comprehensive TSS and firmness standards on stonefruit compared to the other retailers, differentiating between cultivars differing in flesh color (Table 8.3). For example, the minimum TSS recommended for yellow flesh (10% TSS) nectarines was lower than that for white flesh (12% TSS) varieties, while the firmness standard of 5.2 kgf was common across all varieties. A second retailer gave only an "all-variety" minimum TSS of 10% and a firmness of 4 kgf, while a third retailer did not specify for TSS in stonefruit (Table 8.3). Of two European retailers surveyed (data not shown, personal communication), one held a minimum standard of 9% and firmness of 1.4−3.5 kgf for nectarines, while the second provided TSS grades for plums based on color (black plum: 12% TSS and 1.8−3.6 kgf; red: 10% TSS and 1.4−2.3 kgf; yellow 14% TSS and 1.0−1.8 kgf).

F Will it happen?

For the two widely traded commodities, apple and stonefruit, considered as examples above, it is evident that specifications on eating quality are inconsistent. Further, even where such specifications exist within a supply chain, enforcement is uncertain. Thus, these specifications are not standards. This conclusion is consistent with that of Florkowski (1999) who noted that "intrinsic quality attributes are not reflected in grading systems and are excluded from fresh produce standards". Florkowski (1999), continues "this gap leaves a place for government as a monitoring, regulatory or even enforcing agency", however such government action seems unlikely in developed countries.

In the last decade, a range of non-invasive technologies have become available for assessing the internal quality of fruit and vegetables (e.g., review by Abbott et al., 1997). For example, fruit firmness can be assessed using technology based on accelerometers, acoustic frequency or acoustic velocity. Ripeness can be assessed using electronic noses or volatile "badges". Chlorophyll florescence can be used for assessment of maturity. X-ray transmission systems can be used to visualize density-related internal defects, and near infrared spectroscopy is available for the assessment of carbohydrate or water content. With the advent of these technologies, there exists an opportunity to refine, adopt and enforce specifications related to eating quality.

A CASE STUDY – TECHNOLOGY ADOPTION AND REGULATION OF FRUIT TSS

Fruit has been traditionally graded by hand and eye on size or weight, color and defects. As supply chains set standards based on these criteria there was an incentive to develop technology to mechanize the sorting process for these criteria. Simple diverging belt graders allowed sorting on size, and mechanical counter-weight tipping bucket graders allowed sorting by weight. With the advent of electronic grading platforms, weight grading using electronic load cells increased in accuracy. The addition of video cameras to the electronic grading platforms allowed for grading on fruit color (1970s), and later (1980s) allowed for defect detection using image classification routines.

However, as we have reviewed above, fruit eating quality is determined by other attributes. For many fruit commodities, texture and sweetness are particularly relevant in this respect. To a scientist/engineer, the "problem" is, thus, obvious, that fruit eating quality is variable, that fruit firmness and sugar levels are a major factor in eating quality for many fruit commodities, and thus the solution is to adopt technologies that allow for fruit grading on these attributes. It might, therefore, be expected that technologies to non-invasively grade fruit firmness and sweetness would be rapidly adopted, given the link between these attributes and eating quality and the existence of criteria on these attributes in many retail specifications. Indeed, fruit firmness and sweetness grading technologies became available from the 1990s onwards, but, except in Japan, have not been widely adopted.

The question of what is limiting technology adoption must be considered using a systems approach. Such an approach aids the identification of critical steps in a system and provides a tool for the integration of specific knowledge into a system (Prussia and Shewfelt, 1992).

Our research group has been involved in developing the sweetness grading technology for western agricultural conditions (lower cost, higher pack-line speeds) (e.g., Golic and Walsh, 2005; Subedi et al., 2007; Walsh et al., 2006; Figure 8.8). Our experience with the adoption of this technology informs the following discussion of technology adoption.

The sweetness grading (near infrared spectroscopy) technology has been in extensive use in other industries, notably the cereal, sugar and dairy industries since the 1970s. Thus, although the technology was not mature in the horticultural application, intending horticultural participants had access to technical advisors from both industry and government sectors.

In Japan, marketing of a high-value "gift" line of fruit of high external appearance and internal quality provided an existing business model/supply chain into which to apply the new technology. Sweetness grading technology was first developed (1989) out of mining/processing groups (Mistui Mining, Sumitomo Metals and Mining), and quasi-government R&D groups (Fantec), and later other groups (Eminet). These groups supplied sensors to the Japanese fruit grading equipment manufacturers. Within little more than a decade, the packing house market in Japan was saturated with this technology.

However, the available (Japanese) technology was very expensive and geared for a different market, in which speed of assessment was not as important. Further, the technical issue of compatibility of this technology with existing on-farm pack-line equipment was not simply resolved. By 2000, Colour Vision Systems (CVS) of Australia, Compac of New Zealand and Unitec of Italy offered sweetness grading technology outside of Japan. Later, by mid 2000, technology would become available through the major European manufacturers of fruit grading equipment (Greefa and Aweta of Holland, and MAF-Roda of France–Spain, through CVS).

Thus, the availability of the technology was not a limiting factor to its adoption. However, the cost (approximately $US30,000 per lane) and relative complexity of the technology were limiting factors, requiring adoption by a supply chain geared to achieve marketing benefits from the "guaranteed sweet" technology.

FIGURE 8.8

Photograph of an electronic grading platform, able to sort on the basis of fruit weight (using a load cell), color and blemish (using a RGB camera) and sweetness (using near infrared spectroscopy).

In 1999/2000, an Australian product supply manager interested in the technology commissioned focus groups with consumers (R. Gray, OneHarvest P/L, personal communication). Fruit with large "flavor gaps" (disparity between consumer taste expectation and actual experience) were identified and the literature was searched for major determinants of taste in those commodities. Commodities such as melons (all seasons), stonefruit (early season) and mangoes were identified as candidates for the sweetness grading technology. In 2000, the Australian supply chain manager negotiated exclusive access to one brand of sweetness grading equipment.

The supply chain manager then sought to contract melon and stonefruit growers to supply fruit, with growers located over a spread of geographic areas to provide constancy and security of supply. As an incentive, packinghouses were initially offered the technology free of charge, and growers were offered a guaranteed (above average market) price for sweet product, with the grower-packhouse marketing remaining fruit through normal channels. It proved difficult, however, to attract established growers who already had established marketing arrangements. More success was achieved with the annual crop (melon) than the perennial crop (stonefruit), attracting growers that had not previously grown this crop. But while growers typically believed they grew consistently sweet fruit, in practice, it was soon evident that pack-out rates on sweet produce was far lower than anticipated. Further, this pack-out rate was variable week-to-week (e.g., Long et al., 2004). In an attempt to address this issue, an R&D program was implemented on agronomic practices and on choice of varieties to maximize sweetness, with good results – though generally at the expense of total yield. For example, thinning of fruit on the tree will result in improved carbohydrate loads in remaining fruit – but at the cost of significant reduction in yield (e.g., Walsh et al., 2006).

Installation of the technology into existing pack-lines was not as simple as bolting a unit above the pack-line. Existing pack-line electronics had to be compatible with the technology. The technology was also disruptive of packinghouse operations. For example, with grading to a sweetness standard, pack-line sorting to five size standards would require 10 pack-out points. Five pallet lines in the cold room would become 10. Further complication arose in that the sweet fruit were largely more mature, and ripened at a different rate to the below TSS standard fruit.

The product supply manager introduced the technology supported sweetness guaranteed program to a major retailer and negotiated a price premium for fruit above the retailers specification level on TSS. However, while the retailer allowed in-store labeling of fruit in the first year of marketing, no labeling was allowed in the second year. With the fruit being offered at a higher price than standard grade fruit, this policy was obviously detrimental to sales. From the third year, the retailer required labeling of the fruit with their own quality label, a label applied a number of lines considered to be of higher eating quality (e.g., a low acid pineapple variety).

Consumer purchasing was disrupted during the year in which in-store labeling was not permitted. In effect, the consumers could not find the fruit. In other seasons, consumer purchasing patterns were disrupted by periods of non-supply. While this was done for the best of intentions, to maintain a standard, the inconsistent supply resulted in a loss of product identity with the consumer. Further, the reallocation of produce display space during periods of non-supply was difficult to recover.

Thus, the sweetness grading technology was a great technological solution – to a problem that the supply chain could not extract value from. That is, the consumer appreciates taste but the supply chain was unable to achieve value from technology able to measure relevant characters. The cost of implementation was not shared, and the need to change practice at several points along the value chain was not realized. In conclusion, use of this technology can be expected to be sporadic until such time as retailer specifications are enforced.

In contrast, the technology was adopted in Japan to support an existing market for quality "gift" fruit. In this market, the premium paid for sweet fruit is sufficient to cover the cost of the technology and to reward growers for the agronomic effort (and loss of yield) incurred in producing sweeter fruit. This "gift fruit" business model/supply chain did not exist in appreciable size in non-Japanese markets, limiting "easy" adoption of the sweetness grading technology.

The technology has been subsequently adopted in value chains as a tool to reward growers, rather than as a tool to enforce a standard enforced to "protect" consumers. Growers are rewarded for fruit above a specified TSS level, and penalized for fruit below this level. This creates a known incentive to support agronomic and varietal selection that results in elevated fruit TSS.

The technology has also evolved to address issues critical to the retailer, e.g., internal browning of apple.

IX Regulatory issues for the future?

Common standards facilitate international trade and improve transparency to consumers. Convergence of heavy metal, chemical residue and microbiological (phyto-sanitary) standards has been driven by national and intergovernmental agencies such as UNECE and the OECD, with the Codex Alimentarius emerging as a global minimum standard. Common processes to deal with quarantine issues have developed under the WTO. These trends are expected to continue, with further intertwining of the UNECE, OECD and Codex standards, and increased adoption by Asian and African countries as a tool to increase export trade. Similarly, consolidation and increased adoption of the organic standards is to be expected. For example, the IFOAM organic specifications could be further mainstreamed into Codex.

This prediction is at odds with the CACs view of its own activity (Codex Alimentarius Commission, 2013c). The CAC reports that its consumer protection elements are gaining in importance, while the "compositional elements of individual commodity standards do not appear to attract as much interest as before". It is noted, however, that future directions depend on community attitudes and demands.

The interpretation of standards is indispensable to their application in practice and so the availability of explanatory brochures on standards and inspection guidelines is important. Organizations like OECD and AMS can be expected to continue to inform Codex.

However, standards need to be enforced, which can only happen if there is a "will" (in the form of government or value chain regulation) and a "method", e.g., in the form of certifying bodies. The organic movement developed through the efforts of a many industry associations, leaving a legacy of many standards and many private certifying agencies. It is likely that there will be some consolidation and internationalization of these organizations. Another example lies in food safety standards, with horticultural produce from some markets often held in some suspicion with respect to chemical residues on products entering international value chains. This situation arises, despite existence of official standards, when enforcement is ad hoc.

China, for example, has a largely uneducated farmer base and a push for cheap food, predisposing supply chains to food safety issues. Collen (2007) reported that traders of Chinese "certified organic" product were questioning the status of the product, given that over 430 institutions offer organic certification in China, and that counterfeit organic labels exist. Further, it was noted that food control is spread over a number of government departments, leading to inconsistent regulation and a concern that produce is meeting international food safety standards. There has been some attempt to address this subsequently – the China Green Food Development Center (http://www.greenfood.org.cn) now oversees two Green Food Standards relevant to horticultural production: A (which allows some use of synthetic agricultural chemicals) and AA (which allows less use of such chemicals), but it is reported that the AA standard is consequently less popular with producers. Consistent pressure from value chains is required to see consistent enforcement of standards in such an environment.

With the continued rise of the global retailers and global production groups, it is to be expected that private sector regulation will increase, to match consumer demands and to insure against official (government imposed) regulation. For example, the GAP program is on track to become a generic certifying body. Thus the large retailers, working through their category managers, will continue to develop as setters and enforcers of standards.

In the decades to come, new social drivers will emerge, with related regulatory pressures. The issues of an aging population and of an increasingly sedentary lifestyle and poor diet are probable drivers. The "Two-and-Five" fruit and vegetable consumption campaigns are forbears in this area. The use of nutritionally and functionally enhanced fruit and vegetables will rise, e.g., the Gates Foundation funded, vitamin-enhanced bananas for Uganda. Issues related to labeling of "food miles" or carbon cost of production may become regulated. With increasing population and increased industrialization, urbanization and competition for water, some markets might require labeling for water efficiency or the use of recycled sewage water in irrigation. Perhaps fruit will be labeled with a water efficiency star rating (ML/tonne). The rise of on-line ordering of groceries is another trend that comes with a new set of issues as the consumer buys on the strength of a website picture. Perhaps the future holds a requirement to link back to information on the history of the consignment. Already Dole offer links to pictures and information on the farm supplying the product (www.doleorganic.com, accessed 12 July, 2013), and various businesses are jostling to provide information via 3G phones (e.g., Locavore provides information on closest farmers markets and produce, with producers paying listing fees; http://www.getlocavore.com, accessed 7 October, 2013). Thus, the regulatory environment of the next decade is likely to be quite different than that outlined in this chapter!

Acknowledgments

My thanks to Wojciech Florkowski for encouragement and feedback in the preparation of this chapter. The efforts of Robert Long, now graduated PhD student, in preparation of the tables is also acknowledged.

Bibliography

Abbott, J.A., Lu, R.F., Upchurch, B.L., Stroshine, R.L., 1997. Technologies for nondestructive quality evaluation of fruits and vegetables. In: Janick, J. (Ed.), Horticultural Reviews, vol. 20. John Wiley & Sons Inc., Canada, pp. 1−119.

Agricultural Marketing Service − USDA, 2013a. AMS Fruit and Vegetable Programs. <http://www.ams.usda.gov/AMSv1.0/fruitandvegetable> (accessed 18.07.13).

Agricultural Marketing Service − USDA, 2013b. Fruit and Vegetable Programs, Fresh product grading and quality certification: Program Overview and Inspection Fees. <http://www.ams.usda.gov/AMSv1.0/Grading> (accessed 26.07.13).

Agrilink, 2001. Avocado Information Kit. Department of Primary Industries, Queensland Nambour.

Asia Fruit Magazine, 2007. Retail. Asia Fruit Mag. July/August, 17.

Australian Government − Department of Foreign Affairs and Trade, 2013. Australia−United States Free Trade Agreement Chapter Three − Agriculture. <http://www.dfat.gov.au/trade/negotiations/us_fta/final-text/chapter_3.html> (accessed 01.08.13).

Australian Horticultural Corporation, 1999. Guide to Quality Management − Apples. Australian Horticultural Corpopation, Sydney.

Australian Quarantine Inspection Service, 2013a. About AQIS. <http://www.daff.gov.au/biosecurity> (accessed 22.07.13).

Australian Quarantine Inspection Service, 2013b. Industry Advice Notice no. 2004/12: Detection of Citrus Canker in Queensland. <http://www.daff.gov.au/biosecurity/quarantine/naqs/naqs-fact-sheets/citrus-canker> (accessed 22.07.13).

Baldwin, E.A., 1993. Citrus fruit. In: Seymour, G.B., Tucker, G.A. (Eds.), Biochemistry of Fruit Ripening. Chapman and Hall, London, pp. 107−149.

Bally, I.S.E., Johnson, P.R., Kulkarni, V.J., 2000. Mango production in Australia. Acta Hortic. 509, 59−67.

Bartholomew, D.P., 2003. The pineapple, botany, production and uses. CABI Publishing, New York.

Batten, D.J., 1989. Maturity criteria for litchs (lychees). Food Qual. Prefer. 1, 149−155.

Bell, B., Elliott, R.E.W.E., 1993. Aspects of New Zealand's Experience in Agricultural Reform since 1984. <http://www.maf.govt.nz/mafnet/rural-nz/profitability-and-economics/structural-change/reform-of-nz-agriculture/httoc.htm> (accessed 24.11.07).

Bowden, R.P., 1969. Further studies on ripeness in pineapples. Food Technol. Aust. 21, 160−163.

Brady, C.J., 1993. Stone fruit. In: Seymour, G.B., Tucker, G.A. (Eds.), Biochemistry of Fruit Ripening. Chapman and Hall, London.

Bruckner, B., Grant Wyllie, S. (Eds.), 2008. Fruit and Vegetable Flavours. Recent Advances and Future Prospects. CRC Press, Boca Raton FL., USA.

Capespan, 2013. Annual report 2012. <http://www.capespangroup.com/index.php?c=cgl_investor_info/annual_reports> (accessed 10.08.13).

Cheah, L.H., Irving, D.E., 1997. Kiwifruit. In: Mitra, S.K. (Ed.), Postharvest Physiology and Storage of Tropical and Subtropical Fruit. Cab International, New York.

Chen, H., De Baerdemaeker, J., 1993. Effect of apple shape on acoustic measurements of firmness. J. Agric. Eng. Res. 56, 253–266.

Choon, S.C., Choo, C.G., 1972. Comparative evaluations of some quality aspects of banana (Musa acuminata (Colla) I. Flavour, sources and sweetness. Malays. J. Agric. Res. 1, 54–59.

Codex Alimentarius Commission, 2013a. Welcome. <http://www.codexalimentarius.net> (accessed 19.07.13).

Codex Alimentarius Commission, 2013b. Strategic Framework: Strategic objectives and priorities. <http://www.fao.org/docrep/004/Y2361e/y2361e03.htm> (accessed 10.08.13).

Codex Alimentarius Commission, 2013c. <http://www.fao.org/docrep/w9114e/w9114e00.htm> (accessed 12.07.13).

Collen, C., 2007. Mounting food safety scares spur organic demand in China. Asiafruit Mag. July/August, 120.

Crisosto, C.H., 1994. Stone fruit maturity indices: a description review. Postharvest News Inf. 5, 65–68.

Crisosto, C.H., Crisosto, G.M., Echeverria, G., Puy, J., 2007. Segregation of plum and pluot cultivars according to their organoleptic characteristics. Postharvest Biol. Technol. 44, 271–276.

DAFF, 2013a. Horticultural Code of Conduct. <http://www.daff.gov.au/agriculture-food/hort-policy/code-of-conduct> (accessed 10.08.13).

DAFF, 2013b. Mangoes from the Philippines. <http://www.daff.gov.au/ba/ira/final-plant/mangoes-phillippines> (accessed 17.08.13).

Davies, F.S., 1986. The naval orange. Hortic. Rev. 8, 129–180.

European Commission – Agriculture and Rural Development, 2013. Quality products catch the eye: PDO, PGI and TSG. <http://ec.europa.eu/agriculture/foodqual/quali1_en.htm> (accessed 20.07.13.).

Fellars, P.J., 1985. Citrus: sensory quality as related to rootstock, cultivar, maturity and season. In: Pattee, H.E. (Ed.), Evaluation of Quality of Fruits and Vegetables. AVI Publishing, Westport.

Firth, S., 2006. In: Firth, S. (Ed.), Globalisation and Governance in the Pacific Islands. ANU EPress, Canberra, ACT, Australia.

Florkowski, W.J., 1999. Economics of quality. In: Shewfelt, R.L., Bruckner, B. (Eds.), Fruit and Vegetable Quality: An Integrated Approach. Technomic Publishing Co., Inc, Lancaster, PA.

Food Standards Australia New Zealand, 2013. Welcome to Food Standards Australia New Zealand. <http://www.foodstandards.gov.au/> (accessed 17.07.13).

Given, N.K., 1993. Kiwifruit. In: Seymour, G.B., Tucker, G.A. (Eds.), Biochemistry of Fruit Ripening. Chapman and Hall, London.

Golic, M., Walsh, K.B., 2005. Robustness of calibration models based on near infrared spectroscopy to the in-line grading of stonefruit for total soluble solids. Anal. Chim. Acta 555, 286–291.

Good Fruit and Vegetables, 2007. Freshness system wins award. Good Fruit Vegetables 17, 5.

Goodenough, P.W., Atkin, P.K., 1981. Quality in Stored and Processed Vegetables and Fruits. Academic Press, New York.

Greer, N., 1990. Growing Lychee in South Queensland. Queensland Department of Primary Industries, Brisbane, Australia.

Growcom, 2013. About Us. <http://www.growcom.com.au> (accessed 26.07.13).

HACCP Australia, 2013. HACCP based food safety programs and endorsements. <http://www.haccp.com.au/> (accessed 11.07.13).

Harker, F.R., 2001. Consumer responses to apples. Washington Fruit trees Postharvest Conference. March 13–14, 2001, Wenatcheewa, USA.

Harker, F.R., et al., 1997. Texture of fresh fruit. Hortic. Rev. 20, 121–223.

Harker, F.R., Gunson, F.A., Brookfield, P.L., White, A., 2002. An apple a day: the influence of memory on consumer judgement and quality. Food Qual. Prefer. 13, 173–179.

Harker, F.R., Gunson, F.A., Jaeger, S.R., 2003. The case for fruit quality: an interpretative review of consumer attitudes and preferences for apples. Postharvest Biol. Technol. 28, 333–347.

Hey, J., 2007. Thailand – Thailand develops globally recognised system. Asia Fruit Mag. July/August, 30–34.

Hobson, G.E., Davies, J.N., 1971. The tomato. In: Hulme, A.C. (Ed.), The Biochemistry of Fruits and their Products, vol. 2. Academic Press, London, pp. 347–482.

Jen, J.J. (Ed.), 1989. Quality Factors of Fruit and Vegetables. American Chemical Society, Washington D.C., USA.

Kader, A.A., 2002. Standardisation and inspection of fresh fruits and vegetables. In: Kader, A.A. (Ed.), Postharvest Technology of Horticultural Crops. University of California, Oakland, pp. 287–299.

Kader, A.A., Morris, L.L., 1976. Tomato firmness as a quality attribute. Proceedings of the Second tomato Quality Workshop. University of California, Davis.

Kappel, F., et al., 1995. Ideal pear sensory attributes and fruit characteristics. HortScience 30, 988–993.

Lill, R.E., O'Donoughue, E.M., King, G.A., 1989. Postharvest physiology of peaches and nectarines. Hortic. Rev. 11, 413–452.

Lockie, S., Lyons, K., Lawrence, G., Halpin, D., 2006. Going Organic. Mobilizing Networks for Environmentally Responsible food Production. CABI, Cambridge, MA, USA.

Long, R., Walsh, K., Rogers, G., Midmore, D., 2004. Source-sink manipulation to increase melon (*Cucumis melo* L.) fruit biomass and soluble sugar content. Aust. J. Agric. Res. 55, 1241–1251.

Marsili, R., 1997. Techniques for Analyzing Food Aroma. Marcel Dekker, New York.

McGlasson, B., 2001. Editorial. Aust. Fresh Stone Fruit Q. 3, 2.

Menzel, C., Bagshaw, J., Campbell, T., Greer, N., Noller, J., Olesen, T., et al., 2001. Lychee Information Kit. Queensland Department of Primary Industries, Brisbane, Australia.

Mitchell, F.G., et al., 1991. Effect of harvest maturity on storage performance of 'Hayward' Kiwifruit. In: Warrington, I.J., et al. (Eds.), Proceedings of the second International Symposium on Kiwifruit, vol. 297, pp. 617–625.

Mutton, L.L., et al., 1981. The objective definition of eating quality in rockmelons (*Cucumis melo*). J. Sci. Food Agric. 32, 385–390.

OECD, 2013a. Fruit and vegetables: standards applicable under OECD scheme. <http://www.oecd.org/document/38/0,3343,en_2649_33907_1890726_1_1_1_1,00.html> (accessed 25.07.13).

OECD, 2013b. Guidance on objective tests to determine quality of fruits and vegetables and dry and dried produce. <http://www.oecd.org/dataoecd/32/47/19515719.pdf> (accessed 19.07.13).

Palmer, J.W., Harker, F.R., Tustin, D.S., Johnston, J., 2010. Fruit dry matter concentration: a new quality metric for apples. J. Sci. Food Agric. 90, 2586–2594.

Pascale, A.M., 1992. Quality in the fruit and vegetable sector: EEC regulations and influence of quality on trade and processing. Options Mediterraneennes. Seie A, Seminaires Mediterraneens 19, 89–97.

Philippine National Standards, 2013. Philippine National Standard on Mandarin (ICS 065.020.20) <www.afmis.da.gov.ph/index.php/component/docman/. . ./175-mandarin.html> (accessed.12.8.13.).

Pineiro, M., Diaz, L.B., 2007. Improving the safety and quality of fresh fruit and vegetables (FFV): A practical approach. In: Fardous, A.N., Schnitzler, W., Qaryouti M. (Eds.), ISHS Acta Horticulturae 741: I International Symposium on Fresh Food Quality Standards: Better Food by Quality and Assurance, ISBN 978-90-66053-28-1. <http://www.actahort.org/books/741/741_1.htm> (accessed 11.2.14).

Prussia, S.E., Shewfelt, R.L., 1992. A systems approach to postharvest handling. Ch. 3 in Postharvest Handling. A Systems Approach. Academic Press.

Sale, P.R., 1985. In: Williams, D.A. (Ed.), Kiwifruit Culture. New Zealand Government Printer, Wellington.

Samson, J.A., 1989. Tropical Fruits. Longman Scientific and Technical, Singapore.

Sankat, C.K., Maharaj, R., 2001. Papaya. In: Mitra, S.K. (Ed.), Postharvest Physiology and Storage of Tropical and Subtropical Fruits. CAB International, New York, pp. 167–189.

Satyan, S.H., Chaplin, A., 1986. An assessment of fruit quality of various mango cultivars. In: Proceedings of the First Australian Mango Research Workshop, Carins, Queensland, 1986, pp. 324–333.

Scrimgeour, F., Sheppard, R., 1998. An Economic Analysis of the Deregulation of Selected Israeli, South African and South American Producer Boards, A Report Prepared for MAF Policy *by* MAF Policy Information Paper No. 20 ISSN 1171 4654 ISBN 0-478-07497-2. <http://maxa.maf.govt.nz/mafnet/rural-nz/profitability-and-economics/trends/deregulation-analysis/dereg.htm> (accessed 25.07.13).

Seymour, G.B., Tucker, G.A., 1993. Avocado. In: Seymour, G.J., et al., (Eds.), Biochemistry of Fruit Ripening. Chapman and Hall, London, pp. 53–81.

Shewfelt, R.L., Bruckner, B. (Eds.), 2000. Fruit and Vegetable Quality. Technomic Publishing, Lancaster, Pennsylvania, USA, ISBN 1-56676-785-7.

Smith, L.G., 1984. Pineapple specific gravity as an index of eating quality. Trop. Agric. (Trinidad) 61, 196–199.

Smith, L.G., 1988a. Indices of physiological maturity and eating quality in smooth cayenne pineapples. Indices of eating quality. Qld. J. Agric. Anim. Sci. 45, 219–228.

Smith, L.G., 1988b. Indices of physiological maturity and eating quality in smooth cayenne pineapples. 1. Indices of physiological maturity. Qld. J. Agric. Anim. Sci. 45, 213–218.

Story, A., Martyine, A., 1996. AUF National Product Description Language. The Australian United Fresh fruit and Vegetable Association, Flemington Market, Australia, ISBN 0 959388 22 2.

Subedi, P., Walsh, K.B., Owens, G., 2007. Prediction of mango eating quality at harvest using short wave near infrared spectroscopy. Postharvest Biol. Technol. 43, 326–334.

Tasmania – Department of Primary Industries and Water, 2013. History of platypus fungal disease. <http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SSKA-7AH66E?open> (accessed 15.07.13).

Tesco, 2013. Greener living – what we are doing. <http://www.tescoplc.com/index.asp?pageid = 636#carbon_targets> (accessed 22.07.13), <http://www.tesco.com/climatechange/speech.asp>.

Truter, A.B., Hurndall, R.F., 1988. New findings on determining maturity of ‘Starking’, ‘Tropical’ and ‘Starkrimson’ apples. Deciduous Fruit Grower 38, 26–29.

Underhill, S.J.R., Wong, L.S., 1990. A maturity standard for lychee (*Litchi Chinensis* Sonn.). In: Paull, R.E. (Ed.), Proceedings of the Symposium on Tropical Fruit in International Trade, vol. 269, pp. 181–187.

United Nations Economic Commission for Europe, 2013a. Trade. <http://www.unece.org/trade/welcome.htm> (accessed 19.07.13).

United Nations Economic Commission for Europe, 2013b. Working Party on Agricultural Standards. <http://www.unece.org/trade/agr/welcome.html> (accessed 09.07.13.).

United Nations Economic Commission for Europe, 2013c. Working Party on Agricultural Quality Standards. Specialised section on Standardisation of Fresh fruit and Vegetables. Report on 1st session, 15 July 2007 (ECE/TRADE/C/WP.7/GE.1/2006/2). <http://www.unece.org/trade/agr/meetings/wp.07/2006/2006_01e.pdf> (accessed 18.08.13).

Valero, C., Riuz-Altisent, M., 2000. Design guidelines for a quality assessment system of fresh fruits in fruit centres and hypermarkets. Agric. Eng. Int. 2, 1–20.

Walsh, K.B., Long, R., Middleton, S., 2006. Use of near infra-red spectroscopy in evaluation of source-sink manipulation to increase stonefruit soluble sugar content. J. Hortic. Sci. Biotechnol. 82, 316–322.

Ward, G., Melvin-Carter, E., 2001. Strategies to Rescue losses from Internal Breakdown in Plums – Project SF00024. Horticulture Australia Limited, Sydney.

Weaver, J.R., 1976. Grape Growing. John Wiley and Sons, New York.

World Trade Organisation, 2013. Understanding the WTO: basics – What is the World Trade Organization? <http://www.wto.org/english/thewto_e/whatis_e/tif_e/fact1_e.htm> (accessed 11.07.13).

Yahia, E.M., 1994. Apple flavour. Hortic. Rev. 16, 197–234.

Yamashita, K., 2000. Mango production in Japan. Acta Hortic. 509, 79–85.

Zespri, 2013. Zespri history. <http://www.zespri.com/about-zespri/history.html> (accessed 10.08.13).

This page intentionally left blank

CHAPTER

Fresh-Cut Produce Quality: Implications for a Systems Approach

9

Silvana Nicola[a] **and Emanuela Fontana**[b]

[a]*Department of Agricultural, Forest and Food Sciences — AgriForFood, DISAFA, Università di Torino, Grugliasco (Torino), Italy* [b]*Emanuelafontana.com Consulting, Vinovo (Torino), Italy*

I Introduction

Fresh-cut produce implies fruit or vegetables that have been prepared and subsequently packaged to provide convenient and safe ready-to-eat products for consumers, while maintaining their live, fresh state. Fresh and raw vegetables and fruits are subjected to minimal process operations such as cutting, trimming, shredding, peeling, washing, decontamination, dipping, rinsing and packaging. Fresh-cut products, thus, are highly perishable, but also agronomically and technologically more susceptible to quality deterioration than whole vegetables or fruit. The processing operations eliminate any inedible parts, but reduce the edible product shelf life by several weeks or months, depending on the raw material. The nutritional and sensory quality should be comparable to the unprocessed product. Leafy vegetables, particularly baby leaves, are the consumers' favorite, but they are very delicate and susceptible to process manipulations. Control and innovation technology implementation needs to be pursued to optimize all the fresh-cut production and processing procedures.

A fresh-cut product is physically altered from its original state during trimming, peeling, washing and cutting operations. However, it remains in a fresh state and is thus characterized by living tissues that undergo or are susceptible to enzymatic activity, texture decay, undesirable volatile compound production and microbial contamination, which reduce the shelf life. In the fresh-cut industry, shelf life is the time required by a fresh-cut product to lose quality attributes, such as freshness, firmness, texture, color, aroma and nutritional value, to below a level acceptable to the consumer. The relative importance of each quality factor varies according to the product and market. The final potential postharvest quality and shelf life of fresh produce are determined before harvesting. Processing practices, e.g., packaging and storage temperature, do not improve quality; they can only slow the rate at which deterioration occurs. Practices such as washing, sorting, and sizing are services performed with the consumer in mind, and generally

Postharvest Handling.

do not improve the inherent quality (Brecht et al., 2003). The first and most important aspect that affects the subsequent postharvest processing and shelf life phases is the raw material quality at harvest.

Fresh produce in general, and fresh-cut produce in particular, is perishable. Once harvested, quality deterioration occurs, leading to raw material losses even before the produce reaches the consumer. Fresh fruit and vegetable postharvest losses have been estimated to be between 2% and 20% in developed countries and between 24% and 40% in developing countries, respectively (Sirivatanapa, 2006). High levels of waste result in higher prices for the final product. Improper handling during the harvest on farms causes quality deterioration. Quality in the supply chain is crucial in terms of food safety, quality and environmental impact. Low input and efficient cultural practices, postharvest technologies and supply chain management contribute to "making the difference" in an industry that wishes to be efficient and competitive. The critical points that need to be improved in the fresh-cut sector include:

- early cold chain implementation;
- storing and shipping conditions prior to reaching the processing plant;
- logistics;
- processing inputs;
- handling in distribution.

For these reasons, innovative technologies have been developed to enhance raw material production, preserve quality, guarantee safety, prolong shelf life and diversify the fresh-cut products available to consumers.

A Consumer trends and the fresh-cut market

Most fruit and vegetables are low-cost foods that contain low levels of fat and high levels of a number of nutritionally important compounds, such as vitamins, minerals, fiber, bioactive compounds, etc., many of which cannot be synthesized by the human body. Changing eating habits such as snacking, year-round product availability and a growing trend towards vegetarianism and healthy eating have resulted in an increasing demand for convenient products that fit into the modern consumer lifestyle, while offering healthy food. Fresh-cut products, especially vegetables, have thus become very popular.

In recent years, the consumer demand for fruit and vegetables has decreased in Europe (see also Chapter 7). However, instead of a decrease, the ready-to-eat product sector has reported an increase in sales. In the past few years, fresh-cut produce has seen an increase in sales throughout the world. Out of the total produce sales, fresh-cut sales have an estimated share of 18% in Europe, of 9% in the United States, and of 5% in Australia, respectively (Premier, 2007; Premier et al., 2007). Fresh-cut produce sales in the United States are ca. $12 billion, according to the International Fresh-cut Produce Association reported by the fruitgrowersnews.com professional portal (Fruitgrowersnews.com, 2013), with an increase of more than 50% in the last decade. This is an indication that the fresh-cut industry remains the fastest growing segment in the produce sector. The fresh-cut segment supplies both the food service industry and retail outlets in the United States. Approximately 60% of fresh-cut produce ends up in the food service industry and 40% in the retail market. Of the retail market, 62% consists of salads, 31% of vegetables, and 7% of fruit, respectively (Premier, 2007). The fresh-cut industry keeps growing in many European countries with the UK, Italy and France leading in terms of market share. The Rabobank estimated the value of the European fresh-cut fruit and vegetables market at about €3.4 billion (Van Rijswick, 2010). The market volume growth in the European Union (EU) is estimated at 4% year-to-year. Currently, EU market volumes are represented by 50% fresh-cut salads, 40% other fresh-cut (stir-fry, crudités, etc.), and 10% fresh-cut fruit. The UK is the market leader in Europe, with €1.1 billion in fresh-cut fruit and vegetables sales and one-third of total EU fresh-cut fruit and vegetables consumption (ca. 480,000 tons, elaborated data).

In Italy, the second most important country after the UK for market value in Europe, fresh-cut production reached 90,000 tons in 2008, with a corresponding value of ca. €700 million (Pirazzoli and Palmieri, 2011). These values remained constant until 2012 when an increase of 4.4% was registered compared to the previous year, reaching 98,000 tons and €767 million (Aldinucci, 2013). Spain is the European country with the highest and most constantly increasing production and market value in the latest years. In 2008, the Spanish fresh-cut market value was €200 million with a production of almost 57,500 tons, of which 25% was produced for the food service and 75% for the retail market (Andujar Sànchez et al., 2010). The sector continued to grow at 4–6% per year, reaching 70,000 tons in 2010 with a market value of more than €300 million (Fabbri, 2011; Van Rijswick, 2010).

Consumer demand for fresh-cut fruit and vegetables increased significantly in 2011 according to a survey of the Hartman Group commissioned by the Produce Marketing Association (PMA) (FreshFruitportal.com, 2012). The survey results showed that 22% and 15% of consumers were buying, respectively, more fresh-cut vegetables and fruit compared to 2010. The fresh-cut fruit and vegetable consumption per capita varies from 3 kg in Europe to 30 kg in the USA (Andujar Sànchez et al., 2010). Among the leading European countries for the fresh-cut industry, the consumption per capita is 12 kg in the UK, 6 kg in France, 3.7 kg in Italy and 1.5–2.0 kg in Spain, respectively.

Fresh-cut production is widespread throughout the world; in some countries it is devoted to exports aimed at western countries (e.g., Thailand to the UK, Mexico to the United States). The fresh-cut market is developing in South-East Asia and Latin America. In Asia, fresh-cut product sales are driven by demand in countries like Japan, Singapore and the Republic of Korea. Sales of fresh-cut produce in Japan have grown from approximately $1 billion in 1999 to $2.6 billion in 2005, of which 89% consisted of fresh-cut vegetables and 11% of fresh-cut fruit (Kim, 2007). In 2011, sales were $1.9 billion, of which ca. 37% was sold in retail outlets, ca. 49% in food service industry and ca. 14% in others

(Izumi, 2013, personal communication from Agriculture and Livestock Industries Corporation). In the Republic of Korea, sales have grown from $0.5 billion in 2003 to $1.1 billion in 2006. These sales implied the production of 110,000 tons of which 33% consists of vegetable salads, 42.1% of ready-to-cook vegetables, 8.7% of wild vegetables, 15.6% of fruit and 0.3% of mushrooms. It has been reported that fresh-cut produce has been increasing in China since the late 1990s, with an annual growth rate estimated at 20%, although no exact figures are available (Zhang, 2007). Despite the opportunity that this sector can offer the overall produce industry, the lack of reliable published data makes it difficult to appreciate the importance of fresh-cut business around the world.

B Food safety risks in the fresh-cut chain

The safety of fresh-cut vegetables is related to inherent anti-nutritional substances, such as nitrate and oxalate, accumulating during growth (Reinink and Blom-Zanstra, 1989; Weerakkody, 2003), and external microbial (see Chapter 11) and chemical contamination during postharvest (Cantwell and Ermen, 2006). These critical factors can be controlled throughout the entire chain by implementing targeted cultural techniques and observing sanitation programs. Good agricultural practices (GAPs) and good manufacturing practices (GMPs) provide recommended guidelines that guarantee a minimum safety level; the hazard analysis critical control point (HACCP), which includes good hygiene practices (GHPs), is regulated in the EU by EU Reg. N. 852-853-854/2004. Produce sanitation should start in the field and should encompass all growing, harvesting, handling and processing areas and all the procedures applied should be documented by the producer (logbook).

Food safety management in the fresh-cut chain is expected before processing, thus the food safety risks depend on cultivation site location, planting materials (e.g., seeds, seedlings, bulbs, shrubs, trees), process technology, crop production practices, pre- and postharvest technology and food quality management (Kirezieva et al., 2013). From 1996 to 2006, 26% of all food-borne disease outbreaks caused by the consumption of fresh produce implicated fresh-cut produce (FDA, 2007). Most of the outbreaks linked to fresh produce from 2005 to 2011 were caused by *Salmonella*, *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Shigella sonnei* (Olaimat and Holley, 2012). In Europe, over 400 cases of Salmonellosis occurred from baby spinach and alfalfa sprouts and 3911 cases of *E. coli* from vegetable sprouts in 2011; in the USA over 2000 cases of Salmonellosis occurred from tomatoes, spinach, cantaloupe and sweet pepper, and over 500 cases of *E. coli* from leafy vegetables.

A larger volume and greater variety of fresh-cut products have become available because of the fresh-cut sector growth. Fresh fruit and vegetables normally contain high amounts of microorganisms at harvesting but before processing. Soil, water, air and insects all contribute to the microflora of vegetables, but their importance differs according to the edible part of the plant. For example, leaves are primarily exposed to water, whereas roots have more contact with the soil. The numbers and the species of microorganisms found on fresh produce, and specifically on fresh-cut products, are highly variable. Fresh produce is considered to be a possible source of food-borne outbreaks caused by a variety of pathogens. Several specific pathogen−food combinations have emerged in recurrent outbreaks, such as *Salmonella* infections from melons and tomatoes, *E. coli* O157: H7 infections from leafy green vegetables, *Cyclospora* infections from raspberries and hepatitis A infections from green onions (Lynch et al., 2009). The range of contamination depends on the harvest time, weather conditions at harvesting, applied fertilizer, handling by workers during harvest, hygiene worker's conditions, sorting and the subsequent processing, e.g., contact with cutting knives, transport belts, boxes or water used for washing.

The difficulties involved in killing and removing microorganisms from raw material can originate from preharvest sources, such as feces, soil, sewage and sludge, irrigation water, water used to apply fungicides, insecticides and herbicides, improper manure, dust, wild and domestic animals and human handling (Beuchat, 2007). Controlling these contamination sources can enhance the successful management of microbial safety risk in the fresh-cut industry. Four types of microbes are present on the surface of fresh-cut produce (see also Chapter 11):

1. useful microbes, such as some lactic acid bacteria, which should not be removed or killed;
2. spoilage microbes, such as pectinolytic Gram-negative bacteria belonging to *Pseudomonadaceae* or *Enterobacteriaceae* and yeasts with fermentative metabolism like *Saccharomyces* spp., found on fruit, which should be minimized during processing because they reduce shelf life;
3. pathogens (e.g., *Clostridium botulinum*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* spp., *Staphylococcus aureus*) responsible for food-borne disease outbreaks;
4. commensal organisms, with no positive or harmful effect on either humans or plant and plant pathogens with no harmful effect on humans.

The aim of the fresh-cut industry is to prevent the presence of pathogens and ensure that they are not introduced during the processing system. Because of their growth, internalization and infiltration behavior, sanitizer treatments are not effective and cannot ensure safety, thus GAPs, GMPs and HACCP are essential for preventing human pathogen contamination.

II Cultivation management for the fresh-cut industry

A Raw material quality for the fresh-cut industry

Any preharvest condition that stresses a plant will affect the quality and shelf life of the final product. The understanding of these conditions is crucial to assessing the postharvest potential of fresh produce, especially those that will be further stressed by fresh cutting. The raw material going to the fresh-cut industry must be in a perfect state with regard to safety, physiology and extrinsic and internal quality before processing. The most important prerequisites concern:

- the absence of insects, soil, metals and weeds, which increase the length and the cost of the washing phase and jeopardize the quality;
- a low level of microbial contamination that accelerates metabolic processes which reduce the shelf life;
- the absence of pathogens that cannot be either controlled or eliminated during processing;
- a high quality standard in terms of appearance, texture, flavor and nutritional value.

Cultivation conditions, such as the culture system, irrigation, climate and fertilization, influence the quality of the raw material and can modify its physiological behavior and suitability for fresh-cut processing. The preharvest and harvest conditions that affect vegetable quality and shelf life are related to:

- genetically controlled factors (cultivar, strain);
- climatic conditions (light, temperature, relative humidity (RH), etc.);
- soil conditions (type of soil, pH, moisture, microflora, soil-borne diseases, etc.);
- culture systems (open field cultivation, protected cultivation, soil-less system, etc.);
- agricultural practices (use and kind of fertilizers, pesticides, growth regulators, irrigation, etc.);
- harvesting (harvest timing and temperature, mechanical harvest, manual harvest, etc.).

The influence of genome, growing conditions, maturity at harvest and storage regime are critical factors that determine the ultimate quality level in fresh produce before fresh-cut processing (Kader, 2008). Climatic conditions (temperature, light, rain, wind) and cultural practices (planting density, tree pruning, fruit thinning, plant nutrition, cultural system, control of weeds, diseases and pests) allow high yields to be reached, but can be detrimental to producing inherent quality. It is necessary to identify the optimal cultural practices that maximize both quality and yield avoiding nutrient and water excess, and to encourage the growers to adopt cultural practices that will enhance produce quality even with a reduction in yield, to provide premium quality raw material for fresh-cut processing. Raw material variability remains a challenge: cultivars, growing conditions, climatic conditions, preprocessing handling and storage all affect the visual quality, shelf life, flavor and the compositional and textural quality (Cantwell and Ermen, 2006).

B Cultivars

Choosing the proper cultivar is not an easy task, because various parties in the fresh-cut production and distribution have often conflicting needs. Breeding selects cultivars that can solve problems of growers and processors (see also Chapter 19), reduce production costs and optimize postharvest technology efficiency. In recent years, breeding programs have been focused on developing new varieties and selections especially for yield, fruit size, disease resistance, long shelf life, minimum harvest maturity and lowest storage and shipping temperatures. All these parameters are crucial for growers, processors, buyers and retailers, but can have negative consequences on the flavor quality of the product (Kader, 2008).

Growers want cultivars that are resistant to biotic and abiotic factors, while ensuring a high yield, suitability for mechanical harvesting, plant size uniformity, low waste and uniform maturity. The absence of biotic and abiotic damage reduces both the metabolic processes after harvest and microbial contamination at any stage. Resistance to biotic and abiotic factors allows not only reduction of pesticide use, but also production of unblemished raw material. Breeders have selected *Cichorium intybus* L. (chicory) cultivars with high bolting tolerance and frost resistance without any variation in color. Cultivars with high bolting tolerance satisfy commercial and organoleptic maturity requirements and lead to a reduction in the discarded material, thus lowering postharvest losses. Baby leaf cultivars of lettuce (*Lactuca sativa* L.) have been selected because of their resistance to different *Bremia lactucae* strains, while spinach (*Spinacia oleracea* L.) cultivars have been selected because of their resistance to *Peronospora farinosa*.

Processors want cultivars with low respiration and enzymatic rates and with tolerance to stress due to mechanical operations, such as washing, sorting, cutting, and drying. Selecting varieties with low respiration rates and lowering the respiration rate after harvest are very useful tools to extend the shelf life of the fresh produce. Seefeldt et al. (2012) studied the effect of variety and harvest time on respiration rate of broccoli florets (*Brassica oleracea*, Italica group) and found that the respiration rate among the tested broccoli varieties can be related to the structure of the heads and the inflorescences size. Varieties with a low respiration rate for oxygen (RRO_2) had small inflorescences, gathered in a compact head, while those with high RRO_2 had a large inflorescence in loose heads. In addition, the varieties with high dry matter contents also had a high RRO_2 within the same species. Also preferred are cultivars tolerant of low temperatures used in the supply chain. For instance, head vegetables (e.g., lettuce, chicory) are preferred to baby leaves (e.g., rocket, *Eruca sativa* Mill; corn salad, *Valerianella olitoria* L.) because they are more resistant to mechanical stress and have extended storability prior to processing. The latter feature improves logistic management of the produce flow. However, the recent consumer demand for softer leaves with variation in taste, color, and shape has encouraged the development of new lettuce typologies. Martínez-Sánchez et al. (2012) compared the whole-head lettuce, as the most common raw material for the fresh-cut industry, with baby-leaf and multi-leaf as the newest baby-sized lettuce leaves (Green Leaf, Red Leaf and Lollo Rosso cultivars). The new baby-sized leaves, both at immature and mature stages, have been developed as high quality lettuce varieties for the fresh-cut sector.

Baby-sized lettuce compared to the whole-head lettuce presents some advantages:

- greater efficiency due to the higher percentage of usable product;
- easier and faster processing because the entire leaf is harvested and processed;
- more attractive presentation in the packaging because of 3-D structure;
- minimal oxidation due to the smaller stem diameter.

Martínez-Sánchez et al. (2012) recommended the development of baby-sized lettuce varieties because of their excellent sensory characteristics and nutritional quality; they meet fresh-cut specific requirements in terms of visual quality, microbial load and high content of phytochemicals.

Leaf shape often depends on cultivar and can facilitate cleaning and washing operations during processing. This is typified by the case of spinach. Spinach cultivars are often classified according to leaf shape, i.e., smooth, savoy or semi-savoy. The smooth and semi-savoy types are mainly used for processing, while the savoy type is used for the fresh market. The savoy types are preferred for shipping because they are less likely to wilt or turn yellow before reaching the market. The smooth type spinach cultivars are suitable for canned, frozen or fresh-cut produce, because the leaves are easy to clean before processing.

Enzymatic rates can depend on cultivar. Cantwell and Ermen (2006) described lettuce cultivars that differed according to their enzymatic browning rate and the phenylalanine ammonia lyase (PAL) activity of the cut pieces. All types of "radicchio", a chicory cultivar famous for its color and slightly bitter flavor, have a long shelf life associated with a reduced oxidation of the cutting point.

Cultivar selection is of great importance in fresh-cut fruit processing, because cultivars can widely differ in flesh texture, skin color, flavor, nutritional value, susceptibility to mechanical damage and browning potential. The commercial success of fresh-cut peach and nectarine slices (*Prunus persica* [L.] Batsch) has been limited due to their short shelf life because of cut surface browning and pit cavity breakdown (Gorny et al., 1999). Their shelf life can vary between two and 12 days at 0°C, depending on the cultivar. The selection of appropriate cultivars, along with an appropriate maturity at harvest and proper storage conditions, can be considered the most important factors that determine the shelf life of fresh-cut fruits. The shelf life of fresh-cut slices of pear cultivars (*Pyrus communis* L.) varies greatly due to their different degrees of flesh softening and surface discoloration. The shelf life of pear slices is reduced with an increased incidence of cut surface browning. Gorny et al. (2000), when comparing Bartlett, Bosc, Anjou and Red Anjou varieties, stated that Bartlett pears were the most suitable cultivars for fresh-cut processing, because they exhibited the longest post-cutting shelf life of all cultivars tested.

Ethylene receptors can be bound by 1-Methylcyclopropene (1-MCP) which then can prevent the physiological action of ethylene for extended periods. The effectiveness of 1-MCP is cultivar-specific and influenced by the maturity of the fruit. Calderon-Lopez et al. (2005) found that slices prepared from apple cultivars (*Malus* × *domestica* Borkh.) treated with 1-MCP had lower ethylene effects and were firmer than those of untreated fruits. Fruit firmness generally decreases with increasing core temperature, but postharvest quality decay due to storage temperature is not only species-specific but also cultivar-specific. This is, for instance, the case for apples. Toivonen and Hampson (2009) investigated the response of four apple cultivars (Gala, Granny Smith, Ambrosia, Aurora Golden Gala™) to fresh-cut processing at core temperatures of 1, 5, 13 and 20°C. It was concluded that Gala apples were best processed at low core temperatures, Ambrosia could be processed at all temperatures tested, and Aurora Golden Gala produced better quality slices when fruit was stored at room temperature (20°C) before slicing. These results mark the necessity of developing new apple lines directed to their quality as fresh-cut products in addition to the potential storage quality of the intact fruit.

Nowadays, it is crucial to satisfy consumer expectations in terms of quality. One of the main parameters considered by consumers when choosing a product is its color. Consumers associate color with freshness, better taste, flavor and ripeness, and these depend on genotype, growing conditions, harvesting stage, processing, storage and distribution conditions. In fruit such as apples, cherries (*Prunus avium* L., *Prunus cerasus* L.) and strawberries (*Fragaria* × *ananassa* Duch.), there has been much interest in breeding varieties with different color, hues, patterns, or with a total anthocyanin content. Red-skinned apples are preferred to those of any other color.

Differences between cultivars may give rise to specific, different postharvest quality aspects valuable for the fresh-cut industry. Gonzalez-Aguilar et al. (2008) assessed the physiological and biochemical changes of different fresh-cut mango (*Mangifera indica* L.) cultivars (Keitt, Kent, Ataulfo) stored at 5°C. Ataulfo had a much greater shelf life than the other two cultivars, almost double or triple; there was also a correlation between the carotene and vitamin C content of Ataulfo mango and its longer shelf life compared to the other cultivars. The importance of a high vitamin C content has extensively been indicated as a factor delaying tissue senescence (Lee and Kader, 2000; Bergquist et al., 2007). Wall et al. (2010) evaluated the physicochemical, nutritional and microbial quality of fresh-cut papaya (*Papaya carica* L.) prepared from five cultivars with varying resistance to internal yellowing (IY) (Sunrise, SunUp, Rainbow, resistant; Kapoho, Laie Gold, susceptible), a disease caused by *Enterobacter cloacae*, an opportunistic pathogen. A zero-tolerance for food-borne coliforms makes resistance to IY an important criterion in breeding papaya cultivars suitable for fresh-cut food, but because the infection is restricted to the flesh surrounding the seed cavity, infected fruit cannot be sorted from good-quality fruit based on external appearance.

Microbial quality is fundamental to observing food safety guidelines, and the use of IY-resistant cultivars could eliminate or reduce coliform bacteria load. Kapoho and Laie Gold cultivars are not good candidates because of their susceptibility to IY, although Laie Gold is high in vitamins and sugar. Rainbow is one of the IY-resistant cultivars. The latter, in addition, is better than the former for its higher vitamin A and sugar content, and it does not develop the flesh translucency problem. The authors concluded that the processors of fresh-cut papaya products should choose the best cultivars for processing by considering not only appearance, but also texture, flavor and nutritional content.

Raw material for the fresh-cut industry produces a certain amount of waste after sorting and processing that could be valuable as a source of bioactive compounds. The waste amount is species and cultivar dependent. Tarazona-Díaz et al. (2011) tested five fresh-cut watermelon (*Citrullus lanatus* Thumb.) cultivars to determine: (1) the percentage of waste product produced during fresh-cut processing, (2) the difference among the cultivars in terms of their bioactive compounds, and (3) the composition of watermelon rind and flesh, with the possibility of reusing the rind as an additive in functional foods. The authors compared the following cultivars: (1) Fashion, seedless, dark rind, (2) Azabache, seeded, dark rind, (3) Motril, seedless, striped rind, (4) Kudam, micro-seed (open-pollinated cultivar), striped rind, (5) Boston, seedless, striped rind. Results indicated that the amount of by-product generated by processing varied from 31.27% to 40.61% of initial fresh weight depending on the cultivar. All cultivars were poor in terms of total antioxidant content. However, the sensory panel indicated that the five cultivars would have a good acceptance in the market. "Fashion" watermelon had the highest citrulline content (an amino acid that may help regulate blood pressure) and could be used as a source for human consumption as fresh-cut watermelon or for citrulline extraction from discarded rind.

In conclusion, during the last decade processing technologies and distribution chain development have driven the demand of cultivar selection and breeding mostly based on yield and post-processing performance in terms of shelf life, leaving at a lower priority the consumer demand for high organoleptic quality, flavor and nutritional values. Nevertheless, there is an increasing interest in selecting and breeding cultivars which satisfy the production and processing needs of growers and processors as well as producing the nutritional and organoleptic characteristics requested by the consumer. Furthermore, research has been focused basically on few species that are the core of the fresh-cut industry, such as lettuce, spinach, melon, watermelon, apple and lately some tropical fruit. There is a need to expand investigations on genetic material for several species that represent a niche in the fresh-cut industry but could gain popularity thanks to ameliorated performance. The constant expansion of the fresh-cut business all over the world can drive the demand for improved and new varieties or even species to be included in the supply chain.

C Growing conditions and raw material production

Climatic conditions, including light and temperature, and soil type have an important influence on the chemical composition of horticultural crops (see also Chapter 5). The amount and intensity of light during the growing season have a definite influence on the amount of ascorbic acid that is formed, thus affecting the postharvest shelf life (Lee and Kader, 2000). A study on baby leaves (spinach, red chard – *Beta vulgaris* L., pea shoots – *Pisum sativum* L., rocket and corn salad) obtained from a grocery store throughout the season showed that total vitamin C content, that is, ascorbic acid (AA) and dehydro-ascorbic acid (DHA), vary significantly between species, between cultivars and over the season (Mogren et al., 2011). Variations in chemical composition in spinach due to season were also found by Conte et al. (2008), who showed that the product harvested in February had a lower AA content than that in March, probably due to lower solar radiation occurring in February. The total vitamin C levels were very high (1494 mg/kg f.w. and 1559 mg/kg f.w., respectively), most probably because the favorable environmental growing conditions (Southern Italy).

High light intensity reduces the amounts of oxalate and nitrate in leaves (Proietti et al., 2004; Conte et al., 2008). Lowest levels of nitrate are accumulated in plants when higher radiation is available during plant growth, because of the high light-dependent activity of the nitrate reductase enzyme in reducing the nitrate taken up by the plants. Light and temperature affect anthocyanin synthesis in several species which, in many instances, is favored by UV wavelengths and low temperatures (Kleinhenz et al., 2003, and citations therein). Sunlight is the most important external factor that regulates anthocyanin synthesis in apple skin (Takos et al., 2006).

Environmental conditions and seasonal variation influence vegetable and fruit resistance to biotic and abiotic factors. Adverse conditions that negatively stress a plant make vegetables and fruits unsuitable for processing. Conte et al. (2008) studied the effect of seasonality on the microbiological quality at harvest of baby leaf spinach grown in open fields in a sandy clay soil over three different periods from October to January. The authors found that the growing period did not affect the total mesophilic bacterial contamination, which was equal to 10^5 cfu/g for all investigated samples. Nicola et al. (2011) studied the effect of seasonality on microbial contamination at harvest (total plate count, TPC; yeast and mold count, YMC) of green lettuce ("Green Lollo") grown in greenhouses with a continuous flotation system (FL) in three different periods (summer, fall and winter). Even in this case the seasonality did not affect the microbial quality at harvest in terms of TPC or YMC, leading to an average contamination of 1.7×10^3 cfu/g and 4.7×10^1 cfu/g, respectively. At the end of nine days of shelf life of the fresh-cut species results confirmed no effect due to seasonality (data not published). Rastogi et al. (2012) evaluated the effect of growing season (summer versus winter), field location (northern region – California, summer season, versus southern region – Arizona and South California, winter season) and environmental conditions on the variability of bacterial community composition in open field grown lettuce. The total bacterial population averaged between 10^5 and 10^6 per gram of tissue, whereas counts of culturable bacteria were, on average, one (summer season) or two (winter season) orders of magnitude lower. The bacterial core phyllosphere microbiota on lettuce was represented by *Pseudomonas*, *Bacillus*, *Massilia*, *Arthrobacter* and *Pantoea* genera. Summer-grown lettuce showed an over-representation of *Enterobacteraceae* sequences and culturable coliforms compared to the winter-grown lettuce. In winter samples, coliforms were much lower than in summer samples, following the seasonality of *E. coli* O157:H7. The specific mechanisms that allowed a clear separation between summer and winter in terms of the bacterial community composition that characterized the lettuce that was grown in the two regions was however not clear. Seasonal differences such as RH, temperature or irrigation practices can have a different degree or a different mechanism of action on the observed variation in bacterial community composition. Northern or southern production regions could have had, for instance, an influence per se rather than the summer or winter season on the observed variation.

After harvesting, quality deterioration can be accelerated in produce damaged by pests, fungi, bacteria and viruses, which alter the plant's metabolism and increase the risk of a second microbial contamination. Cultivation for fresh-cut processing should take place in areas far from chemical, atmospheric or animal husbandry pollutant sources, which jeopardize the safety of the raw material.

Water influences the raw material microbial quality throughout the entire processing cycle. Water used for production and harvest operations can contaminate vegetables if the edible portions have been in direct contact with water containing pathogens harmful to humans or through water-to-soil and soil-to-product contact (Solomon et al., 2003). It is important to ensure appropriate chemical and microbial quality of the irrigation water and the water used in harvesting operations. The chemical quality of water can influence plant growth. An example is salinity, which increases the susceptibility of plants to many diseases such as *Fusarium* spp. and *Verticillium* spp. wilts (Besri, 1997). The water should be periodically controlled through microbial and chemical analyses, including tests on the levels of fecal coliforms (i.e., *E. coli*) and heavy metals, whose absence is a safety indicator. However, growers may encounter difficulties in controlling water quality because it originates from a source that could become polluted. Irrigation water comes from surface and underground sources that can be contaminated by drift, run off or leaching of water from polluted areas (Lunati, 2001; Steele and Odumeru, 2004).

Irrigation methods (e.g., drip irrigation, overhead sprinkler, furrow, subirrigation systems) can be chosen according to their potential to introduce or promote the growth of pathogens on produce. Water quality, irrigation and postharvest disinfecting treatments appear to be of paramount importance in reducing the risk of *E. coli* contamination in lettuce (University of Arizona-Cooperative Extension, 2004a). Fonseca (2006) evaluated the postharvest quality and microbial population of iceberg lettuce affected by moisture at harvest. Iceberg lettuce irrigated for four days before harvest had microbial counts that were over 0.4 log cfu/g higher than on lettuce irrigated 16 days before harvest. In addition, the microbial population of lettuce irrigated four days before harvest with overhead sprinklers was much higher than lettuce irrigated using the furrow system. Fonseca et al. (2011) assessed the contamination risk of *E. coli* in commercial lettuce grown under three different irrigation systems (overhead sprinkler, subsurface drip, surface furrow), investigated the survival of the pathogen once the bacterium reaches the soil, and determined its potential relationship with irrigation management. These authors confirmed that the risk of *E. coli* contamination on leafy vegetables increases when sprinkle irrigation is used and water is contaminated. Furthermore, *E. coli* survival in furrow-irrigated soil marks the importance of an early irrigation stopping for both sprinkler and furrow methods. After a three year survey, the researchers concluded that the highest risk of finding the pathogen in irrigation water is in warmer periods, but its survival in soil is lower in the same period.

Water influences not only the microbial quality, but also the shelf life of vegetables. Some studies suggest that in some cases "controlled" water stress during plant growth can produce beneficial effects during postharvest storage (University of Arizona-Cooperative Extension, 2004b). Moisture stress imposed on broccoli (*Brassica oleracea* L. var. *italica*) during maturity increased their shelf life from 2−3 days to up to 13 days at 15°C. Similarly, water stress can improve the postharvest quality of carrots (*Daucus carota* L.), melons (*Cucumis melo* L.) and celery (*Apium graveolens* L.), but the positive effect of stress depends on when the plants are subjected to it.

Because water influences cell expansion and leaf water status, it might be expected that irrigation would affect postharvest quality of leafy vegetables. Luna et al. (2013a) studied the influence of both deficit and excess irrigation on respiration rate, tissue browning and microbial quality of fresh-cut romaine lettuce, the second most important type of lettuce after iceberg. The authors tested six different irrigation regimes set according to a standard irrigation regime (SIR): −35% SIR (<221 mm), −15% SIR (221−265 mm), SIR (266−320 mm), +15% SIR (321−370 mm), +35% SIR (>430 mm), +75% SIR (>430 mm). Irrigation regime influenced significantly not only the raw material at harvest, but also the post-cutting quality and the shelf life of fresh-cut romaine lettuce. An excess of irrigation increased polyphenol oxidase (PPO) activity and accelerated cut edge browning and microbiological growth, while a deficit of irrigation reduced cut edge browning despite the accumulation of phenolic compounds. Luna and co-authors (2013a) concluded that phenolic compounds in romaine lettuce are not a browning limiting factor, as had been reported in iceberg lettuce in another paper (Luna et al., 2012). The highest respiration rate was observed when lettuce was cultivated under the most severe deficit (−35% SIR) or excess of irrigation (+35% SIR). As expected, the highest deficit of irrigation decreased yield in terms of fresh weight, but also with the most extreme excess of water, as it was indicated by Fonseca (2006). A similar study conducted by the same authors growing iceberg lettuce gave similar results (Luna et al., 2012). Iceberg lettuce had greater head weight with a medium irrigation regime than those cultivated under deficit or excess regimes. Browning at the cut edge was increased with storage time particularly when the irrigation regime was increased during plant growth. Increasing the irrigation regime had a negative effect on lettuce quality, as high enzymatic activities were positively correlated with browning, while irrigation deficit preserved the quality and shelf life of fresh-cut iceberg lettuce.

The soil type and management not only affects the nutritional quality, but also the safety of the raw material. Frequent soil chemical analyses are essential for the efficient management of the soil–water–plant system to avoid crop production losses and decrease the environmental impact. The soil texture influences the mobility and efficiency of nitrogen and mineral uptake, which in turn has an impact on the quality of the final product. Cantaloupe grown in clay soil produced better-tasting fruit in terms of sweetness and flavor, with superior fresh-cut quality, in terms of less sour taste and off-flavor, than melons grown in sandy soil (Bett-Garber et al., 2005). Mylavarapu and Zinati (2009) found that the incorporation of compost improved the physical and chemical properties of sandy soils where parsley (*Petroselinum crispum* Mill.) was cultivated as well as increasing parsley yields. Compost application was beneficial for water and nutrient properties of sandy textured soils.

Soil type and management is also fundamental for the prevention of preharvest contamination of fresh produce by pathogens, heavy metals and pollutants. In order to develop strategies that minimize the risk of pathogen survival and spread within an agricultural system and food chain, it is important to understand the fate of pathogens, such as *E. coli*, in environmental substrates like manure-amended soils, and how manure-amended soils affect their survival. Franz et al. (2008) studied the effects of manure-amended soil characteristics on the survival of *E. coli* O157:H7 in 36 Dutch soils. Comparing sandy soils to loamy soils the authors observed that the initial rate of decline of *E. coli* O157:H7 is faster in sandy soils, but that the decline rate slows down more with progressing time than in loamy soils. The pathogen survival increased in soils with a history of low-quality manure application (artificial fertilizers and slurry) compared to those with high-quality manure application (farmyard manure and compost). The authors concluded that *E. coli* O157:H7 population declines faster in soil with a high carbon:nitrogen ratio and consequently a relatively low rate of nutrient release.

The pathogen contamination risk is high when growing vegetables, especially leafy vegetables like spinach, lettuce or rocket which are in direct contact with the soil and are consumed raw. In general, the presence of pathogens in soil amendments can be solved by using stabilizing organic residues instead of fresh organic wastes, ensuring proper composting. The use of animal slurry is rare in intensive vegetable production in Mediterranean regions, mainly due to food safety issues (Nicola et al., 2013). In fact, several food-borne disease outbreaks in recent decades have discouraged many vegetable growers from manure and slurry use, most probably as a preventive action because the safety of the available slurry and manure can be limited. The survival of food-borne pathogens is a potential threat to humans, and is far more important than any other quality aspect. Jensen et al. (2013) reported the transfer of *E. coli* from animal slurry fertilizer to lettuce. This occurred in a pilot study in which animal slurry was applied as fertilizer in three Danish agricultural fields, prior to the planting of lettuce seedlings, with *E. coli* serving as an indicator of fecal contamination and of potential bacterial enteric pathogens. The study revealed frequent contamination (44.9%) and levels above 2 log cfu/g in 42.4% of the contaminated samples of lettuce grown under natural conditions in slurry-amended soils. This fecal contamination indicates the potential presence of pathogens such as *Salmonella* and *Campylobacter*, which could represent a real hazard to human health. In addition, streptomycin- and ampicillin-resistant *E. coli* were found in 15.0% and 1.4% of the lettuce pools, respectively, which indicates a risk of transferring antimicrobial-resistant genes. Because a relatively high number of *E. coli* in lettuce was found at harvest compared with the numbers found in the soil, it was suggested that animal slurry fertilization was not the sole source of fecal contamination, but that the surrounding environment and wildlife played a role in the contamination with *E. coli*.

Evidently, all the environmental conditions surrounding plant growth have to be taken into account to set the most appropriate conditions to obtain optimal raw material at harvest. As fresh-cut produce is prepared from a raw material that is in contact with soil, microbial contamination can occur. GAPs and GHPs suggest that land used for grazing livestock is not suitable for growing vegetables, and it is recommended that manure and compost are avoided as fertilizers because they can be sources of microbial and heavy metal contamination.

Inherent fruit quality parameters, such as sugar and acid content, ripening and storability, and external fruit quality parameters, such as color, shape, stage of growth and firmness, are closely correlated to the main nutrients: nitrogen, phosphorus, potassium, calcium and magnesium. The nutrients can be supplied to the plant through distribution on the soil surface or by fertigation. Fertigation increases the efficient use of fertilizers and nutrient availability at root level, and in particular increases the mobility of potassium and phosphorus.

In fruits, nitrogen (N) is negatively correlated with the firmness, dry matter percentage, refractometric index, soluble sugar content and acidity. An excess of N availability causes poor fruit skin color development and increases plant susceptibility to pests and physiological disorders. In vegetables, particularly leafy vegetables, N supplied as nitrate is negatively correlated with dry matter percentage and directly correlated with the nitrate content in the edible portion (Fontana et al., 2004; Nicola et al., 2005b). In leafy vegetables, N fertilization can be scheduled to reduce the nitrate accumulation in plant parts in order to reach acceptable threshold levels, which are generally below 2500 mg/kg f.w. In the EU, specific limitations are set for the nitrate content in the final product for lettuce (*Lactuca sativa* L.), spinach (*Spinaca oleracea* L.) and rocket (*Eruca sativa, Diplotaxis* sp., *Brassica tenuifolia*, *Sisymbrium tenuifolium*) (EU Reg. 1258/2011, amending EU Reg. 1881/2006 which amended EU Reg. N. 563/2002).

Nitrate accumulation in plant parts depends on species, cultivar, season and cropping system and affects product marketability and postharvest shelf life (Fontana et al., 2004; Nicola et al., 2005b). Koh et al. (2012) compared the levels of nitrate, oxalate, ascorbic acid, vitamin C and flavonoids in 27 varieties of spinach grown in certified organic and conventional cropping systems. The nitrate content varied in organic (316.3−1170.4 mg/kg f.w.) and conventionally grown spinach (961.3−2453.5 mg/kg f.w.) depending on the cultivar. The nitrate content was significantly higher in the conventionally grown spinach than the organically grown spinach, and correlated positively with oxalate and negatively with ascorbic acid, vitamin C and flavonoids. The cropping system did not influence the oxalate content in spinach leaves, but did influence the ascorbic acid, vitamin C and total flavonoids. For all these parameters, spinach grown organically had higher contents than those grown conventionally. Of the 17 flavonoids determined, the levels of 10 were higher in the organic spinach than the conventional spinach.

Among the plant mineral nutrients, potassium (K) is the cation having the strongest effect on fruit quality attributes that determine fruit marketability, consumer preference and the concentration of phytonutrients (Lester et al., 2010, and citations therein). K effects on fruit marketability attributes include maturity, yield, firmness, soluble solids and sugars; on consumer preference they include sugar content, sweetness and texture; on phytochemical concentrations they include ascorbic acid and carotenoid concentrations. All these aspects depend on K application mode (wet, through foliar or hydroponic application, or dry, in soil), doses (applications number) and timing (plant stage, cultural season). Supplementing soil K with additional foliar K applications during cantaloupe development and maturation improves the fruit marketable quality by increasing firmness and sugar content, and boosts fruit nutritional quality by increasing ascorbic acid, beta-carotene and K levels (Lester et al., 2007).

The preharvest nutritional status of fruit, especially with respect to calcium (Ca), is an important factor that affects the potential storage life (Gąstoł and Domagała-Świątkiewicz, 2006). Fruits with a high level of Ca have lower respiration rates and longer potential storage lives than those containing low levels of Ca. Ca plays a key role in the retention of firmness, delaying fruit ripening and reducing physiological disorders. Many physiological disorders in fruits are associated with Ca deficiency. The easiest way to maximize the Ca level in fruit is to use a foliar spray, although in many instances the uptake required and penetration of Ca into the fruit and its movement within the fruit tissues is difficult to achieve (Mengel, 2002). Preharvest Ca sprays on apples increase fruit Ca, and frequently improve flesh firmness at harvest, especially during stressful seasons in which fruit Ca content is suspected to be relatively low, reduce the incidence of bitter pit and lenticel blotch after cold storage (Casero et al., 2009). The total fruit Ca increases in all seasons with Ca treatments, but this increase is not proportional to the number of applications.

Leafy vegetables used for the fresh-cut industry are, in general, obtained from open field production. Conversely, in Italy, most of them are obtained from protected cultivations, leading to increased yields and crop cycles, allowing out-of-season production, and the control of abiotic factors and facilitating pest management. In 2011, it was estimated that 6500 ha were used for the cultivation of leafy vegetables and greens, most of them in greenhouses (Casati and Baldi, 2011). The produce originates from different geographic areas, according to season. Each geographic area is characterized by different environmental conditions, cultivar availability and cultural practices. These factors can influence not only the quality of the raw material at harvest, but also the efficiency of postharvest technologies, such as the choice of operational temperatures and packaging systems. Fruit and vegetables are produced both in open field (Figure 9.1) and in protected cultivations, either in macro-tunnel or in greenhouse (Figure 9.2); some baby leaf species (e.g., rocket, corn salad, baby lettuce, spinach) or aromatic plants are produced in soil-less culture such as floating systems (FS) (Figure 9.3). Compared to the open field system, the protected culture system offers many advantages, for example, protection from damaging winds and other adverse weather conditions such as rain and hail, a reduction in evapotranspiration rate, an increase in photosynthesis rate and an advance in the harvest date. The covering material of the greenhouses enhances the internal air temperature, and leads to reduced air and soil temperature amplitudes. All these aspects affect plant health, and improve raw material quality, yield and safety.

Voća et al. (2006) compared strawberry crops grown in open field cultivation, soil protected cultivation and soil-less protected cultivation systems, and found that the cultivation system had a great influence on the color and firmness of the strawberry fruit (cv. Elsanta). Overall better fruit color was obtained in the protected cultivation systems, although the soil-less system gave the lowest fruit

FIGURE 9.1

Head lettuce varieties grown in open field.

FIGURE 9.2

Red Lollo grown in marco-tunnel (A) and baby leaf lettuce under greenhouse (B).

firmness. The overall chemical composition of the fruit indicated that the highest quality was reached with soil protected cultivation.

Vegetables usually contain relatively high numbers of microorganisms at harvest because they are in contact with soil during growth (Tournas, 2005). Not all microorganisms are capable of proliferating on vegetables. Several microbial species can break the protective cover of plants and then grow and cause spoilage; others can enter the plant tissue through wounds and can grow and damage the vegetable. Some fungal spores can survive for some time in the soil and

FIGURE 9.3

Soil-less culture system with sub-irrigations: the flotation system for basil (A) and lettuce (B).

contaminate plants one season after another; these organisms may cause plant disease in the field, as well as spoilage during storage. In these circumstances, field treatments with fungicides and the use of resistant cultivars are necessary to avoid disease development and spoilage. The avoidance of disease development and spoilage are main factors that favor the development of the soil-less culture system.

Protected cultivation is increasingly shifting from traditional culture systems (TCS) in soil to soil-less culture systems (SCS) (Nicola and Fontana, 2007), as SCS, based on the growing media, have some advantages over TCS. Most of the studies comparing TCS to SCS have indicated that SCS increase earliness, yield or both (Incrocci et al., 2001; Santamaria and Valenzano, 2001; Ferrante et al., 2003; Fontana et al., 2004; Nicola et al., 2005a,b; Fontana and Nicola, 2009). The protected SCS allows higher qualitative and quantitative standardization of cultural techniques, and the reduction of both production costs and environmental impact. The system is a valid alternative to the soil cultivation system as it helps to avoid soil-borne diseases, and controls mineral plant nutrition to standardize the qualitative characteristics of the final product. The use of mineral and sterile media with a low environmental impact may be an alternative to the practice of soil disinfection. When investigating a soil-less system to obtain uniform produce of high quality, it is crucial to adjust the nutrient solution, moisture and water content of the growing medium because they are the most important aspects, apart from growing environmental conditions.

The soil-less protected cultivation system is highly productive and has proved capable of enhancing the postharvest shelf life of many fresh-cut vegetables (Fontana et al., 2003, 2004, 2006; Fontana and Nicola, 2008, 2009; Hoeberechts et al., 2004; Nicola et al., 2003, 2004, 2005a,b; Sportelli, 2003). By comparing soil and soil-less culture systems for lettuce production in open field, Selma et al. (2012) showed that fresh-cut lettuce from SCS had a significantly higher antioxidant content and better microbial quality than fresh-cut lettuce from soil. The same research group (Luna et al., 2013b) studied the influence of different nutrient solution ion concentrations (low: 1.40 dS/m; medium: 1.90 dS/m; high: 2.40 dS/m) on the quality characteristics of three lettuce genotypes, including one green (butterhead cv. Daguan) and two red-leafed lettuces (Lollo Rosso cv. Evasion and red oak leaf cv. Jamai), cultivated in a soil-less system in open field in summer and winter. Postharvest shelf life of the fresh-cut product was also evaluated. The study indicated that quality differences at harvest and post-cutting changes depend more on the seasonal variation and genotypes than on the nutrient solution ion concentration. In summer, the maturity index was higher and the dry matter lower than in winter. Red-leafed lettuces showed the highest antioxidant content, helping the maintenance of sensory characteristics throughout storage; they are preferred to butterhead varieties because they are more resistant to mechanical stress and have a longer shelf life, thus red-leafed genotypes could be better for growing under medium nutrient solution ion concentration.

Of the different soil-less cultivation systems, the floating system (FS) is a recent innovation that has led scientists and extension specialists to consider it as a way of producing leafy vegetables with characteristics that satisfy the requirements of the entire production chain. The system is suitable for raising vegetables with both a short production cycle and high plant density; it can be considered an efficient system to produce leafy vegetables with high added value, processed as fresh-cut produce.

The FS is a sub-irrigation system that consists of trays that float on a water bed or nutrient solution (Nicola, 1993; Pimpini and Enzo, 1997; Thomas, 1993) (Figure 9.3). FS can be implemented either with continuous flotation (FL) or with an ebb-and-flow flotation (EF) scheduling. EF is scheduled with drying (ebb) periods. A sub-irrigation system increases the precision of fertilizer application to plants by reducing water leaching during irrigation. FS allows the produce quality at harvest to be improved, reduces microbial contamination and eliminates soil and chemical residue spoilage. Normally, produce obtained from TCS can reach a total bacterial count of 10^6-10^9 cfu/g, which can be reduced by 2−3 log cfu/g after washing and sanitation practices. On purslane (*Portulaca oleracea* L.) grown in FL, the initial mesophilic load and *Enterobacteria* counts load was 2.7−3.0 log cfu/g and 2.1−2.2 log cfu/g, respectively, on processing day (Rodríguez-Hidalgo et al., 2010).

FL used to grow green lettuce, red lettuce and spinach, and EF used to grow rocket resulted at harvest in an average TPC of 10^3 cfu/g and YMC of 10^2; only spinach had a higher contamination of TPC (10^6 cfu/g) (Nicola et al., 2011). In general, fresh-cut green lettuce at the end of nine days of shelf life at 4°C had same magnitude of contamination, while fresh-cut mix of green lettuce and either red lettuce, rocket or spinach increased of two logs. The raw material obtained using FS in a confined greenhouse is free of soil residue and dirt, and considering the overall very low microbial contamination, it was hypothesized that washing is considered a critical point in the production process of ready-to-eat vegetables. The use of floating systems allows softer washing procedures to be used, such as eliminating chlorine from the water sanitation process, resulting in less stress for the leaf tissue.

Selma et al. (2012) assessed the microbiological quality of fresh-cut lettuce obtained by soil- and soil-less procedures. Cultivation was in open field and the SCS used was the NGS™ (New Growing System, NGS™ Almería, Spain, patent no. 2.221.636/7). The soil-less culture system was more effective in controlling microbial contamination because soil-less grown lettuce had a lower initial microbial load and showed slower microbial growth during storage. At the end of the intended shelf life period, the differences in microbial counts were 3 and 1.5 log units higher for lactic acid bacteria and total coliforms than in samples from soil-grown lettuce. A higher sanitary quality can be provided by the soil-less culture system as an alternative to traditional soil cultivation, because it avoids soil contaminants and achieves lower coliform counts.

D Raw material harvest and handling

Good preharvest and harvest practices are necessary to reduce commodity damage. It has been extensively reported that the quality of a raw material and the storage conditions before processing are very important to keep the quality of a vegetable (Wiley, 1994). The harvest, handling, shipping and storage (HHSS) before processing are stages where low temperature conditions are vital to preserving the quality of the raw material. The cold chain should, in fact, begin as early as possible and be maintained from the field to the processing plant. Low temperatures, in the range 0 to 10°C, depending on the species and cultivar, keep the turgor in vegetables unaltered and slow microbial contamination. However, production operations are not yet broadly organized or optimized to handle the harvest phase with a minimum lag time before implementing the cold chain.

Currently, fresh-cut vegetable shelf life is ca. 6–7 days in Italy and in many other EU countries. The shelf life of fresh-cut produce in the United States exceeds two weeks, depending on the species. The long shelf life is achieved, apart from the limited range of species and typologies produced, due to prompt cooling and the maintenance of the cold chain (see also Chapter 16), with temperatures generally below 4°C, after harvest and during processing, shipping and distribution, while these temperatures are rarely maintained in many European countries.

The stage of maturity of fruit and vegetables destined for fresh-cut processing is a critical factor that helps to determine the potential quality and shelf life of the product. The eating quality and shelf life of fresh-cut fruit products are influenced by the stage of ripeness at cutting (Gorny et al., 2000). Leafy vegetables taste best when harvested immature, while fruit vegetables and fruits taste best when harvested fully ripe (Kader, 2008). Maturity and ripeness stage at harvest are critical issues for fruits. Harvesting fruits before they reach optimal maturity is a common commercial practice because of the higher prices obtained when the supply is low at the beginning of the harvest season. Early harvesting of climateric fruits ensures fruits are more resistant to mechanical stresses and store longer. Conversely, harvesting at optimal maturity based on flavor would be more appropriate to allow increase the synthesis of non-volatile and volatile compounds influencing fruit flavor, or good eating quality cannot be achieved (Kader, 2008). Currently, customer dissatisfaction with produce flavor contributes to the low consumption of fruits and vegetables (Mitcham, 2010). It is necessary to encourage the growers to harvest fruits at partially ripe to fully ripe stages by developing handling techniques to protect fruit from physical damage (Kader, 2008).

Currently, the shelf life of fresh-cut fruits is ca. five days because it is quite difficult for the fresh-cut industry to maintain the proper ripening stage on a commercial scale. Fruit is generally harvested at the "partially ripe" stage, which is an imprecise definition (Bai et al., 2009) and varies within the same species according to the species and cultivar. The maturity stage of fruit for the fresh-cut industry is much debated: harvesting "partially ripe" fruit means easier management of fresh-cut processing and quality control during distribution compared to harvesting "riper" fruit, which is more flavorful and softer, but more difficult to handle for growers, processors, and retailers. For these reasons, fresh-cut apple offer has rapidly increased in recent years because apples are easier to manage compared to other fruit, such as peach, pear or tropical fruit. Bai et al. (2009) suggested that pear fruit should be harvested one month later than current commercial practice to improve the quality of flat flavor, firm and rough texture, and to limit the high potential for browning. Results from experiments showed that by delaying harvesting, the fruit had larger size, lower flesh firmness, lower titratable acidity, lower phenolic content and higher volatiles. These parameters enhance consumer acceptance and, in fact, a panel preferred the delayed-harvest cut fruit compared to those from commercial harvest, especially in terms of visual quality, flavor, texture and overall quality.

In the case of leafy vegetables, there is a wide range of possibilities for harvesting raw material depending on the final destination of the produce, the requested quality attributes and their resistance to the postharvest handling and processing. The maturity indicators of intact leafy vegetables are size, head length, head width, firmness and compactness; while for non-heading lettuces, the number of leaves can be used as a harvest index (Gil et al., 2012, and citations therein). Size is the maturity indicator for Belgian endive, cabbage, endive, iceberg lettuce, radicchio, spinach and Swiss chard. Furthermore, head compactness is an important maturity indicator for cabbage and iceberg lettuce. In general, different maturity indicators can be used for harvesting lettuce for the fresh-cut industry. Head weight is the main parameter for quality evaluation of head vegetables, while for baby and mature leaves, leaf and petiole length are good maturity parameters to ensure the quality of the fresh-cut product. For culinary herbs, the harvest maturity can have an effect on the aromatic profile. Early harvesting, fresh-cut processing and shelf life conditions can differently influence each compound, improving or worsening the essential oil (EO) quality according to the final use by the industry (Fontana et al., 2010). The aromatic profile of dill (*Anethum graveolens* L.) changed when dill leaves were harvested as young leaves (38 days after sowing), at pre-blossoming and blossoming stage (50−70 days after sowing) or at full fruit maturity (130 days after sowing) (Tibaldi et al., 2010a).

The growth stage at harvest can influence the shelf life of the baby leaves harvested at an early growth stage due to market demand. The rate of deterioration has often been related to metabolic processes and respiration rate, which are usually higher in younger leaves. The high respiration rate explains why it is hard to reach a commercial shelf life longer than seven days. Young and tender baby leaf vegetables of new varieties and species are continuously been developed for the fresh-cut industry, but younger plants tend to accumulate more nitrate (Fontana and Nicola, 2008). It is then crucial to establish the harvest maturity indicators to describe the right time for harvesting raw material with high nutritional value and optimal postharvest performance.

Harvesting directly affects the appearance and shelf life of the final product. The safety and quality of fresh-cut produce depend not only on the cultural practices and postharvest conditioning, but also on the harvesting and handling procedures. Factors that can affect the microbial condition of the raw material include the climatic conditions which the plants are produced in, and the temperature and the air conditions at which the produce is stored after harvest. Harvesting in the heat of the day causes wilting, shriveling, softness and a high respiration rate and shortens shelf life considerably (Perkins-Veazie, 1999). Zhan et al. (2009) found that leaving garden cress (*Lepidium sativum* L.) harvested leaves at 28°C for 1 h, simulating summer air temperatures, negatively influenced the pigment content, which decreased over time, and caused ca. 13% loss in ascorbic acid before packaging. PPO and peroxidase (POD) activities were higher in garden cress leaves kept for 1 h at 28°C than leaves processed promptly. The high air temperature affects the leaf turgidity and increases the susceptibility of leafy vegetables to the physical damage during harvest handling practices. An efficient and rapid harvest handling and storage implementation after the cultivation phase are fundamental factors that favor the quality of the raw material, thus improving the processing and reducing the quality deterioration during shelf-life.

Rough handling creates areas that darken, soften and make the product vulnerable to pathogen attacks. Microbes can also readily attach to cut leafy vegetable surfaces (Takeuchi and Frank, 2001) reducing the safety and nutritional quality (see also Chapter 11). At harvest, appropriate measures should be taken to reduce or eliminate the potential risk of pathogen contamination through soil contact at the cut surface. The reduction or elimination of pathogens can be achieved by cleaning the cutters and containers, by increasing the cutting quality, e.g., cutter sharpening, and by guaranteeing the hygiene of the field workers.

The harvesting method, whether by hand or mechanical, and the handling can determine the variation in maturity and physical injury and, consequently, can influence the nutritional composition of vegetables. The use of good preharvest, harvest and handling practices is necessary to reduce commodity damage. Harvesting early in the morning, before plants become warm and their respiration rate increases, reduces the need for cooling and often lengthens the preprocessing storage. Placing the harvested produce quickly under shade, in opaque or dark boxes, or using white tarpaulins to reflect heat from the filled bins can cut the load temperature by 30% (Perkins-Veazie, 1999). The often disregarded stages of the supply chain, the harvesting and handling, should be optimized and the cool chain implemented as early as possible to maintain product quality (Thompson et al., 2001) in order to guarantee food safety and to reduce the amount of cooling needed afterwards (Figure 9.4; see also Chapter 16).

Fresh fruit and vegetables are living tissues, and subject to continual changes after harvest. Fresh produce consumes photosynthates that were stored in the product before the harvest. The consumption rate depends on the respiratory

FIGURE 9.4

Harvested iceberg lettuce stored in a dark, cold room (4°C) before processing.

activity of a particular commodity and its temperature. Delays between harvesting and cooling or processing can result in direct losses due to water loss and microbial contamination and indirect losses, such as flavor and nutritional quality loss (Thompson et al., 2001; Zhan et al., 2009) (see also Chapter 5). The rate of product deterioration is proportional to the rate of respiration, which increases exponentially with the temperature (Cantwell, 2007). Shriveling and the loss of fresh and glossy appearance are two of the most noticeable effects of cooling delays, particularly for commodities that lose water quickly and show visible symptoms at low levels of water loss, like most leafy vegetables. A correlation has been found between the respiration rate and shelf life (Ninfali and Bacchiocca, 2004). Vegetables characterized by low respiratory rates, such as carrots, have a long shelf life. Preprocessing storage conditions are fundamental to preserve raw material quality; the optimal vegetable storage temperature should be observed to avoid chilling injuries, such as browning or pitting, and vegetable thermal shock due to the high temperature gap between the field and the storage room.

III Processing management for the fresh-cut chain

Fresh-cut processing accelerates the color, texture, firmness, flavor and nutritional value deterioration of a product and compromises its shelf life. Moreover, wounded surfaces provide favorable conditions for microbial growth. Therefore, adequate control strategies during the storage of fresh-cut produce should minimize nutritional and sensorial loss and microbial growth. Proper handling, the use of effective sanitizers, adequate temperature storage, and packaging are the main ways of reducing rapid degradation of the fresh-cut produce.

A The postharvest quality of fresh-cut produce

It was previously stated that cultivars, environmental conditions, irrigation practices, fertilizers and pest control programs affect produce quality. Practices such as washing, sorting (see also Chapter 12), sizing, cutting, blending and packaging do not change the inherent quality, but add value for the consumer, who is looking for convenience, yet healthy and tasty food (Figure 9.5). Like any perishable product, fresh-cut fruit and vegetables are characterized by an irreversible deterioration of quality. Therefore, the sensory quality of these types of products cannot improve during further storage; it can only be retained or deterioration can be retarded by applying optimal processing and packaging techniques, a proper storage temperature, and eventually application of enzymatic browning inhibitors (Watada and Qi, 1999) and ethylene or oxygen absorbers (Markarian, 2004). Because consumer preferences differ between consumer segments, part of the postharvest activity is also related to direct the appropriate product to the responsive consumer segment.

Fresh products are susceptible to deterioration between harvest and consumption and this may reach very high values after harvest, depending on the species, harvesting and handling methods, processing, length and temperature of storage and distribution, market conditions, etc. A longer shelf life, therefore, depends on a combination of correct cooling storage throughout the entire chain, modified atmosphere packaging conditions and good manufacturing and handling practices (Kader, 2002a). The main objectives of postharvest technology concern quality and safety assurance, and loss reduction in the postharvest chain.

B Cutting

Producing fresh-cut fruit and vegetables involves substantial mechanical injury due to peeling, slicing, dicing, shredding or chopping (Portela and Cantwell, 2001) (Figure 9.6). Thus, the physiology of minimally processed fruit and vegetables is essentially the physiology of wounded tissues, which are subjected to an increase in respiration rate and ethylene production, membrane degradation leading to cellular disruption and de-compartmentalization of enzymes and substrates, and accumulation of secondary metabolites. All these biochemical reactions are responsible for changes in quality characteristics, such as texture, color, flavor and nutritional value (Portela and Cantwell, 2001, and citations therein). Many factors affect the intensity of the wound's response in fresh-cut tissues. These factors include species and cultivar, stage of physiological maturity,

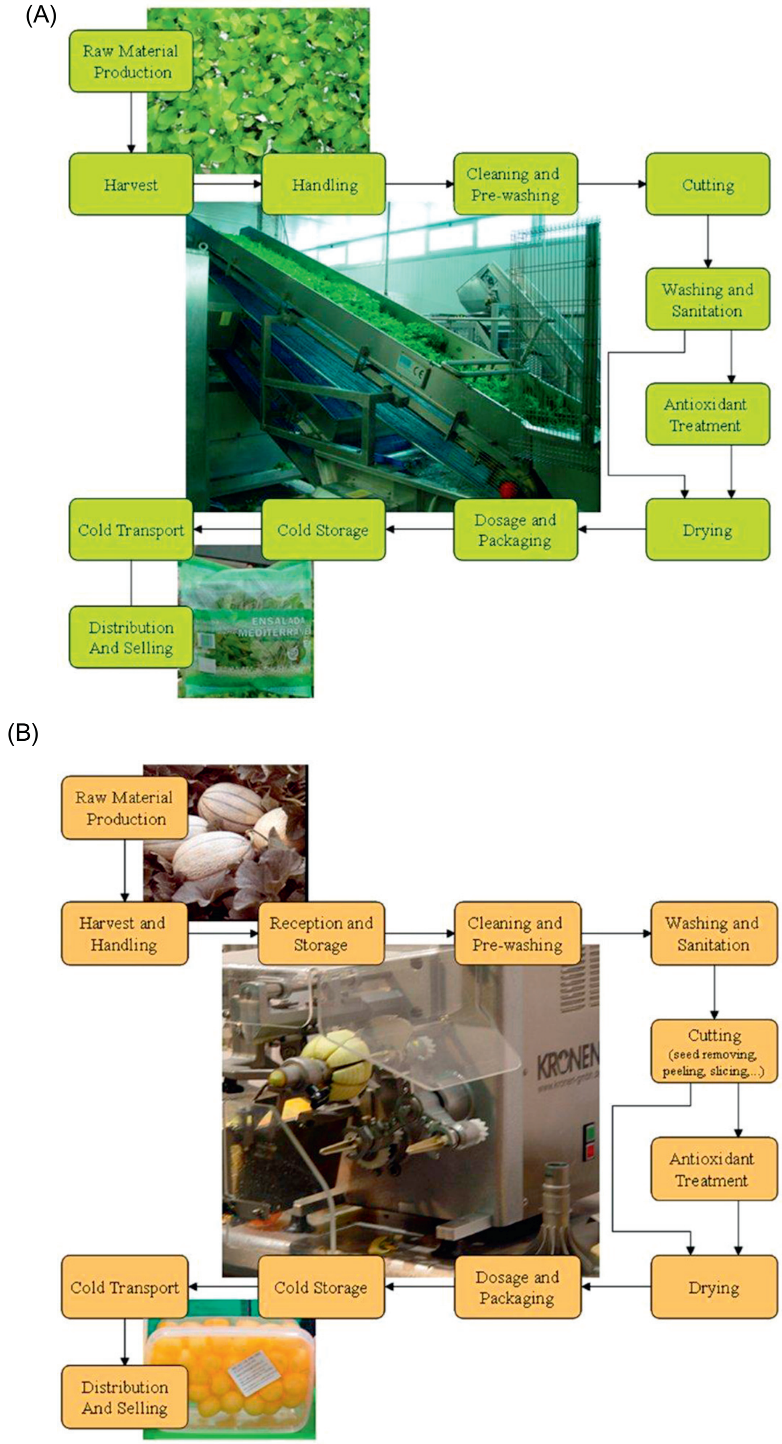

FIGURE 9.5

General flow diagrams of processing operations for leafy vegetables (top) and fruit (bottom).

FIGURE 9.6

Slicing onions (A), trimming asparagus (B), peeling carrots (C), slicing tomatoes (D) in fresh-cut processing plants.

temperature, O_2 and CO_2 concentrations, water vapor pressure, various inhibitors and severity of wounding (Cantwell, 1992; Brecht, 1995).

The severity of wounding depends on the type of cutting, cutting area size and cutting shape. The response of the tissue to processing wounds usually increases as the severity of the injury increases. Peeling and cutting increase the respiration rate from one-fold to seven-fold, compared with the same fresh whole produce (Rivera-López et al., 2005). Del Aguila et al. (2006) measured the differences in respiration rate, ethylene production and soluble solids between whole and shredded radish (*Raphanus sativus* L. cv. Crimson Gigante) and between shredded and sliced radish. During cold storage, the respiration rate of whole radish remained stable, while oscillations in fresh-cut radish were observed, with a generally higher respiration in shredded radish. Nine hours after processing, ethylene production was higher in the shredded and sliced radish than in the whole radish, and the shredded radish lost more soluble solids than the sliced or whole radish. The decrease in soluble solids was partially attributed to the consumption of carbohydrates during respiration related to the repair of injury, and the higher injured area of shredded radish may have caused an amplification of the response to injury.

Tibaldi et al. (2010b), when comparing two cutting shapes (slice versus dice) in fresh-cut processing operations of pumpkin (*Cucurbita moschata* Duchesne), packaging the fresh-cut products in three films with different permeance to O_2 and storing the packaged bags either at 4° or 8°C, found that fresh-cut pumpkin can be stored for nine days at 4°C if it is sliced and packaged with a film permeance above 1300 $cm^3\ m^{-2}\ d^{-1}\ bar^{-1}$ because of its lower respiration rate compared to dice-shaped pumpkin. Nicola et al. (2012) repeated the same experiment on *Cucurbita maxima* Duchesne and confirmed the previous results. The larger cutting area of pumpkin dices compared to that of pumpkin slices accelerated the quality decay promoting anaerobic processes at the end of the shelf-life. Deza-Durand and Petersen (2011) investigated the effect of cutting direction on aroma compounds and respiration rates in fresh-cut iceberg lettuce. During fresh-cut processing operations, lettuce was cut either longitudinally or transversally to the mid-rib and then stored either at 6°C or 10°C for four days after having placed the fresh-cut lettuce in jars sealed with punctured films. The results showed that cutting the lettuce transversally to the mid-rib caused more severe damage to the tissue than cutting longitudinally, based on the increase in the levels of volatiles produced through the lipoxygenase (LOX) pathway responsible of off-odor development. Deza-Durand and Petersen (2011) hypothesized that, because LOX is a stress-related enzyme, the higher damage in lettuce cut in the transverse direction might indicate a greater disruption of membranes. A higher respiration rate of lettuce was observed for transverse cutting at the beginning of the storage period in comparison with longitudinal cutting, but decreased sharply after one day of storage. The respiration rate was not as good an indicator of stress as cutting direction because it was mainly affected by storage temperature.

Cutting and shredding should be performed with the sharpest possible knives or blades made from stainless steel (Allende et al., 2006). Saltveit (1997) considered that very sharp cutting tools could limit the number of injured cells. Barry-Ryan and O'Beirne (1998) observed that carrot slices prepared using a sharp blade had a reduced microbial load and off-odor development, and were characterized by a higher microscopic cellular integrity and a longer shelf life than slices prepared using a blunt blade. Portela and Cantwell (2001) evaluated the consequences of blade sharpness and thereby the degree of wounding on the appearance and physiology of fresh-cut cantaloupe. Pieces prepared using a sharp borer maintained marketable visual quality for at least six days, while those prepared using a blunt borer were unacceptable at six days, due to surface translucency and color changes. Borer sharpness did not affect the changes in decay, firmness, sugar content or aroma, while blunt-cut pieces had increased ethanol concentrations, off-odor and electrolyte leakage compared to sharp-cut pieces.

Cutting technique quality can influence microbial growth and the bacterial cross-contamination. Gleeson and O'Beirne (2005) evaluated the effects of different slicing methods on the subsequent growth and survival of *E. coli*, *L. innocua*, and background microflora during storage at 8°C on modified atmosphere packaged vegetables (sliced carrot, and sliced iceberg and butterhead lettuce). In general, the slicing method had no significant effect on the initial inoculation levels. *L. innocua* grew better and *E. coli* survived better on vegetables sliced with blades that caused the most damage to cut surfaces. Slicing manually with a blunt knife or with machine blades gave consistently higher *E. coli* and *L. innocua* counts during storage than slicing manually with a razor blade. The effects of hand tearing were similar to slicing with a razor blade. The slicing method also affected the growth of the total background microflora; razor-sliced vegetables tended to have lower counts than other treatments. Product respiration was also affected by the slicing method; the use of a razor blade resulted in lower respiration rates.

Different new solutions have been tested to prevent the acceleration of decay due to peeling, cutting or slicing, e.g., the "immersion therapy", which consists of cutting a fruit while it is submerged in water. The cutting of a submerged fruit controls turgor pressure, due to the formation of a water barrier that prevents movement of fruit fluids, while the product is being cut (Allende et al., 2006). Additionally, the watery environment helps to flush potentially damaging enzymes away from plant tissues. Another technique is the cutting operation performed under ultraviolet-C (UV-C) radiation. Lamikanra et al. (2005) observed that post-cut application of UV improved shelf life of cut cantaloupe, while cutting fruit under UV-C radiation further improved product quality. More specifically, the study found that UV-C radiation during processing reduced rancidity and improved firmness retention in the stored fruit. The UV-C radiation also reduced spoilage microorganisms such as mesophilic and lactic acid bacteria.

Finally, the "water jet cutting" method which is successfully used for, e.g., meat, poultry, and vegetables (McGlynn et al., 2003), can also be used in the fresh-cut industry. This is a "non-contact" cutting method (Allende et al., 2006) which slices fresh fruit and vegetables utilizing a high pressure fluid jet that minimizes bruising in the cut pieces and tissue damage in the vicinity of the cut surface (http://www.freepatentsonline.com/4751094.html). This method reduces the excessive tissue damage caused by compression and tearing the piece along the cut surfaces. It has been found that in fruit and vegetables sliced with a high-pressure fluid jet, the cell tissue damage is minimized, so that when the fruit or vegetable is subsequently eaten, it provides essentially the same sensory qualities, odor, texture, and taste as the freshly harvested fruit or vegetable. This type of slicing, together with proper storage conditions, allows produce shelf life to be prolonged in comparison to other conventional cutting methods, such as regular kitchen paring knives, commercial rotary blade cutters, razor-sharp, or thin-blade knives. The vegetables particularly adapted to being cut by this method are fresh root vegetables, leafy vegetables and fruit and vegetables with firm tissue. The efficiency of this cutting method depends on the orifice size, water pressure, and standoff distance, which must be tuned according to the inherent characteristics of the species and cultivar (Bansal and Walker, 1999). McGlynn et al. (2003) assessed the effect of water jet cutting on the shelf life of cut watermelon (*Citrullus lanatus* cv. Sangria). A comparison of pieces cut with a water jet with those cut with a knife showed that the former were firmer than the latter after seven and 10 days of storage, and this difference was presumed to be due to weight loss. The experiment showed that water jet-cut watermelon pieces tended to lose less moisture during storage than knife-cut pieces. The decrease in weight loss due to the loss of liquid during storage could have a significant impact on the consumer perception of freshness and texture, and could influence microbial control strategies.

C Washing, sanitation systems and processing aids

During processing, pre- and post-cutting washing operations of produce are crucial to make the product ready to eat. The produce has to be clean, free of soil residue, insects, metals and weeds and safe. The raw material should be carefully cleaned before processing, because fresh-cut produce is prepared from material grown mostly in contact with soil and without any strong antimicrobial treatments, such as pasteurization or sterilization. Even healthy-looking products from the field can harbor large populations of pathogens, particularly during warm weather.

Washing raw material before cutting (fruit and vegetables) and during fresh-cut processing (leafy vegetables) is the most effective way of minimizing the risk of the presence of pathogens and of removing any residue left on the produce from harvest and handling conditions (Figure 9.7). When fruit and vegetables are exposed to water containing pathogens, they often become infected and subsequently decay during shipping and handling. Pathogens present on freshly harvested products accumulate in recirculated water handling systems and greatly reduce sanitation efficiency. Fresh-cut produce is highly susceptible to microbial contamination, because microbial cross-contamination can occur through shredders and slicers and the inner tissues can be exposed to microbial attachment and growth after cutting. Many postharvest decay problems result from the ineffective sanitizing of dump tanks, flumes and hydro-coolers. Moreover, the operations should be conducted at a low temperature to reduce microbial growth. A delay between pre-washing and subsequent operations without product refrigeration can allow microbial growth and a subsequent shortening of the shelf life, as reported by Sinigaglia et al. (1999) concerning cut lettuce salad and shredded carrots.

The effectiveness of washing to remove soil impurities and microbial contaminations is related to numerous factors, such as raw material spoilage, the duration of the washing treatment, the washing water temperature, the method of washing (dipping, rinsing or dipping/blowing), the type and concentration of the sanitizer, the type of the sanitation method (chemical or physical treatment) and the type of fresh-cut fruit or vegetable. At the moment, the disinfection agents used and tested for water and produce sanitation are chlorine, ozone, organic acids, hydrogen peroxide, alcohols, phosphoric acids, while the physical methods used and tested are ultraviolet (UV) light radiation, ultrasound, high pressure (HP), high-intensity electric field pulses (HEP), radio frequency (RF), ionizing radiation and hot water treatments, including the combination of some of them for synergistic

FIGURE 9.7

Washing of fresh-cut lettuce (A) and basil (B) in processing plants. View of a processing plant (C).

effects (Weyer et al., 1993; Zhuang and Beuchat, 1996; Beuchat et al., 1998; Sapers and Simmons, 1998; Day, 2001; Seymour et al., 2002; Allende et al., 2006, and citations therein; Artés et al., 2007; Kim et al., 2007, 2013; Gil et al., 2009; Gopal et al., 2010; Nou and Luo, 2010; Beirão-Da-Costa et al., 2012; Birmpa et al., 2013; Ramos-Villarroel et al., 2014; Wulfkuehler et al., 2013).

In the last decade, essential oils (EOs) have also been studied as natural disinfectants or antimicrobial agents (Roller and Seedhar, 2002, and citations therein; Scollard et al., 2013). In a review written by Ayala-Zavala et al. (2009) on using the antimicrobial and aromatic attributes of essential oils to enhance safety and aromatic appeal of fresh-cut fruits and vegetables, the antimicrobial effect of thymol, eugenol, menthol and other compounds against pathogens, together with suggested possible combinations of fresh-cut fruit and vegetables and essential oils are extensively reported. However, the high risk of transference of off-odors from the essential oils to the commodities raises the need for further sensorial investigations; the positive or negative sensorial impact of essential oil on fresh-cut produce should be additionally considered. Scollard et al. (2013) examined the anti-listerial effectiveness of selected EOs and shredded herbs (thyme, oregano and rosemary) on a range of modified atmosphere packaged fresh-cut vegetables (lettuce, carrot discs, cabbage and dry coleslaw mix). The authors found that the anti-listerial effects were in the order: thyme EO > oregano EO > rosemary herb. The antimicrobial effects of EOs varied depending on which EO was used and the type of fresh-cut vegetable involved. Both anti-listerial and general antibacterial effects were observed for thyme and oregano EOs. Thyme EO was found to be the most effective treatment against *Listeria*. Oregano EO was also found to have strong anti-listerial effects, but not as strong as those of thyme EO. Rosemary EO showed no anti-listerial effects except in the presence of shredded cabbage, and these effects were considerably smaller than those of the other EOs. By contrast, strong anti-listerial effects were evident from rosemary herb, but only after stomaching, indicating that the herb is only effective when it is completely macerated with the vegetable sample in the stomacher. Furthermore, the efficacy of the treatments varied according to the vegetable tested.

Alternative methods to extract the active compounds recently became available. They have the advantages of being less time and energy consuming than hydro-distillation, the traditional procedure used for the industrial extraction of EOs. Additionally, they do not require re-distillation to obtain the pure product and avoid the problems of compound thermal degradation (Orio et al., 2012). The techniques include supercritical fluid extraction, ultrasound-assisted extraction and microwave-assisted extraction. Comparison between the extraction methods has indicated a comparable profile of volatile secondary metabolites in the EOs obtained from mint species (Orio et al., 2012) and other *Lamiaceae* species (Binello et al., 2014). Several studies are ongoing to test the efficacy of the EO extracts with these different methods for studying the antimicrobial effects directly on microbial culture obtained from organically grown lettuce (Nicola et al., data not published).

Ozone reduces the amount of wastewater, lowers the refrigeration costs of chilled water because of the less frequent flume water changing, and it can be combined with chlorine, whose use can be reduced by 25% leaving less residual odor on the product (Strickland et al., 2010). The main systems for ozone application include gaseous phase storage or ozonated dips. Several studies have demonstrated that gaseous ozone is generally more effective than aqueous solutions (Ramos et al., 2013). The use of ozonated water has been suggested as an interesting alternative to chlorine due to its efficacy at low concentrations (0.2−5 ppm) and short contact times (from 15 s to a few minutes). However, the efficacy of ozonated water depends on ozone solubility, which increases as the water temperature decreases and is influenced by the organic content and pH of the water (Artés et al., 2009; Ölmez and Kretzschmar, 2009).

Organic acid (e.g., lactic, citric, acetic or tartaric acid) dippings have a much greater residual antimicrobial effect than ozone and chlorine treatments on the microflora of lettuce during storage (Akbas and Ölmez, 2007). The antimicrobial action of organic acids depends on several factors, such as a reduction in pH, the ratio of the un-dissociated fraction of the acid, chain length, cell physiology and metabolism. Organic acids with only one carboxylic group, such as lactic acid, have been found to be less active than citric acid which has more carboxylic groups. A calcium lactate treatment has been reported to have potent antibacterial properties (Saftner et al., 2003). Martín-Diana et al. (2005) compared calcium lactate with chlorine as a washing treatment for fresh-cut lettuce and carrots. Calcium lactate was not significantly different from chlorine treatment in terms of maintaining color and texture during the entire storage period. Furthermore, carotenoid levels were higher in calcium lactate-treated carrots than in chlorine-treated samples after 10 days of storage at 4°C. Ultimately, the mesophilic, psychrotropic and lactic acid bacteria counts were not significantly different for the calcium lactate and chlorine treatments for either vegetable. Thus, calcium lactate appears to be a suitable washing treatment, having no post-treatment bleaching effect on fresh-cut lettuce and does not cause the appearance of whiteness on the surface of sliced carrots.

At present, chlorination is used primarily in processing plants, although there have been many attempts to find alternative washing treatments to chlorine because of the formation of carcinogenic chlorinated compounds (chloroamines and trihalomethanes) in water. Furthermore, chlorine compounds can burn the skin and release dangerous chlorine gas into the work environment (Martín-Diana et al., 2005; Page et al., 1976; Parish et al., 2003; Suslow, 2006; Wei et al., 1995). However, a sure and conclusive disinfection system that is able to remove dirt, weeds, pesticide residues and microorganisms, while at the same time not negatively affecting the intrinsic and extrinsic quality of the product has yet to be found.

When planning the concentration of chlorine to be used one should consider its reaction with organic matter. When the chlorinated solution comes in contact with cut produce, the sanitizer will react with the organic matter (such as vegetable tissue, cellular juices, soil particles, microbes) and the available (free) chlorine will be depleted. The difference between total chlorine and available chlorine depends on the amount of organic matter and inorganic compounds that react with the free chlorine (resulting in combined chlorine) during washing (Pirovani et al., 2004). The lower the amount of organic cellular compounds released by cutting the produce, the smaller the difference between the total and available chlorine. Consequently, the proper concentration of chlorine to be used during sanitation should also be considered according to the type of produce, cut size and type (e.g., slice, shred, whole leaf).

The chlorine concentrations and washing times vary to a great extent from processor to processor, and these differences are mainly related to the different operational temperatures and the resulting bleaching effects that are tolerated by the consumers in any given market. Chlorine lethal effect increases with temperature and its effect on microbial removal occurs when the water is warmer than the produce (Hernandez-Brenes, 2002; Beuchat, 2007). According to Beuchat (2007), the lethal effect of chlorine occurs within the first few seconds of treatment, and the population of microorganisms decreases as the concentration of chlorine increases to about 300 μg/ml, above which its effectiveness is not proportional to the increased concentration. Treatments with 50–200 μg/ml chlorine and a washing time of 1–2 min can reduce the number of microorganisms by 1–2 log cfu/g in some instances, but can at the same time be completely ineffective in others (Hernandez-Brenes, 2002; Roller and Seedhar, 2002). Most fresh-cut processors in the Mediterranean use a concentration of chlorine of between 30 and 50 μg/ml to avoid bleaching and fading effects on the products, with operational water temperatures close to 12°C. Several studies have demonstrated that chlorine rinses can decrease the bacterial load from < 1 log cfu/g to 3.15 log cfu/g, and its efficacy depends on inoculation method, chlorine concentration, contact time, and microorganism type (Ramos et al., 2013).

Raw material is generally washed in cold water, because low temperatures slow down plant respiration, transpiration, warming and microbial activity. Water temperatures range between 4°C and 12°C, although washing hot raw material (e.g., summer in the Mediterranean) with colder water could cause the vegetable tissues to absorb any chemical contaminants present in water (Hernandez-Brenes, 2002, and citations therein). Maintaining the water temperature 5°C above the internal temperature of the produce can prevent this "suction" effect. One precaution could be an initial air-cooling step before washing to minimize the temperature gap between the produce and the water temperature.

After washing, with or without a chemical sanitizer, a sanitation physical method or a dipping treatment could occur on whole or cut or peeled produce. Several studies have investigated the effects of dipping treatments on the quality and safety of fresh-cut fruit and vegetables. Dipping operations are processing aids used for chemical and physical treatments and post-cutting application of additives. Heat treatments are becoming very popular in the fresh-cut industry, especially in preventing the detrimental effects of enzymatic browning responsible for color, flavor and texture change as well as of nutritional value decrease and in inhibiting microorganism growth. Heat treatments can be applied in the form of hot water treatment, vapor heat treatment, hot air treatment or hot water rinse brushing (Sivakumar and Fallik, 2013). The former treatment is currently the most common in the fresh-cut industry. Several studies have investigated the application of heat treatments by dipping for quality retention and safety control to replace the use of chemical treatments in fresh-cut carrot (Alegria et al., 2012), melon (Aguayo et al., 2008), broccoli florets (Moreira et al., 2011), potato (Tsouvaltzis et al., 2011), mango (Djioua et al., 2010), peach (Steiner et al., 2006; Koukounaras et al., 2008) and kiwifruit (Beirão-da-Costa et al., 2008). In general, temperatures used for hot water dips on different fresh-cut products can range from 40° to 60°C, while dipping duration ranges from a few seconds to many minutes (up to 70 min). The hot water treatment conditions depend on the type of produce (leaf, fruit, root, etc.), maturity stage, fruit size, cultivar, growing conditions and on timing of application as a pre- or post-cutting treatment. The selection of appropriate treatment conditions (temperature × duration) is a crucial factor in determining the overall quality of the horticultural product at the end of treatment and during shelf life.

Dipping treatments could consist of using a solution containing anti-browning compounds, such as ascorbic acid or a calcium salt with an organic acid, antimicrobial agents or edible coatings to extend the post-cutting shelf life of fruit and vegetables. Edible coatings, a new strategy to prolong the shelf life and improve the food quality of fresh-cut fruits, have been applied to many fresh-cut products, such as papaya (Tapia et al., 2008), carrots (Vargas et al., 2009), pears (Oms-Oliu et al., 2008; Xiao et al., 2010, 2011), banana (Bico et al., 2009) apple (Rojas-Graü et al., 2007; Freitas et al., 2013), melon (Poverenov et al., 2013) and mango (Robles-Sánchez et al., 2013). The coating supplies a selective barrier to moisture transfer, gas exchange or oxidation processes, which slows ripening, reduces weight loss and helps to preserve fresh aroma and flavor. One of the most important advantages of using the edible coating is that several active ingredients can be incorporated into the polymer matrix and consumed with the food (Rojas-Graü et al., 2009a). Edible coatings are also used as carriers of active ingredients, such as anti-browning (ascorbic acid), antimicrobial (organic acids, fatty acids esters, polypeptides, plant essential oils) and texture enhancer (calcium chloride, calcium lactate, calcium gluconate) compounds, as well as flavors and nutraceuticals (vitamins, minerals, fatty acids), to improve the quality, safety and nutritional value of fresh-cut fruits. Among the edible coatings, alginate, chitosan, gellan and pectin are the most common coating materials used in the fresh-cut fruit industry.

Chitosan (CH) is a natural, non-toxic, biodegradable polymer with antimicrobial activity and film-forming capacity, and the functional properties of chitosan films can be enhanced by combining chitosan with other hydrocolloids, controlled atmosphere or chemical dip. Xiao et al. (2010) investigated the effects of pure oxygen pretreatment and chitosan coating containing 0.03% rosemary extract on the quality of fresh-cut Huangguan pears. The authors found that the combination of pure oxygen pretreatment prior to slicing and chitosan coating plus rosemary extract may be a potential method to maintain the fresh-cut fruit quality and to reduce browning, softening and decay, which are the main problems in fresh-cut pears during storage. Xiao et al. (2011) evaluated the effects of sodium chlorite dip treatment and chitosan coatings on the quality of fresh-cut d'Anjou pears. The edible coatings were prepared from chitosan and its water-soluble derivative carboxymethyl chitosan. The authors found that the combination of sodium chlorite with carboxymethyl chitosan had beneficial effects in reducing the cut surface discoloration and in inactivating *E. coli* O157:H7. At the moment, the dipping operation to provide anti-browning and antimicrobial agents, texture enhancer and edible coatings is used only for fruits. After dipping, the cut fruits are drained and dried by air, then packaged.

D Drying systems

An important factor for the stability of fresh-cut produce is moisture control. After washing, the excess water should be removed from the fresh-cut product before packaging to prevent rapid microbial development and enzymatic processes that lead to product quality deterioration. Various methods exist to remove washing water, including centrifugation, passing the produce over vibrating

FIGURE 9.8

Iceberg lettuce after drying centrifugation.

screens with air blasts or blotting. Water remaining on the product is a critical issue.

The duration and speed of centrifugation need to be adjusted for each product (Figure 9.8). Minimal centrifugation can leave residual water on the produce surface, thus favoring microbial growth, while excessive centrifugation can result in cellular damage and cause cellular leakage. Fresh-cut products are often left with too much moisture, which causes their rapid deterioration. Pirovani et al. (2003) evaluated the effect of speed (from 0 rpm to 1080 rpm) and operation duration (from 1 min to 9 min) of spin drying on the excess water remaining on washed, fresh-cut spinach as well as the microbial growth and sensory deterioration during storage of fresh-cut packaged spinach. The combination of the centrifugation speed and operation duration affected the water removal. According to their results, it is necessary to reach higher centrifugal speeds than 600−700 rpm and a duration longer than 4 min to obtain an optimal drying level for spinach (i.e., 0.1−0.3% of water excess).

Luo and Tao (2003) used imaging technology to determine the tissue damage of fresh-cut iceberg lettuce and baby spinach during a centrifuge drying process. Large differences in damage were found for fresh-cut iceberg lettuce between the two centrifuge drying speeds of 150 rpm and 750 rpm. Furthermore, a significant difference was found at 750 rpm depending on the location of the samples in the centrifuge drying basket; the tissues of samples located near the side of the drying basket were more damaged than those located at the top, in the center or at the bottom. For baby spinach, the damage due to the centrifugal force was similar to the results for iceberg lettuce; the samples at the bottom of the basket in addition to those near the side of the basket suffered from severe tissue damage. The damage to the spinach tissues was possibly influenced by both the centrifuge speed and the weight of the product in the drying basket.

Drying tunnels with continuous air flows are also used, especially for more delicate vegetables (Donati, 2003). The critical points when using air drying tunnels are the optimal adjustment of the air temperature to avoid possible raw material fading, the thermal shock between air temperature flow and raw material temperature and the residual water on the raw material, all of which are factors that could reduce shelf life. Some companies have recently introduced cool-drying tunnels, which are very efficient but require an additional cost.

E Packaging

Packaging is not only the final operation of fresh-cut processing that allows the products to be distributed and safely reach the consumers, but also the tool which, together with the cold chain maintenance, allows the quality of fresh-cut product to be preserved and prolongs its shelf life (Figure 9.9). The most studied packaging method is modified atmosphere packaging (MAP). Low O_2 concentrations (1−5%) reduce the respiration rate, chlorophyll degradation and ethylene biosynthesis, while high CO_2 concentrations (5−10%) reduce the respiration rate and slow plant metabolism. The aim of packaging is to create an atmosphere that slows produce respiration, so that the minimal necessary O_2 concentration or maximum tolerated CO_2 concentration of the packaged produce is not exceeded, and both fermentation and other metabolic disorders are avoided (Jacxsens, 2002). However, Rojas-Graü et al. (2009b) reported that the use of elevated O_2 atmospheres ($\geq$70 kPa O_2) has been recently proposed as an alternative to low O_2 atmospheres to inhibit the growth of naturally occurring microorganisms, to prevent undesired anoxic respiration processes and to preserve the fresh-like quality of fresh-cut produce. According to several authors, high O_2 concentrations can generate reactive oxygen species (ROS) that damage microbial cells and, thus, reduce microbial growth in packages. However, there is still limited information about the effects of high O_2 concentrations on the antioxidant content of fresh-cut produce.

A modified atmosphere (MA) is generated by respiration of fresh-cut produce (passive MAP) or attained by gas flushing (active MAP) (Bolin and Huxsoll, 1991; King et al., 1991; Artés, 2000a,b; Kader, 2002a). The passive MAP is applied to fresh-cut vegetables sealed within bags of semi-permeable films, harnessing the naturally occurring respiration of the living vegetable tissues, which will obviously modify the atmospheric conditions (Thomas and O'Beirne, 2000). One of the most important factors of this technique is the gas permeability of the selected film that must allow an adequate O_2 and CO_2 exchange between the

FIGURE 9.9

Packages for fresh-cut produce.

product and the atmosphere in order to establish the desired gas composition inside the bag. Due to perishability of freshly processed produce, the MA is often actively established, either by flushing with the desired atmosphere or by creating a slight vacuum and replacing the package atmosphere with the desired gas mixture (Artés, 2000a; Kader, 2002a).

The choice of packaging film depends on the permeability of the film to O_2 and CO_2, and must be adapted to the O_2 consumption rate and CO_2 production rate of the produce. If the permeability to O_2 and CO_2 is perfectly matched to the respiration rate of the produce, an ideal equilibrium modified atmosphere (EMA) can be established inside the package. The EMA depends on many factors: the product respiration rate, respiring surface area, storage temperature, packaging film permeability and equipment, RH, filling weight, pack volume, film surface area, degree and kind of illumination of the display in the retail store as well as the initial microbial load (Artés and Martínez, 1996; Jacxsens et al., 1999; Day, 2000; Kader, 2002a,b; Nicola et al., 2010).

It has previously been mentioned that the biological agents that limit the shelf life of vegetables differ because of a number of factors. Thus, it is expected that the range of recommended atmosphere composition will vary according to the different kinds of products as well as the success of the atmosphere modification (Saltveit, 1997). The subsequent maintenance of the optimum atmosphere during storage is, therefore, effective in delaying quality deterioration, as well as the deterioration during shipping. It has also been observed that when shipping fresh-cut products by air, the volume of the packages increases with decreasing external air pressure; the packages can open and, thus, become unmarketable (Emond, 2007).

At the moment, traditional MAP atmospheres are not sufficient to ensure safe, high quality products. Most of the currently used MAP systems alone are not effective in preventing tissue browning, decay processes and slowing microbial growth. The polymeric films used in MAP have some limitations because of their structure and permeation properties. They may cause water loss, which results in softening, translucency or weight loss, or, on the contrary, they can increase the formation of water condensates which promote microbial growth. For these reasons, recent research has been focused on increasing the effectiveness of a MAP by combining it with other sanitation technologies, such as ozonation and UV light, or with dipping operations, such as the application of edible coating with added anti-browning and antimicrobial agents (Rojas-Graü et al., 2009b; Chauhan et al., 2011; Krasnova et al., 2013). Rojas-Graü and co-authors (2009a) have extensively reviewed the scientific works of the last few years on the use of innovative atmospheres and edible coatings for maintaining the freshness and safety of fresh-cut fruit and vegetables.

Packaged fruit and vegetables are usually exposed to different surrounding temperatures during shipping from the processing plant to the consumer, storage, and display at retail; MAP is not a substitute for proper cold chain management, but it can help extend the shelf life. A change in the environmental temperature creates a specific problem in EMA establishment because the respiration rate is influenced more by temperature changes than film permeability to O_2 and CO_2 (Jacxsens et al., 2002).

F Temperatures and cold chain

The temperature of fresh and fresh-cut produce should be maintained below 7–8°C at least to delay quality loss and to reduce the proliferation of spoilage microorganisms, but often we experience temperature abuse. Therefore, an important step in cold chain management is recording the temperature of fresh produce throughout the entire supply chain (see also Chapters 1 and 6), also helping a good HACCP implementation and allowing corrective measures to be taken. One of the limitations of research is that it is usually conducted in simulated situations, that is, in laboratories or controlled cell rooms. There are, however, some results from investigations conducted in realistic circumstances encountered in the food industry. Rediers et al. (2009) used time−temperature data loggers to follow endive temperature from the on-farm refrigerators to the on-processor storage to the distributor company and to restaurants up to the act of consumption. All these steps were at the air temperature setting of 4°C. In the production facility the processing water was at 4°C and the facility was at 8°C. The researchers found that in the on-farm refrigerators, where heads were stored in Euro Pool System (EPS) crates piled up on pallets, the endive was cooled more rapidly at the top of the pallet than in the middle or in the bottom (2.5 h extra to reach 8°C for the heads in the middle of the pallet and 3.5 h extra for those in the bottom of the pallet). In addition, regardless of the refrigeration temperature, endive required 3 h of cooling on a warm day (temperature range 14−35°C), but only 2 h on a moderate day (temperature range 5−19°C). During transport, the endive temperature was 16°C and, once stored in the processing facility, it took from 5:00 p.m. to 4:00 a.m. to reach a temperature of 4°C. At that point, endive was kept at 4°C during processing and during transport to the distribution company. However, during the final transport to the three restaurants temperature rose by 2−4°C and kept fluctuating in the restaurant refrigerators, because of their proximity to ovens and because the doors were opened more often than industry refrigerators. In conclusion, it seems that the real critical points when fresh-cut produce increases in temperature were during transport from farm to processor, from the distributor company to restaurant delivery and during storage in restaurants. The levels of all indicator microorganisms and pathogens were confined to be within the limits prescribed by EU Reg. EC 2073/2005. Thus, the critical issue is not food safety, but cooling costs, product quality and product waste due to temperature abuse.

Fresh-cut packaged products need to be stored at low temperatures with 95% RH to slow the respiration rate, enzymatic processes and microbial activity. Storage conditioning generally refers to the storage or holding temperature, the time/temperature and the RH the fresh-cut products may encounter. However, other factors can play a role during storage, such as the effectiveness of the packaging material in preserving food safety and quality, the technical characteristics of the storage in the processing plant and the cold chain implementation from the processing plant to the consumer. The storage temperature required by fresh-cut products needs to be adjusted not only according to their metabolic and microbial activities, but also according to the species/cultivar and applied processing techniques.

Several authors have studied the effects of storage temperature and storage time on quality and microbial growth. Lamikanra and Watson (2003) evaluated the effects of storage time and temperature (4°C or 15°C) on esterase activity in fresh-cut cantaloupe. The enzymatic activity, after 24 h in storage, was reduced by 40% and 10% in fruit stored at 4°C and 15°C, respectively. Pectin methyl esterase activity in cut fruit also decreased by about 25% at both temperatures after 24 h, but was greatly increased after 72 h in fruit stored at 15°C. Fontana and Nicola (2008) studied the effect of storage temperature (four, eight or 16°C) on the freshness of fresh-cut garden cress stored for seven to 10 days. The fresh weight loss increased linearly with increasing temperature, reaching a maximum value of 1.9% at 16°C after eight days of storage. An optimal temperature was defined as 4°C to guarantee microbial and sensory quality. Ukuku and Sapers (2007) investigated the effects of a waiting period at room temperature (ca. 22°C) before refrigerating fresh-cut watermelon, cantaloupe and honeydew pieces contaminated with *Salmonella*. The *Salmonella* populations in the fresh-cut watermelon and honeydew pieces declined by 1 log cfu/g when stored immediately at 5°C for 12 days, while the populations in the fresh-cut cantaloupe did not show any significant changes. The *Salmonella* populations in the fresh-cut melons stored immediately at 10°C for 12 days increased significantly from 10^2 to 10^3 cfu/g in the watermelon, $10^{1.9}$ to 10^3 cfu/g in the honeydew and 10^2 to $10^{3.6}$ cfu/g in the cantaloupe pieces. Keeping freshly prepared, contaminated fresh-cut melon pieces at 22°C for 3 h or more prior to refrigerated storage could increase the chances of *Salmonella* growth, especially if the fresh-cut melons were subsequently stored at an improper temperature.

Storage temperature is found to be of paramount importance for the evolution of the microbial and visual quality of fresh-cut products. Knowledge of temperature oscillations of fresh-cut product in the cold chain is necessary to determine the influence of the temperature on the loss of quality and shelf life. Many European countries lack specific regulation concerning temperature control for fresh-cut products. Italy is the first EU country to introduce a national law specifically for the fresh-cut industry (D.L. 13 May 2011, n. 77) that will have the specific decree in which temperature limits in the distribution chain are set to be below 8°C, and the temperature limit is planned to be written in any package label for domestic refrigeration storage as well. Fresh-cut products are classified as refrigerated products, whose storage temperature must be kept at a maximum of 7°C with a tolerance of up to 10°C in the warmest conditions (Jacxsens et al., 2002).

The time/temperature conditions at harvest and during postharvest handling are an essential critical control point and should be monitored. The air temperature during sorting and preparation must be lower than 12°C, while during washing, cutting and packaging, the air temperature should be maintained at between 4°C and 6°C. Temperature ranges (≥10°C) can be found in a fresh-cut product cold chain during shipping and unloading at the supermarket, storage and display at retail, and in domestic refrigerators. During transport in refrigerated vehicles, the main problem is maintaining the cold chain as the door may be opened and closed frequently, and may be left open for variable periods of time while orders are prepared and delivered. A rapid increase in product temperature can occur on transfer from temperature-controlled vehicles to ambient conditions during unloading at the distributor. The control of temperature performance and display units in supermarkets is rather poor, and the temperature of the fresh-cut product depends on its location on the chilled display shelf. The temperature distribution in the display environment is critical. The temperature is usually not optimal (8−10°C), and may accelerate fermentation inside packages and reduce both the shelf life and the packaging effectiveness (Emond, 2007). Finally, improper cold chain management continues in home refrigerators. Temperature abuse, such as storage at ambient temperature and improper cooling, has been identified as the main cause of microbial and quality deterioration. Nunes et al. (2009) investigated the temperatures registered inside local distribution trucks or in retailer displays and the effects of improper temperature management on the produce quality. The study evaluated the segment of the distribution chain that includes the time over which the produce arrives from distribution center to the store, is displayed at the store, and then stored under home conditions. A wide variation in the temperature measured inside retail displays was registered depending on the store and the displays, from −1.2°C to 19.2°C in refrigerated displays and from 7.6°C to 27.7°C in non-refrigerated displays. The major cause of produce waste was the improper temperature management (55%), while the expired date and mechanical damage counted for 45%. Thus, fruit and vegetables are often kept under improper storage conditions, resulting in produce with poor quality and shorter shelf life, and in increased waste at retail and consumer levels.

In recent years research has paid attention to the light conditions during shelf-life to simulate the retail display conditions, especially in leafy vegetables and greens, such as garden cress, broccoli, cauliflower, Swiss chard leaves, lettuce or celery (Olarte et al., 2009; Zhan et al., 2009, 2012a,b, 2013a,b, 2014; Kasim and Kasim, 2012). However, the information on the effects of the exposure to light at retail store on the physiological response of fresh-cut products is still poor, and the scientific results are contradictory. Although the display of vegetables in stores is mostly done in light conditions, several studies recommend low light intensity conditions or darkness to delay the leaf yellowing of vegetables in retail markets. Light conditions favor chlorophyll degradation causing leaf yellowing, which is one of the most important factors determining the fresh-like appearance of the product and, thus, the consumer purchase. Despite this, some studies have been reported in which continuous light stored leaves of fresh-cut products retained more chlorophyll than dark stored leaves (Noichinda et al., 2007; Zhan et al., 2012a, 2013a, 2014). Zhan et al. (2013a) found that light stored leaves of fresh-cut romaine lettuce preserved more Chl *a* during seven days of storage at 4°C than dark stored leaves. Light delayed the decline of soluble sugar and total soluble solid content and concurrently increased the dehydroascorbic acid (DHA) and dry matter content in comparison leaves stored in a dark environment. Studies conducted by Zhan and coworkers highlighted that light exposure accelerates fresh weight loss during storage; this occurred in broccoli (Zhan et al., 2012a), romaine lettuce (Zhan et al., 2012b, 2013a) and celery (Zhan et al., 2014), confirming similar results in the literature (in Chinese kale, Noichinda et al., 2007; in romaine lettuce, Martínez-Sánchez et al., 2011). A general

FIGURE 9.10

Display cabinets in supermarkets.

tendency was that light conditions preserve or increase the amount of ascorbic acid compared to dark conditions (Zhan et al., 2012a,b, 2013a, 2014), as well as an inhibition of PPO and POD and a decrease in browning (Zhan et al., 2012b, 2013b). Light conditions can affect not only the physiological response of fresh-cut produce, but also the packaging performance in preserving sensorial attributes (Olarte et al., 2009).

Further detailed studies need to be conducted on the effect of light on the physiological responses of fresh-cut fruit and vegetables. Ultimately, the effect of light and the type of bulbs used for the experiments should be checked in interaction with the temperature of the display cabinets, given that most of these are open and, thus, subjected to ambient temperatures (Figure 9.10). The latter is not only often much higher than refrigeration temperature, but it can also increase due to the type of bulbs used: incandescent and halogen bulbs increase the ambient temperature, while fluorescent lights do not. In-bag product temperature is expected to be higher than out-bag temperature due to the greenhouse effect, to the reduced evaporative cooling and trapped warm air if the light is used in open display cabinet. Lastly, the effect of continuous light should be checked against store opening hours, that is, the fluctuation of light/dark conditions have not yet been investigated.

IV Future considerations

The preharvest and postharvest issues described in this chapter highlight the research efforts that are being made to test and implement innovations to increase fresh-cut sector competitiveness in terms of safety and quality. A continuous exchange between scientists and the fresh-cut industry is necessary to guarantee the success of the fresh-cut system. It is advisable that new experiments are conducted in real world situations after being tested in simulated conditions, that is, in laboratories or controlled cell rooms, to verify the studies under realistic situations. In addition, there is still little connection between preharvest and postharvest conditions in the mind of researchers: most postharvest research is conducted without knowledge of the preharvest conditions of the raw material; in most cases it is obtained from a grocery store, making many hypotheses of any determining cause in the field on postharvest quality unreliable.

The fresh-cut sector has progressed tremendously around the world in the last decade, especially in the fruit sector and, particularly, in tropical and exotic fruit. This development is in line with the general trend occurring in fresh produce. Thus, the critical issues in fresh-cut management are similar to those in the fresh produce management. The wide spread of fresh-cut fruit and vegetables is visible in many emerging economies even though statistics are unavailable. In the coming decade it is expected that the importance of the sector will increase even more, with the most likely increase being in the importance of safety rather than quality. Nevertheless, assessing fresh-cut produce quality remains of great importance because consumers are expecting more flavor and taste, especially from such high-price products as fresh-cut products. Despite the five years of economic slowdown around the world that has hit some countries more severely than others, the demand for fresh-cut products keeps rising. The offer of new species and varieties expands the offer of fresh-cut items. There are promising innovations both at farm production level and at postharvest processing level: cultivation techniques are becoming standardized, environmentally friendly; they conserve water, reduce waste and emphasize the inherent and organoleptic quality of the raw material. Therefore, research should focus on the implementation of innovative tools and processing aids in postharvest processing able to preserve the freshness and organoleptic quality obtained in the field.

Lastly, the sector is facing a striking challenge in the coming years: "waste footprint". Food waste is top of the issues when it comes to the food sector's current sustainability agenda, and fresh-cut products are among the most targeted products for waste production (Burrows, 2013). In fact, the latest figures for the UK indicate that 68% of salad grown for fresh-cut salad bags is wasted. If it is true that tackling the issue of waste reduction starts from breeding and ends in homes, it is also true that solutions should be found either by reducing the discharge of "not compliant" raw material along the chain or by making better use of it, such as re-cycling or re-using waste for other purposes, e.g., composting or the extraction of the bioactive compounds it contains.

Bibliography

Aguayo, E., Escalona, V.H., Artés, F., 2008. Effect of hot water treatment and various calcium salts on quality of fresh-cut 'Amarillo' melon. Postharvest Biol. Tec. 47, 397–406.

Akbas, M.Y., Ölmez, H., 2007. Effectiveness of organic acid, ozonated water and chlorine dippings on microbial reduction and storage quality of fresh-cut iceberg lettuce. J. Sci. Food Agr. 87, 2609–2616.

Aldinucci, M., 2013. Il 2013 della IV gamma parte bene dopo un 2012 in chiaroscuro. Corriere Ortofrutticolo 3, 51–53.

Alegria, C., Pinheiro, J., Duthoit, M., Goncalves, E.M., Moldão-Martins, M., Abreu, M., 2012. Fresh-cut carrot (cv. Nantes) quality as affected by abiotic stress (heat shock and UV-C irradiation) pre-treatments. LWT- Food Sci. Technol. 48, 197–203.

Allende, A., Tomás-Barberán, F.A., Gil, M.I., 2006. Minimal processing for healthy traditional foods. Trends Food Sci. Tech. 17, 513–519.

Andujar Sànchez, M., Martínez Mínguez, F., López Garcia, A., 2010. Comportamiento de lechugas para IV gama en Murcia. Hortic. Glob. 287, 32–37.

Artés, F., 2000a. Conservación de los productos vegetales en atmósfera modificada. In: Lamúa, M. (Ed.), Aplicación del frío a los alimentos. AMV-Mundi Prensa, Madrid, Spain, pp. 105–125.

Artés, F., 2000b. Productos vegetales procesados en fresco. In: Lamúa, M. (Ed.), Aplicación del frío a los alimentos. AMV-Mundi Prensa, Madrid, Spain, pp. 127–141.

Artés, F., Martínez, J.A., 1996. Influence of packaging treatments on the keeping quality of 'Salinas' lettuce. Lebensm.-Wiss. u.-Technol. 29, 664–668.

Artés, F., Gómez, P., Artés-Hernández, F., Aguayo, E., Escalona, V., 2007. Improved strategies for keeping overall quality of fresh-cut produce. Acta Hort. 746, 245–258.

Artés, F., Gómez, P., Aguayo, E., Escalona, V., Artés-Hernández, F., 2009. Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities. Postharvest Biol. Tec. 51, 287–296.

Ayala-Zavala, J.F., González-Aguilar, G.A., Del Toro-Sánchez, L., 2009. Enhancing safety and aroma appealing of fresh-cut fruits and vegetables using the antimicrobial and aromatic power of essential oils. J. Food Sci. 74 (7), R84–R91.

Bai, J., Wu, P., Manthey, J., Goodner, K., Baldwin, E., 2009. Effect of harvest maturity on quality of fresh-cut pear salad. Postharvest Biol. Tec. 51 (2), 250–256.

Bansal, R.K., Walker, J.T., 1999. A study of high pressure water jets for cutting chicken breast meat. J. Food Process Eng. 22, 307–318.

Barry-Ryan, C., O'Beirne, D., 1998. Quality and shelf life of fresh cut carrot slices as affected by slicing method. J. Food Sci. 63 (5), 851–856.

Beirão-Da-Costa, S., Moura-Guedes, M.C., Ferreira-Pinto, M.M., Empis, J., Moldão-Martins, M., 2012. Alternative sanitizing methods to ensure safety and quality of fresh-cut kiwifruit. J. Food Process. Pres. Available from: http://dx.doi.org/10.111/j.1745-4549.2012.00730.x.

Beirão-da-Costa, S., Steiner, A., Correia, L., Leitão, E., Empis, J., Moldão-Martins, M., 2008. Influence of moderate heat pre-treatments on physical and chemical characteristics of kiwifruit slices. Eur. Food Res. Technol. 226, 641–651.

Bergquist, S.A.M., Gertsson, U.E., Nordmark, L.Y.G., Olsson, M.E., 2007. Ascorbic acid, carotenoids, and visual quality of baby spinach as affected by shade netting and postharvest storage. J. Agric. Food Chem. 55, 8444–8451.

Besri, M., 1997. Alternatives to methyl bromide for preplant protected cultivation of vegetables in the Mediterranean developing countries. Proceeding of Annual International Research Conference on 'Methyl Bromide Alternatives and Emissions Reductions'. November 3–5, 1997, San Diego, California, USA, <http://mbao.org/1997airc/015besri.pdf> (accessed 02.12.13).

Bett-Garber, K.L., Lamikanra, O., Lester, G.E., Ingram, D.A., Watson, M.A., 2005. Influence of soil type and storage conditions on sensory qualities of fresh-cut Cantaloupe (Cucumis melo). J. Sci. Food Agr. 85, 825–830.

Beuchat, L.R., 2007. Managing food safety risks in the fresh-cut industry. Acta Hort. 746, 103–111.

Beuchat, L.R., Nail, B.V., Adler, B.B., Clavero, M.R.S., 1998. Efficacy of spray application of chlorinated water in killing pathogenic bacteria on raw apples, tomatoes and lettuce. J. Food Protect. 61, 1305–1311.

Bico, S.L.S., Raposo, M.F.J., Morais, R.M.S.C., Morais, A.M.M.B., 2009. Combined effects of chemical dip and/or carrageenan coating and/or controlled atmosphere on quality of fresh-cut banana. Food Control 20, 508–514.

Binello, A., Orio, L., Pignata, G., Nicola, S., Chemat, F., Cravotto, G., 2014. Effect of microwaves on the *in situ* hydrodistillation of four different *Lamiaceae*. C. R. Chimie. 17, 181–186. Available from: http://dx.doi.org/10.1016/j.crci.2013.11.007.

Birmpa, A., Sfika, V., Vantarakis, A., 2013. Ultraviolet light and ultrasound as non-thermal treatments for the inactivation of microorganisms in fresh ready-to-eat foods. Int. J. Food Microbiol. 167 (1), 96–102.

Bolin, H.R., Huxsoll, C.C., 1991. Control of minimally processed carrot (*Daucus carota*) surface discoloration caused by abrasion peeling. J. Food Sci. 56, 416–418.

Brecht, J.K., 1995. Physiology of lightly processed fruits and vegetables. HortScience 30 (1), 18–22.

Brecht, J.K., Ritenour, M.A., Sargent, S.A., 2003. Preharvest nutrition impacts postharvest quality. Am. Vegetable Grower April, 36–38.

Burrows, D., 2013. The Great Waste Debate. FreshProduce Journal, <http://www.fruitnet.com/fpj/article/159758/the-great-waste-debate> (accessed 06.11.13).

Calderon-Lopez, B., Bartsch, J.A., Lee, C.Y., Watkins, C.B., 2005. Cultivar effects on quality of fresh cut apple slices from 1-methylcyclopropene (1-MCP)-treated apple fruit. J. Food Sci. 70 (3), S221–S227.

Cantwell, M., 1992. Postharvest handling systems: minimally processed fruits and vegetables. In: Kader, A.A. (Ed.), Postharvest Technology of Horticultural Crops, second ed. University of California, Division of Agriculture and Natural Resources, Oakland, California, USA, pp. 277–281, Publ. 3311.

Cantwell, M., 2007. Biology of Fresh-cut Products. Proceeding of European Short Course on 'Quality and safety of fresh-cut produce', March 12–14, 2007, Bari, Italy.

Cantwell, M., Ermen, H., 2006. Causes of quality and Postharvest losses, <http://www.postharvestquality.com/uwilectures/davis_postharvest/LeafyVegetables.pdf> (accessed 02.12.13).

Casati, D., Baldi, L., 2011. Il trend è positive. Ora va consolidato. Terra e Vita 27, 32–36.

Casero, T., Benavides, A.L., Recasens, I., 2009. Interrelation between fruit mineral content and pre-harvest calcium treatments on 'Golden Smoothee' apple quality. J. Plant Nutr. 33 (1), 27–37.

Chauhan, O.P., Raju, P.S., Ravi, N., Singh, A., Bawa, A.S., 2011. Effectiveness of ozone in combination with controlled atmosphere on quality characteristics including lignification of carrot sticks. J. Food. Eng. 102, 43–48.

Conte, A., Conversa, G., Scrocco, C., Brescia, I., Laverse, J., Elia, A., et al., 2008. Influence of growing periods on the quality of baby spinach leaves at harvest and during storage as minimally processed produce. Postharvest Biol. Tec. 50 (3), 190–196.

Day, B., 2000. Novel MAP for freshly prepared fruit and vegetable products. Postharv. News Inform. 11, 27–31.

Day, B., 2001. Fresh prepared produce: GMP for high oxygen MAP and non-sulphite dipping. Guideline No. 31. Campden & Chorleywood Food Research Association Group, Chipping Campden, Gloshister, UK, pp. 1–76.

Del Aguila, J.S., Fumi Sasaki, F., Sichmann Heiffig, L., Ortega, E.M.M., Jacomino, A.P., Kluge, R.A., 2006. Fresh-cut radish using different cut types and storage temperatures. Postharvest Biol. Tec. 40, 149–154.

Deza-Durand, K.M., Petersen, M.A., 2011. The effect of cutting direction on aroma compounds and respiration rate of fresh-cut iceberg lettuce (*Lactuca sativa* L.). Postharvest Biol. Tec. 61, 83–90.

Djioua, T., Charles, F., Freire, M., Filgueiras, H., Ducamp-Collin, M.N., Sallanon, H., 2010. Combined effects of postharvest heat treatment and chitosan coating on quality of fresh-cut mangoes (*Mangifera indica* L.). Int. J. Food Sci. Tech. 45, 849–855.

Donati, V., 2003. Solo se si mantiene la catena del freddo. Colture protette 8, 39–43.

Emond, J.P., 2007. Modified atmosphere packaging: plastic film technology and selection. Proceeding of European Short Course on 'Quality and Safety of Fresh-Cut Produce'. March 12–14, 2007, Bari, Italy.

Fabbri, G., 2011. Spagna: frutta e verdura di quarta gamma in rialzo nei primi 8 mesi del 2011. FreshPlaza.it, Article 37340, <http://www.freshplaza.it/article/37340/Spagna-frutta-e-verdura-di-quarta-gamma-in-rialzo-nei-primi-8-mesi-del-2011> (accessed 30.10.13).

FDA, 2007. Fresh-cut fruits and vegetables draft final guidance. March 12, 2007. FDA press office. <http://www.fda.gov/oc/factsheets/foodsafety2007.html> (accessed 12.9.13).

Ferrante, A., Incrocci, L., Maggini, R., Tognoni, F., Serra, G., 2003. Preharvest and postharvest strategies for reducing nitrate content in rocket (*Eruca sativa*). Acta Hort. 628, 153–159.

Fonseca, J.M., 2006. Postharvest quality and microbial population of head lettuce as affected by moisture at harvest. J. Food Sci. 71 (2), M45–M49.

Fonseca, J.M., Fallon, S.D., Sanchez, C.A., Nolte, K.D., 2011. *Escherichia coli* survival in lettuce fields following its introduction through different irrigation systems. J. Appl. Microbiol. 110, 893–902.

Fontana, E., Nicola, S., 2008. Producing garden cress (*Lepidium sativum* L.) for the fresh-cut chain using a soilless culture system. J. Hortic. Sci. Biotech. 83 (1), 23–32.

Fontana, E., Nicola, S., 2009. Traditional and soilless culture systems to produce corn salad (*Valerianella olitoria* L.) and rocket (*Eruca sativa* Mill.) with low nitrate content. J. Food Agric. Environ. 7 (2), 405–410.

Fontana, E., Nicola, S., Hoeberechts, J., Saglietti, D., 2003. Soilless culture systems produce ready-to-eat corn salad (*Valerianella olitoria* L.) of high quality. Acta Hort. 604, 505–509.

Fontana, E., Nicola, S., Hoeberechts, J., Saglietti, D., Piovano, G., 2004. Managing traditional and soilless culture system to produce corn salad (*Valerianella olitoria*) with low nitrate content and lasting postharvest shelf life. Acta Hort. 659, 763–768.

Fontana, E., Torassa, C., Hoeberechts, J., Nicola, S., 2006. Il crescione per la IV gamma: aspetti di coltivazione fuori suolo e post-raccolta. Italus Hortus 13 (5), 151–154.

Fontana, E., Tibaldi, G., Nicola, S., 2010. Effect of the Nutrient Solution and Shelf-life Conditions on the essential oil profile of minimally processed dill (*Anethum graveolens* L.) grown in a soilless culture system. Acta Hort. 877, 135–141.

Franz, E., Semenov, A.V., Termorshuizen, A.J., De Vos, O.J., Bokhorst, J.G., Van Bruggen, A.H.C., 2008. Manure-amended soil characteristics affecting the survival of E. coli O157:H7 in 36 Dutch soils. Environ. Microbiol. 10 (2), 313–327.

Freitas, I.R., Cortez-Vega, W.R., Pizato, S., Prentice-Hernández, C., Borges, C.D., 2013. Xanthan gum as a carrier of preservative agents and calcium chloride applied on fresh-cut apple. J. Food Saf. 33, 229–238.

FreshFruitportal.com, 2012. Fresh-cut is in and canned is out, U.S. survey finds. <http://www.freshfruitportal.com/2012/04/30/fresh-cut-is-in-and-canned-is-out-u-s-survey-finds/?country=unitedstates> (accessed 03.11.13).

Fruitgrowersnews.com, 2013. Fresh-cut Remains Fastest-Growing Trend in Produce Industry, <http://fruitgrowersnews.com/index.php/magazine/article/Fresh-cut-Remains-Fastest-Growing-Trend-in-Produce-Industry>. (accessed 03.11.13).

Gil, M.I., Selma, M.V., López-Gálvez, F., Allende, A., 2009. Fresh-cut product sanitation and wash water disinfection: problems and solutions. Int. J. Food Microbiol. 134, 37–45.

Gil, M.I., Tudela, J.A., Martínez-Sánchez, A., Luna, M.C., 2012. Harvest maturity indicators of leafy vegetables. Stewart Postharvest Rev. 1, 2.

Gleeson, E., O'Beirne, D., 2005. Effects of process severity on survival and growth of *Escherichia coli* and *Listeria innocua* on minimally processed vegetables. Food Control 16, 677–685.

Gonzalez-Aguilar, G.A., Celis, J., Sotelo-Mundo, R.R., De La Rosa, L.A., Rodrigo-Garcia, J., Alvarez-Parrilla, E., 2008. Physiological and biochemical changes of different fresh-cut mango cultivars stored at 5°C. Int. J. Food Sci. Tech. 43 (1), 91–101.

Gopal, A., Coventry, J., Wan, J., Roginski, H., Ajlouni, S., 2010. Alternative disinfection techniques to extend the shelf life of minimally processed iceberg lettuce. Food Microbiol. 27, 210–219.

Gorny, J.R., Hess-Pierce, B., Kader, A.A., 1999. Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treatments. J. Food Sci. 64 (3), 429–432.

Gorny, J.R., Cifuentes, R.A., Hess-Pierce, B., Kader, A.A., 2000. Quality changes in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size, and storage regime. J. Food Sci. 65 (3), 541–544.

Gąstoł, M., Domagała-Świątkiewicz, I., 2006. Effect of foliar sprays on potassium, magnesium and calcium distribution in fruits of the pear. J. Fruit Ornam. Plant Res. 14 (2), 169–176.

Hernandez-Brenes, C., 2002. Good manufacturing practices for handling, packing, storage and transportation of fresh produce. Improving the Safety and Quality of Fresh Fruits and Vegetables: A Training Manual for Trainers. Joint Institute for Food Safety and Applied Nutrition, University of Maryland, College Park, Maryland, USA, Chapt. 3, pp. 1–34.

Hoeberechts, J., Nicola, S., Fontana, E., Saglietti, D., Piovano, G., 2004. Medium, cultivar and plant density influenced production and postharvest shelf life of Raphanus sativus grown in a soilless culture system. Acta Hort. 659, 791–798.

Incrocci, L., Lorenzini, O., Malorgio, F., Pardossi, A., Tognoni, F., 2001. Valutazione quanti-qualitativa della produzione di rucola (*Eruca vesicaria* L. Cav.) e basilico

(*Ocimum basilicum* L.) ottenuta in suolo e floating system utilizzando acque irrigue con differenti contenuti di NaCl. Italus Hortus 8 (6), 92–97.
Jacxsens, L., 2002. Literature review. Influence of Preservation Parameters on the Quality of Fresh-Cut Vegetables. Doctoral Dissertation. Universiteit Gent, Gent, Belgium, Chapt. 1, pp. 1–69.
Jacxsens, L., Devlieghere, F., Debevere, J., 1999. Validation of a systematic approach to design equilibrium modified atmosphere packages for fresh-cut produce. Lebensm.-Wiss. u.-Technol. 32, 425–432.
Jacxsens, L., Devlieghere, F., Debevere, J., 2002. Predictive modelling for packaging design: equilibrium modified atmosphere package of fresh-cut vegetables subjected to a simulated distribution chain. Int. J. Food Microbiol. 73, 331–341.
Jensen, A.N., Storm, C., Forslund, A., Baggesen, D.L., Dalsgaard, A., 2013. Escherichia coli contamination of lettuce grown in soils amended with animal slurry. J. Food Protect. 76 (7), 1137–1144.
Kader, A.A., 2002a. Postharvest biology and technology: an overview. In: Kader, A.A. (Ed.), Postharvest Technology of Horticultural Crops, third ed. University of California, Division of Agriculture and Natural Resources, Oakland, California, USA, pp. 39–47, Publ. 3311.
Kader, A.A., 2002b. Quality and safety factors: definition and evaluation for fresh horticultural crops. In: Kader, A.A. (Ed.), Postharvest Technology of Horticultural Crops, third ed. University of California, Division of Agriculture and Natural Resources, Oakland, California, USA, pp. 279–286, Publ. 3311.
Kader, A.A., 2008. Perspective flavor quality of fruits and vegetables. J. Sci. Food Agric. 88, 1863–1868.
Kasim, M.U., Kasim, R., 2012. Color changes of fresh-cut Swiss chard leaves stored at different light intensity. Am. J. Food Technol. 7 (1), 13–21.
Kim, H.J., Fonseca, J.M., Kubota, C., Choi, J.H., 2007. Effect of hydrogen peroxide on quality of fresh-cut tomato. J. Food Sci. 7, S463–S467.
Kim, J.G., 2007. Fresh-cut market potential and challenges in far-east Asia. Acta Hort. 746, 33–38.
Kim, Y.H., Jeong, S.G., Back, K.H., Park, K.H., Chung, M.S., Kang, D.H., 2013. Effect of various conditions on inactivation of *Escherichia coli* O157:H7, *Salmonella Typhimurium*, and *Listeria monocytogenes* in fresh-cut lettuce using ultraviolet radiation. Int. J. Food Microbiol. 166, 349–355.
King Jr., A.D., Magnuson, J.A., Török, T., Goodman, N., 1991. Microbial flora and storage quality of partially processed lettuce. J. Food Sci. 56 (2), 459–461.
Kirezieva, K., Nanyunja, J., Jacxsens, L., van der Vorst, J.G.A.J., Uyttendaele, M., Luning, P.A., 2013. Context factors affecting design and operation of food safety management systems in the fresh produce chain. Trends Food Sci. Tech. 32 (2), 108–127.
Kleinhenz, M.D., French, D.G., Gazula, A., Scheerens, J.C., 2003. Variety, shading, and growth stage effects on pigment concentrations in lettuce grown under contrasting temperature regimes. HortTechnology 13 (4), 677–683.
Koh, E., Charoenprasert, S., Mitchell, A.E., 2012. Effect of organic and conventional cropping systems on ascorbic acid, vitamin C, flavonoids, nitrate, and oxalate in 27 varieties of spinach (*Spinacia oleracea* L.). J. Agric. Food Chem. 60, 3144–3150.
Koukounaras, A., Diamantidis, G., Sfakiotakis, E., 2008. The effect of heat treatment on quality retention of fresh-cut peach. Postharvest Biol. Tec. 48, 30–36.

Krasnova, I., Dukalska, L., Seglina, D., Misina, I., Kārlina, D., 2013. Influence of anti-browning inhibitors and biodegradable packaging on the quality of fresh-cut pears. Proc. Latvian Acad. Sci. Sect. B 67 (2, 683), 167–173.

Lamikanra, O., Watson, M.A., 2003. Temperature and storage duration effects on esterase activity in fresh-cut Cantaloupe melon. J. Food Sci. 68 (3), 790–793.

Lamikanra, O., Kueneman, D., Ukuku, D., Bett-Garber, K.L., 2005. Effect of processing under ultraviolet light on the shelf life of fresh-cut Cantaloupe melon. J. Food Sci. 70 (9), C534–C539.

Lee, S.K., Kader, A.A., 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Tec. 20, 207–220.

Lester, G.E., Jifon, J.L., Stewart, W.M., 2007. Foliar potassium improves Cantaloupe marketable and nutritional quality. Better Crops 91, 24–25.

Lester, G.E., Jifon, J.L., Makus, D.J., 2010. Impact of potassium nutrition on postharvest fruit quality: Melon (*Cucumis melo* L.) case study. Plant Soil 335, 117–131.

Luna, M.C., Tudela, J.A., Martínez-Sánchez, A., Allende, A., Marín, A., Gil, M.I., 2012. Long-term deficit and excess of irrigation influences quality and browning related enzymes and phenolic metabolism of fresh-cut iceberg lettuce (*Lactuca sativa* L.). Postharvest Biol. Tec. 73, 37–45.

Luna, M.C., Tudela, J.A., Martínez-Sánchez, A., Allende, A., Gil, M.I., 2013a. Optimizing water management to control respiration rate and reduce browning and microbial load of fresh-cut romaine lettuce. Postharvest Biol. Tec. 80, 9–17.

Luna, M.C., Martínez-Sánchez, A., Selma, M.V., Tudela, J.A., Baixauli, C., Gil, M.I., 2013b. Influence of nutrient solutions in an open-field soilless system on the quality characteristics and shelf life of fresh-cut red and green lettuces (*Lactuca sativa* L.) in different seasons. J. Sci. Food Agric. 93, 415–421.

Lunati, F., 2001. Linee guida tecniche ed agronomiche per i prodotti di IV gamma. Technical report, Nomisma. <http://venetoagricoltura.regione.veneto.it/archive/00000177/01/La_IV_gamma_prodotti_ad_alto_valore_aggiunto.pdf> (accessed 02.12.13).

Luo, Y., Tao, Y., 2003. Determining tissue damage of fresh-cut vegetables using imaging technology. Acta Hort. 628, 97–102.

Lynch, M.F., Tauxe, R.V., Hedberg, C.W., 2009. The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. Epidemiol. Infect. 137, 307–315.

Markarian, J., 2004. Packaging gets active: additives lead the way. Plastic Addit. Comp. March/April, 22–25.

Martín-Diana, A.B., Rico, D., Barry-Ryan, C., Frías, J.M., Mulcahy, J., Henehan, G.T.M., 2005. Comparison of calcium lactate with chlorine as a washing treatment for fresh-cut lettuce and carrots: quality and nutritional parameters. J. Sci. Food Agr. 85, 2260–2268.

Martínez-Sánchez, A., Tudela, J.A., Luna, M.C., Allende, A., Gil, M.I., 2011. Low oxygen levels and light exposure affect quality of fresh-cut Romaine lettuce. Postharvest Biol. Tec. 59, 34–42.

Martínez-Sánchez, A., Luna, M.C., Selma, M.V., Tudela, J.A., Abad, J., Gil, M.I., 2012. Baby-leaf and multi-leaf of green and red lettuce are suitable raw materials for the fresh-cut industry. Postharvest Biol. Tec. 63, 1–10.

McGlynn, W.G., Bellmer, D.D., Reilly, S.S., 2003. Effect of precut sanitizing dip and water jet cutting on quality and shelf life of fresh-cut watermelon. J. Food Qual. 26 (6), 489–498.

Mengel, K., 2002. Alternative or complementary role of foliar supply in mineral nutrition. Acta Hort. 594, 365–373.

Mitcham, E.J., 2010. Focus on consumers to increase sales. Am. Western Fruit Grower 28.

Mogren, L., Reade, J., Monaghan, J., 2011. Ascorbic acid content varies among baby leaves and over the season. II ISHS International Conference on Quality Management of Fresh Cut Produce: Convenience Food for a Tasteful Life. 17-21 July 2011. Turin, Italy. Book of Abs, 21.

Moreira, M.R., Ponce, A., Ansorena, R., Roura, S.I., 2011. Effectiveness of edible coatings combined with mild heat shocks on microbial spoilage and sensory quality of fresh cut broccoli (*Brassica oleracea* L.). J. Food Sci. 76 (6), M367–M374.

Mylavarapu, R.S., Zinati, G.M., 2009. Improvement of soil properties using compost for optimum parsley production in sandy soils. Sci. Hortic-Amsterdam 120, 426–430.

Nicola, S., 1993. Il vivaismo orticolo nel pianeta Florida (USA). Colture Protette XXII 11, 45–47.

Nicola, S., Fontana, E., 2007. Cultivation management on the farm influences postharvest quality and safety. Acta Hort. 746, 273–280.

Nicola, S., Hoeberechts, J., Fontana, E., Saglietti, D., 2003. Cultural technique influences on post-harvest quality of rocket (*Eruca sativa* Mill.). Acta Hort. 604, 685–690.

Nicola, S., Hoeberechts, J., Fontana, E., 2004. Rocket (*Eruca sativa* Mill.) and corn salad (*Valerianella olitoria* L.): production and shelf life of two leafy vegetables grown in a soilless culture system. Acta Hort. 633, 509–516.

Nicola, S., Hoeberechts, J., Fontana, E., 2005a. Comparison between traditional and soil-less culture systems to produce rocket (*Eruca sativa*) with low nitrate content. Acta Hort. 697, 549–555.

Nicola, S., Fontana, E., Hoeberechts, J., Saglietti, D., 2005b. Raphanus sativus Production in Soilless or Traditional Culture Systems and Postharvest Packaging. Acta Hort. 682, 1303–1310.

Nicola, S., Fontana, E., Tibaldi, G., Zhan, L., 2010. Qualitative and physiological response of minimally processed rocket (*Eruca sativa* Mill.) to package filling amount and shelf-life temperature. Acta Hort. 877, 611–618.

Nicola, S., Fontana, E., Monaco, S., Grignani, C., 2013. The application of the Nitrates Directive to vegetable crops: tools and strategies from NEV2013 for an integrated fertilization management. In: Karoline D'Haene, Bart Vandecasteele, Raf De Vis, Sara Crappé, Danny Callens, Els Mechant, Georges Hofman, Stefaan De Neve, (Eds.), NUTRIHORT: Nutrient Management, Innovative Techniques and Nutrient Legislation in Intensive Horticulture for an Improved Water Quality, 16–18 September 2013, Ghent, Belgium. Proceedings: 2–8. ISBN: 978-9040303463, pp. 388 + XXIV.

Nicola, S., Tibaldi, G., Gaino, W., Pignata, G., 2012. Cutting shape, film and storage temperature in fresh-cut pumpkin affecting shelf-life. 7th ISHS International Postharvest Symposium. 25–29 June 2012. Kuala Lumpur, Malaysia. Book of Abs: 67–68.

Nicola, S., Tibaldi, G., Pignata, G., Fontana, E., 2011. The flotation growing system for baby leafy vegetables can assure low microbial contamination at harvest. II ISHS International Conference on Quality Management of Fresh Cut Produce: Convenience Food for a Tasteful Life. 17–21 July 2011. Turin, Italy. Book of Abs, 70.

Ninfali, P., Bacchiocca, M., 2004. Parameters for the detection of post-harvest quality in fresh or transformed horticultural crops. J. Food Agri. Environ. 2 (1), 122–127.

Noichinda, S., Bodhipadma, K., Mahamontri, C., Narongruk, T., Ketsa, S., 2007. Light during storage prevents loss of ascorbic acid, and increase glucose and fructose levels in Chinese kale (*Brassica oleracea* var. *alboglabra*). Postharvest Biol. Tec. 44, 312–315.

Nou, X., Luo, Y., 2010. Whole-leaf wash improves chlorine efficacy for microbial reduction and prevents pathogen cross-contamination during fresh-cut lettuce processing. J. Food Sci. 75 (5), M283–M290.

Nunes, M.C.N., Emond, J.P., Rauth, M., Dea, S., Chau, K.V., 2009. Environmental conditions encountered during typical consumer retail display affect fruit and vegetable quality and waste. Postharvest Biol. Tec. 51, 232–241.

Olaimat, A.N., Holley, R., 2012. Factors influencing the microbial safety of fresh produce: A review. Food Microbiol. 32, 1–19.

Olarte, C., Sanz, S., Echávarri, J.F., Ayala, F., 2009. Effect of plastic permeability and exposure to light during storage on the quality of minimally processed broccoli and cauliflower. LWT-Food Sci. Technol. 42, 402–411.

Ölmez, H., Kretzschmar, U., 2009. Potential alternative disinfection methods for organic fresh-cut industry for minimizing water consumption and environmental impact. LWT-Food Sci. Technol. 42, 686–693.

Oms-Oliu, G., Soliva-Fortuny, R., Martín-Belloso, O., 2008. Edible coatings with antibrowning agents to maintain sensory quality and antioxidant properties of fresh-cut pears. Postharvest Biol. Tec. 50, 87–94.

Orio, L., Cravotto, G., Binello, A., Pignata, G., Nicola, S., Chemat, F., 2012. Hydrodistillation and in situ microwave-generated hydrodistillation of fresh and dried mint leaves: a comparison study. J. Sci. Food Agr. 92 (15), 3085–3090.

Page, T., Harris, R.H., Epstein, S.S., 1976. Drinking water and cancer mortality in Louisiana. Science 193, 55–57.

Parish, M.E., Beuchat, L.R., Suslow, T.V., Harris, L.J., Garrett, E.H., Farber, J.N., et al., 2003. Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr. Rev. Food Sci. Saf. 2, 161–173.

Perkins-Veazie, P., 1999. Enhancing fruit and vegetable quality for small farm systems in the South. In: 1999 Agricultural Marketing Outreach Workshop Training Manual, <http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=104315> (accessed 02.12.13).

Pimpini, F., Enzo, M., 1997. La coltura della rucola negli ambienti veneti. Colture protette 4, 21–32.

Pirazzoli, C., Palmieri, A., 2011. Prodotti su misura, il futuro della IV gamma. L'Informatore Agrario 24, 34–37.

Pirovani, M., Piagentini, A., Güemes, D., Arkwright, S., 2004. Reduction of chlorine concentration and microbial load during washing-disinfection of shredded lettuce. Int. J. Food Sci. Tech. 39, 341–347.

Pirovani, M.E., Güemes, D.R., Piagentini, A.M., 2003. Fresh-cut spinach quality as influenced by spin drying parameters. J. Food Qual. 26 (3), 231–242.

Portela, S.I., Cantwell, M.I., 2001. Cutting blade sharpness affects appearence and other quality attributes of fresh-cut cantaloupe melon. J. Food Sci. 66, 1265–1270.

Poverenov, E., Danino, S., Horev, B., Granit, R., Vinokur, Y., Rodov, V., 2013. Layer-by-layer electrostatic deposition of edible coating on fresh-cut melon model: anticipated and unexpected effects of alginate-chitosan combination. Food Bioprocess Technol. Available from: http://dx.doi.org/10.1007/s11947-013-1134-4.

Premier, R., 2007. Microbiological quality consideration for the ready-to-eat fresh produce industry. In: The International Conference on Quality Management of Fresh Cut Produce. August 6–8, 2007, Bangkok, Thailand. Keynote presentation.

Premier, R., Jeager, J., Tomkins, B., 2007. Microbiological quality consideration for the ready-to-eat fresh produce industry. Acta Hort. 746, 25–32.

Proietti, S., Moscatello, S., Leccese, A., Colla, G., Battistelli, A., 2004. The effect of growing spinach (*Spinacia oleracea* L.) at two light intensities on the amounts of oxalate, ascorbate and nitrate in their leaves. J. Hortic. Sci. Biotech. 79 (4), 606–609.

Ramos, B., Miller, F.A., Brandão, T.R.S., Teixeira, P., Silva, C.L.M., 2013. Fresh fruits and vegetables – an overview on applied methodologies to improve its quality and safety. Innov. Food Sci. Emerg. 20, 1–15. Available from: http://dx.doi.org/10.1016/j.ifset.2013.07.002.

Ramos-Villarroel, A., Aron-Maftei, N., Martín-Belloso, O., Soliva-Fortuny, R., 2014. Bacterial inactivation and quality changes of fresh-cut avocados as affected by intense light pulses of specific spectra. Int. J. Food Sci. Tech 49 (1), 128–136.

Rastogi, G., Sbodio, A., Tech, J.J., Suslow, T.V., Coaker, G.L., Leveau, J.H.J., 2012. Leaf microbiota in an agroecosystem: spatiotemporal variation in bacterial community composition on field-grown lettuce. ISME J. 6, 1812–1822.

Rediers, H., Claes, M., Peeters, L., Willems, K., 2009. Evaluation of the cold chain of fresh-cut endive from farmer to plate. Postharvest Biol. Tec. 51, 257–262.

Reinink, K., Blom-Zanstra, M., 1989. The relation between cell size, ploidy level and nitrate concentration in lettuce. Physiol. Plantarum 76 (4), 575–580.

Rivera-López, J., Vázquez-Ortiz, F.A., Ayala-Zavala, F., Sotelo-Mundo, R.R., González-Aguilar, G.A., 2005. Cutting shape and storage temperature affect overall quality of fresh-cut papaya cv. 'Maradol'. J. Food Sci. 70 (7), S482–S489.

Robles-Sánchez, R.M., Rojas-Graü, M.A., Odriozola-Serrano, I., González-Aguilar, G., Martin-Belloso, O., 2013. Influence of alginate-based edible coating as carrier of antibrowning agents on bioactive compounds and antioxidant activity in fresh-cut Kent mangoes. LWT-Food Sci. Technol. 50, 240–246.

Rodríguez-Hidalgo, S., Artés-Hernández, F., Gómez, P., Artés, F., Fernandez, J.A., 2010. Quality changes on minimally processed purslane baby leaves growth under floating trays system. Acta Hort. 877, 641–648.

Rojas-Graü, M.A., Tapia, M.S., Rodríguez, F.J., Carmona, A.J., Martin-Belloso, O., 2007. Alginate and gellan-based edible coatings as carriers of antibrowning agents applied on fresh-cut Fuji apples. Food Hydrocolloid. 21, 118–127.

Rojas-Graü, M.A., Soliva-Fortuny, R., Martín-Belloso, O., 2009a. Edible coatings to incorporate active ingredients to fresh cut fruits: a review. Trends Food Sci. Tech. 20, 438–447.

Rojas-Graü, M.A., Oms-Oliu, G., Soliva-Fortuny, R., Martín-Belloso, O., 2009b. The use of packaging techniques to maintain freshness in fresh-cut fruits and vegetables: a review. Int. J. Food Sci. Tech. 44, 875–889.

Roller, S., Seedhar, P., 2002. Carvacrol and cinnamic acid inhibit microbial growth in fresh-cut melon and kiwifruit at 4° and 8°C. Lett. Appl. Microbiol. 35 (5), 390–394.

Saftner, R.A., Bai, J., Abbott, J.A., Lee, Y.S., 2003. Sanitary dips with calcium propionate, calcium chloride, or a calcium amino acid chelate maintain quality and shelf stability of honeydew chunks. Postharvest Biol. Tec. 29, 257–269.

Saltveit, M.E., 1997. Physical and physiological changes in minimally processed fruits and vegetables. In: Tomás-Barberán, F.A., Robins, R.J. (Eds.), Phytochemistry of Fruit and Vegetables. Oxford University Press, New York, New York, USA, pp. 205–220.

Santamaria, P., Valenzano, V., 2001. La qualità degli ortaggi allevati senza suolo. Italus Hortus 8 (6), 31–38.

Sapers, G.M., Simmons, G.F., 1998. Hydrogen peroxide disinfection of minimally processed fruits and vegetables. Food Technol. 52 (2), 48–52.

Scollard, J., Francis, G.A., O'Beirne, D., 2013. Some conventional and latent anti-listerial effects of essential oils, herbs, carrot and cabbage in fresh-cut vegetable systems. Postharvest Biol. Tec. 77, 87–93.

Seefeldt, H.F., Løkke, M.M., Edelenbos, M., 2012. Effect of variety and harvest time on respiration rate of broccoli florets and wild rocket salad using a novel O_2 sensor. Postharvest Biol. Tec. 69, 7–14.

Selma, M.V., Luna, M.C., Martínez-Sánchez, A., Tudela, J.A., Beltrán, D., Baixauli, C., et al., 2012. Sensory quality, bioactive constituents and microbiological quality of green and red fresh-cut lettuces (*Lactuca sativa* L.) are influenced by soil and soilless agricultural production systems. Postharvest Biol. Tec. 63, 16–24.

Seymour, I.J., Burfoot, D., Smith, R.L., Cox, L.A., Lockwood, A., 2002. Ultrasound decontamination of minimally processed fruits and vegetables. Int. J. Food Sci. Tech. 37, 547–557.

Sinigaglia, M., Albenzio, M., Corbo, M.R., 1999. Influence of process operations on shelf life and microbial population of fresh-cut vegetables. J. Ind. Microbiol. Biot. 23, 484–488.

Sirivatanapa, S., 2006. Packaging and transportation of fruits and vegetables for better marketing. In: Asian Productivity Organization (Ed.), Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization, Tokyo, Japan, pp. 43–48.

Sivakumar, D., Fallik, E., 2013. Influence of heat treatments on quality retention of fresh and fresh-cut produce. Food Rev. Int. 29 (3), 294–320.

Solomon, E.B., Pang, H.J., Matthews, K.R., 2003. Persistence of *Escherichia coli* O157:H7 on lettuce plants following spray irrigation with contaminated water. J. Food Protect. 66 (12), 2198–2202.

Sportelli, G.F., 2003. Ortive in fuori suolo, risultati ottimi per qualità e quantità. Colture Protette 2, 29–38.

Steele, M., Odumeru, J., 2004. Irrigation water as source of foodborne pathogens on fruit and vegetables. J. Food Protect. 67 (12), 2839–2849.

Steiner, A., Abreu, M., Correia, L., Beirão-da-Costa, S., Leitão, E., Beirão-da-Costa, M.L., et al., 2006. Metabolic response to combined mild heat pre-treatments and modified atmosphere packaging on fresh-cut peach. Eur. Food Res. Technol. 222, 217–222.

Strickland, W., Sopher, C.D., Rice, R.G., Battles, G.T., 2010. Six years of ozone processing of fresh cut salad mixes. Ozone: Sci. Eng. 32 (1), 66–70.

Suslow, T., 2006. Making sense of rules governing chlorine contact in postharvest handling of organic produce. ANR Publication 8198, <http://anrcatalog.ucdavis.edu/pdf/8198.pdf>. Visited 03/12/2013.

Takeuchi, K., Frank, J.F., 2001. Expression of red-shifted green fluorescent protein by *Escherichia coli* O157:H7 as a marker for the detection of cells on fresh produce. J. Food Protect. 64 (3), 298–304.

Takos, A.M., Jaffé, F.W., Jacob, S.R., Bogs, J., Robinson, S.P., Walker, A.R., 2006. Light-induced expression of a MYB gene regulates anthocyanin biosynthesis in red apples. Plant Physiol. 142 (3), 1216–1232.

Tapia, M.S., Rojas-Graü, M.A., Carmona, A., Rodriguez, F.J., Soliva-Fortuny, R., Martin-Belloso, O., 2008. Use of alginate- and gellan-based coatings for improving barrier, texture and nutritional properties of fresh-cut papaya. Food Hydrocolloid. 22 (8), 1493–1503.

Tarazona-Díaz, M.P., Viegas, J., Moldao-Martins, M., Aguayo, E., 2011. Bioactive compounds from flesh and by-product of fresh-cut watermelon cultivars. J. Sci. Food Agric. 91, 805–812.

Thomas, B.M., 1993. Overview of the speedling, incorporated, transplant industry operation. HortTechnology 3 (4), 406–408.

Thomas, C., O'Beirne, D., 2000. Evolution of the impact of short-term temperature abuse on the microbiology and shelf life of a model ready-to-use vegetable combination product. Int. J. Food Microbiol. 59, 47–57.

Thompson, J., Cantwell, M., Kader, A.A., 2001. Effect of cooling delays on fruit and vegetable quality. Perishables Handl. Quart. Issue 105, 1–4.

Tibaldi, G., Fontana, E., Nicola, S., 2010a. Influence of maturity stage at harvest on essential oil composition of dill leaves (*Anethum graveolens* L.) and of postharvest treatments on freshness of fresh-cut dill. Acta Hort. 880, 261–266.

Tibaldi, G., Battista, G., Fontana, E., Nicola, S., 2010b. Effetto del taglio e del condizionamento post-raccolta sulla shelf-life di zucca di IV gamma. Italus Hortus 17 (3), 52–55.

Toivonen, P.M.A., Hampson, C.R., 2009. Apple cultivar and temperature at cutting affect quality of fresh slices. HortTechnology 19, 108–112.

Tournas, V.H., 2005. Spoilage of vegetable crops by bacteria and fungi and related health hazards. Crit. Rev. Microbiol. 31, 33–44.

Tsouvaltzis, P., Deltsidis, A., Brecht, J.K., 2011. Hot water treatment and pre-processing storage reduce browning development in fresh-cut potato slices. HortScience 46 (9), 1282–1286.

Ukuku, D.O., Sapers, G.M., 2007. Effect of time before storage and storage temperature on survival of Salmonella inoculated on fresh-cut melons. Food Microbiol. 24 (3), 288–295.

University of Arizona-Cooperative Extension, 2004a. More studies indicate E. coli O157:H7 can contaminate lettuce in the field. Western Vegetable Newsl. 2 (1).

University of Arizona-Cooperative Extension, 2004b. Water stress may extend shelf life of vegetables. Western Vegetable Newsl. 2 (2).

Van Rijswick, C., 2010. EU fresh-cut fruits and vegetables market update. Rabobank 10RABINN45 9/10, <http://s3.amazonaws.com/zanran_storage/www.agf.nl/ContentPages/682927373.pdf> (accessed 06.11.13).

Vargas, M., Chiralt, A., Albors, A., González-Martínez, C., 2009. Effect of chitosan-based edible coatings applied by vacuum impregnation on quality preservation of fresh-cut carrot. Postharvest Biol. Tec. 51, 263–271.

Voća, S., Duralija, B., Družić, J., Skendrović Babojelić, M., Dobričević, N., Čmelik, Z., 2006. Influence of cultivation systems on physical and chemical composition of strawberry fruits cv. Elsanta. Agric. Conspect. Sci. 71 (4), 171–174.

Wall, N.M., Nishijima, K.A., Fitch, M.M., Nishijima, W.T., 2010. Physicochemical, nutritional and microbial quality of fresh-cut and frozen papaya prepared from cultivars with varying resistance to internal yellowing disease. J. Food Qual. 33, 131–149.

Watada, A.E., Qi, L., 1999. Quality of fresh-cut produce. Postharvest Biol. Tec. 15, 201–205.

Weerakkody, W.A.P., 2003. Nutritional value of fresh leafy vegetables as affected by pre-harvest factors. Acta Hort. 604, 511–515.

Wei, C.I., Huang, T.S., Kim, J.M., Lin, W.F., Tamplin, M.L., Bartz, J.A., 1995. Growth and survival of *Salmonella montevideo* on tomatoes and disinfection with chlorinated water. J. Food Protect. 58, 829–836.

Weyer, A., van de, Devleeschouwer, M.J., Dony, J., 1993. Bactericidal activity of disinfectants on *Listeria*. J. Appl. Bacteriol. 74, 480–483.

Wiley, R.C., 1994. Introduction to minimally processed fruits and vegetables. In: Wiley, R.C. (Ed.), Minimally Processed Refrigerated Fruits and Vegetables. Chapman and Hall, New York, New York, USA, pp. 1–14.

Wulfkuehler, S., Gras, C., Carle, R., 2013. Sesquiterpene lactone content and overall quality of fresh-cut Witloof Chicory (*Cichorium intybus* L. var. *foliosum* Hegi) as affected by different washing procedures. J. Agric. Food Chem. 61, 7705–7714.

Xiao, C., Zhu, L., Luo, W., Song, X., Deng, Y., 2010. Combined action of pure oxygen pretreatment and chitosan coating incorporated with rosemary extracts on the quality of fresh-cut pears. Food Chem. 121, 1003–1009.

Xiao, Z., Luo, Y., Luo, Y., Wang, Q., 2011. Combined effects of sodium chlorite dip treatment and chitosan coatings on the quality of fresh-cut d'Anjou pears. Postharvest Biol. Tec. 62, 319–326.

Zhan, L., Hu, J., Li, Y., Pang, L., 2012a. Combination of light exposure and low temperature in preserving quality and extending shelf-life of fresh-cut broccoli (*Brassica oleracea* L.). Postharvest Biol. Tec. 72, 76–81.

Zhan, L., Li, Y., Hu, J., Pang, L., Fan, H., 2012b. Browning inhibition and quality preservation of fresh-cut romaine lettuce exposed to high intensity light. Innov. Food Sci. Emerg. 14, 70–76.

Zhan, L., Hu, J., Ai, Z., Pang, L., Li, Y., Zhu, M., 2013a. Light exposure during storage preserving soluble sugar and L-ascorbic acid content of minimally processed romaine lettuce (*Lactuca sativa* L.var. *longifolia*). Food Chem. 136, 273–278.

Zhan, L., Hu, J., Lim, L.-T., Pang, L., Li, Y., Shao, J., 2013b. Light exposure inhibiting tissue browning and improving antioxidant capacity of fresh-cut celery (*Apium graveolens* var. *dulce*). Food Chem. 141, 2473–2478.

Zhan, L., Hu, J., Pang, L., Li, Y., Shao, J., 2014. Effect of light exposure on chlorophyll, sugars and vitamin C content of fresh-cut celery (*Apium graveolens* var. *dulce*) petioles. Int. J. Food Sci. Tech 49, 347–353. Available from: http://dx.doi.org/10.1111/ijfs.12292.

Zhan, L.J., Fontana, E., Tibaldi, G., Nicola, S., 2009. Qualitative and physiological response of minimally processed garden cress (*Lepidium sativum* L.) to harvest handling and storage conditions. J. Food Agric. Environ. 7 (3&4), 43–50.

Zhang, X., 2007. New approaches on improving the quality and safety of fresh cut fruits and vegetables. Acta Hort. 746, 97–102.

Zhuang, R.Y., Beuchat, L.R., 1996. Effectiveness of trisodium phosphate for killing *Salmonella montevideo* on tomatoes. Lett. Appl. Microbiol. 22, 97–100.

This page intentionally left blank

CHAPTER

Postharvest Physiology and Quality Maintenance of Tropical Fruits

10

Chalermchai Wongs-Aree[a,b] and Sompoch Noichinda[c]

[a]Postharvest Technology Program, School of Bioresources and Technology, King Mongkut's University of Technology Thonburi, Bangkok, Thailand [b]Postharvest Technology Innovation Center, Commission on Higher Education, Bangkok, Thailand [c]Division of Agro-Industrial Technology, Faculty of Applied Science, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

I Introduction

Tropical fruits grow and develop naturally in warm climate areas in tropical zones — which are geographically defined as the region between the Tropic of Cancer and the Tropic of Capricorn at latitudes 23°North and South of the equator. The average temperature is around 27°C, with little variation in day length (Samson, 1986). The natural ecosystems are unique, producing dramatically diverse plants in both genotypic and phenotypic aspects. Thus, a series of fruits are grown in that region that are exotic both in visual and other quality characteristics. Changes in fruit attributes after harvest due to the physiology itself or postharvest handling procedures decrease the marketable value. The quality of tropical fresh produce depends on its natural properties and needs to correspond to local or export standards (see also Chapter 8). Local and regional populations show different quality preferences. For example, Malaysian or Indonesian people like consuming over-ripe durians with very soft pulp texture and strong fragrance, whereas Thais prefer ripe—firm pulp with much less aroma. Although translucent flesh is a physiological disorder in mangosteen fruit, some people like the crispy firm flesh. Fruit with this defect has, however, a short shelf life due to flesh fermentation. Furthermore, some postharvest handling procedures increase quality problems in tropical fruits. When Asian people prefer bunches of fruits such as litchi and longkong and, sometimes, bunches with the leaves on, fruits/leaves dropped from bunches during transportation and storage lower the quality grade. Harvesting individual fruit would be more practical for postharvest handling and to maintain quality.

Tropical fruits can be classified into major and minor groups depending on the fresh volume demanded in markets across the world (Table 10.1). In this chapter,

Postharvest Handling.

Table 10.1 Commercial Tropical Fruits in Global Markets

Major Commercial Tropical Fruits	Minor Commercial Tropical Fruits
Citrus	Litchi/Lychee
Banana	Rambutam
Pineapple	Mangosteen
Mango	Durian
Papaya	Longan
Passion fruit	Pummelo

the quality attributes and the physiological changes of minor commercial tropical fruits are emphasized.

II Factors affecting fruit quality

A Cultivars

The quality of fresh produce mostly relies on its visual appearance, which should be fresh without any defects, and relevant to the cultivar. Tropical fruits are attractive, exhibiting many unique shapes and sizes. In addition to an attractive appearance, cultivars should be selected for high yield, resistance to pests and diseases and ease of harvest. Merchants prefer fruits with a long shelf life, whereas consumers desire fruits with good flavor, appropriate firmness and nutritional value. Consequently, the selection of appropriate fruit cultivars is a strong factor in marketable quality.

Two major commercial groups of dragon fruit [*Hylocereus undatus* (Haw) Britt. & Rose.] of white and red flesh are widely traded. White fleshed fruit is characterized by both sweet and sour tastes, while red fleshed cultivars are less sweet but higher in antioxidants, particularly the betalains (Nerd et al., 1999). There are three primary cultivars of durian in Thailand: "Kradoom Thong" is an early-maturing cultivar, ripe "Chanee" pulp exhibits a yellow, smooth custard-like texture, whereas ripe "Mon Thong" pulp is characterized by a coarse–firm texture with less aroma. A new cultivar, "Chanthaburi 1" is a cross between "Chanee" and "Mon Thong" and produces a deep yellow flesh with little of the typical aroma when ripe, and is suitable for export (Somsri, 2008). Pineapple fruit of Smooth Cayenne and Queen groups develop black heart (BH)/internal browning (IB), a form of chilling injury (CI), in the field when maturing in winter (You-Lin et al., 1997; Taniguchi et al., 2008). Cultivars "73-50" and "Gold" were bred for lower susceptibility to IB in Hawaii, United States. "Gold" pineapple fruit is more resistant to IB (Stewart et al., 2002), but it is more susceptible to fruit rot than "Smooth Cayenne" (Chan et al., 2003). Sugar apples in Thailand are divided into two main groups – "Fai" and "Nang". The flesh of "Fai" turns very soft soon after onset of ripening when small fruit berries on the aggregate fruit are easily separated or split from each other during ripening. The flesh of “Nang” type of each fruitlet gels together like custard during ripening (Wongs-Aree and Noichinda, 2011). Mangosteen fruit develop as parthenocarpic fruits and contain some apomictic seeds or are seedless. It is apparent that mangosteen plants are derived from a single clone. However, there are three groups among 37 accessions of mangosteen in terms of genetic diversity (Ramage et al., 2004).

B Fruit structure

Fruit type

Tropical areas are rich in fruits with a wide variation in taxonomy and anatomy (Utsunomiya, 1989). Tropical fruits are classified on the basis of the floral origin such as single fruit from a single flower even though the flower type is an inflorescence. Single fruits develop from a single flower and one ovary, either on the flower bud or inflorescence, such as rambutan, longan and mango. Some single flowers consist of many carpels, which fuse together after fertilization and form an aggregate fruit type, such as the sugar apple. In case of pineapple fruit, the fusion of numerous fruitlets on the same inflorescence is called a multiple fruit type. Normally, fruit develops after fertilization takes place during the flower-blooming stage. In most fertilized flowers, the ovary wall changes to an edible part of fruit pericarp as the fruit pulp. The flesh of some tropical fruits is derived from special tissue, called “aril”, which develops from the funiculus of the seed, when the ovary wall develops into the fruit rind, as is the case with longan, litchi, mangosteen and durian. Mango is classified as a drupe by its physical traits, because the fruit is derived from one carpel with a single seed when the exocarp, mesocarp and endocarp develop in to peel, fleshy flesh, and hard layer covering the seed, respectively. Pummelo and mandarin orange contain a tough rind with numerous carpels separable as “sections” as in the Hesperidium group. Furthermore, in some accessory fruits, an edible fleshy part is composed of a mature ovary along with other enlarged parts of the flower, i.e., receptacle, as exemplified by guava and dragon fruit. The edible parts of gac fruit come from both parts of fleshy pulp pericarp and aril surrounding the seeds, containing very high lycopene content (Aoki et al., 2002).

Fruit anatomy and morphology

The ovary wall (pericarp) of many tropical fruits is composed of an attractive rind surrounding the edible flesh, an aril, such as rambutan, litchi, longkong, mangosteen and durian. It is apparent that the development of the peel and pulp of fruits are independent during fruit ripening. Rapid changes in the pericarp rind will shorten the storage life of the fruit.

Durian

Durian rind (husk), pulp and seeds are anatomically connected only at the fruit placenta. Most ethylene production from the fruit is related to the husk, which is derived from the ovary wall, whereas the pulp produces only small amounts (Siriphanich, 1996). When durian pulp is removed from the fruit, it exhibits low respiration and ethylene production rates compared to the husk (Brooncherm and Siriphanich, 1991) which contains high activities of ethylene biosynthetic enzymes. ACC (1-aminocyclopropane-1-carboxylate) synthase (ACS) and ACC oxidase (ACO) activities in both the husk and pulp increase as the fruit ripens with ACS activity in the husk being higher than that in the pulp (Chaiprasart and Siriphanich, 2000). High endogenous ethylene levels in durian husk induces the biological process of husk dehiscence during fruit ripening. Conversely, ready-to-eat durian pulp usually encounters the problem of failure to properly ripen or uneven ripening, due mainly to the very low levels of ethylene produced by the aril. Furthermore, the pulp is developed from the overlap of several layers of aril, which could result in different physiological inductions between each overlapped layer, responsible for unharmonized ripening of aril pulp which is similar to different maturities between the segments of mangosteen and longkong fruits.

Rambutan

Postharvest quality defects in rambutan fruit are mainly caused by water loss. The presence of special hairy tissues, termed spinterns, developed from sub-epidermal tissues of the rind. Rambutan fruit skin has numerous stomata, especially on the spinterns. The more amount of stomata on the spinterns are 2.5- to 5-fold higher than on the peel. There are $1.15-1.7 \times 10^6$ stomata per fruit resulting in weight loss at 25°C, 60% relative humidity (RH) up to 37.50% on day 6 (Yingsanga et al., 2006a). Microscopic studies show that 15–20 groups of vascular bundles are located in each spintern and connect to peel vascular bundles. The vascular bundles are also found in the tissues below the peel surface adjacent to the edible flesh, such that water may move from the peel to the base of spintern and, then, to the tip of spintern. Transpiration via the stomata causes rapid water loss and noticeable wilting (Yingsanga et al., 2006b). Water loss from intact rambutan fruit via spinterns is replaced by water from the skin (Landrigan et al., 1996).

Mangosteen

In general, a whole mangosteen fruit contains four to eight segments which vary in size. Large segments in whole mangosteen fruit usually contain an apomictic seed inside the aril (Figure 10.2B) while small segments are seedless or contain an aborted seed. Small fruit comprise fewer large segments, containing fewer seeds, compared to mid-size and large mangosteen fruit. The mesocarp contains groups of vascular bundles and fiber, connected to aril and seeds and linked to the stem peduncle. The exocarp, mesocarp and endocarp of the fruit consist of numerous yellow latex secretory ducts (Dorly and Tjitrosemito, 2008) that are released when the pericarp is physically damaged. Furthermore, the mangosteen pericarp contains high levels of xanthones, a class of phenolic compounds showing antioxidant properties and potential medicinal benefits. At least 14 xathones

FIGURE 10.1

Distribution of water-soluble carmoisine dye in "Trad Srithong" pineapple fruit (Queen group) following infiltration by transpiration via the peduncle for 3 days at 25°C.

have been detected in the pericarp, including 8-hydroxycudraxanthone G, mangostingone [7-methoxy-2-(3-methyl-2-butenyl)-8-(3-methyl-2-oxo-3-butenyl)-1,3,6-trihydroxyxanthone, 2], cudraxanthone G, 8-deoxygartanin, garcimangosone B, garcinone D, garcinone E, gartanin, 1-isomangostin, α-mangostin, γ-mangostin, mangostinone, smeathxanthone A, and tovophyllin A (Jung et al., 2006).

Pineapple

Pineapple (*Ananas comosus* Merr.), native to South America, is a highly marketable tropical fruit in the Bromeliaceae family consisting of numerous fruitlets fused on a same inflorescence. The communication of fruitlet connection through the fruit core (Figure 10.1) is crucial for fruit development and quality. Pineapple is a non-climacteric fruit as it does not ripen significantly postharvest. Since the pineapple fruit develops from the fusion of fruitlets, those fruitlets near the stem end mature earlier than those at the stylar zone, leading to uneven ripening of the whole fruit. When the stylar zone pulp ripens, the stem zone pulp is overripe.

C Fruit maturity and ripening

Fruit respiration and ethylene production

Climacteric and non-climacteric fruits

Respiration and ethylene production is a crucial biological process in plants that characterize the ripening pattern of the fruit. With the respiration and ethylene

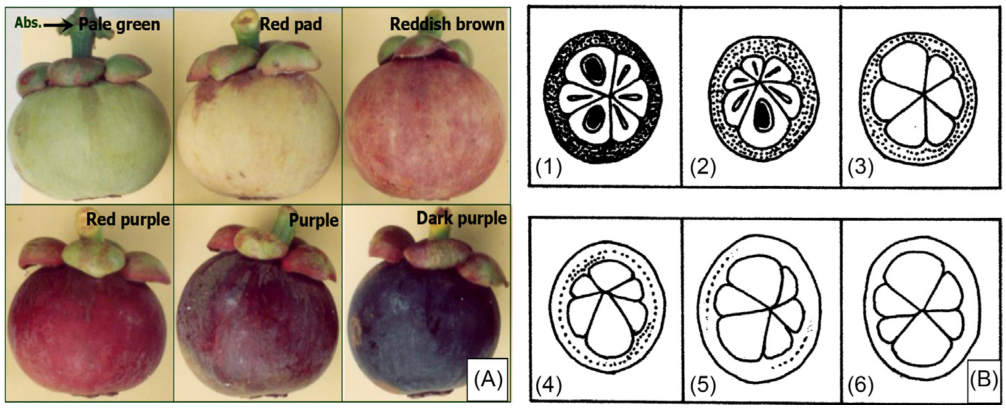

FIGURE 10.2

Maturity index of mangosteen (A) starting from pale green -light green peel (1), red pad - a first indication of red color on peel (2), reddish brown - pink color dispering whole fruit (3), red purple - more red color on peel (4), purple (5), Dark purple - intense dark purple on whole fruit (6). Cross-sectional drawing of the fruit at each stage showing yellow latex tubes as dispersed spots (B).

production patterns during fruit maturity and ripening, tropical fruits are classified into two groups: climacteric and non-climacteric fruits (Table 10.2). Ethylene, a small hydrocarbon molecule, biosynthesized by all plant tissues and organs, induces a wide range of physiological responses, including altered plant growth, abscission, ripening, senescence and physiological disorders. These responses can be beneficial or detrimental, depending on the response. The difficulty of maintaining postharvest quality of tropical fruits includes many factors such as different maturation and ripening levels between pulp and peel.

The rate of respiration and ethylene production at harvest and the peak of climacteric respiration are higher in fruit harvested at a more advanced stage of durian. Days between harvest and the climacteric peak are reduced as maturity stage at harvest advances (Tongdee et al., 1990). Durian fruit produce double ethylene production peaks (EP) such that the EP1 occurs before the climacteric respiratory peak (CP) when it is almost half-ripe. The EP2 is produced at the overripe stage during fruit dehusking when the pulp is very soft and releases a strong fragrance (Brooncherm and Siriphanich, 1991). The respiration behavior during ripening of "Fai" sugar apple fruit also presents two CPs (Kosiyachinda and Young, 1975) which are found in several *Anona* species. The CP1 occurs during fruit pulp softening whereas the CP2 is mostly indicated during fruitlet splitting. The CP1 and EP of "Fai", harvested at the commercial maturities for domestic markets reach the peaks on day 4 at 25°C when the fruit releases high levels of aroma volatiles. Mangosteen, previously believed to be non-climacteric, shows the climacteric respiratory pattern during ripening (Figure 10.3B). Fruit at the red pad stage of maturity, which is the first recommended stage for harvesting, is

Table 10.2 Classification of Tropical Fruits by their Respiratory Pattern during Fruit Ripening

Climacteric Fruit	Non-Climacteric Fruit
Banana (*Musa* spp.)	Longan (*Dimocarpus longan* Lour.)
Durian (*Durio zibethinus* Murr.)	Longkong (*Aglaia dookkoo* Griff.)
Guava (*Psidium guajava* Linn.)	Pineapple [*Ananas comosus* (Linn.) Merr.]
Papaya (*Carica papaya* Linn.)	Rose apple [*Syzygium jambos* (Linn.) Alston]
Sapodilla/Sapota (*Achras sapote* Linn.)	Lime (*Citrus aurantifolia* Swingle)
Jackfruit (*Artocarpus heterophyllus* Lam.)	Pummelo [*Citrus grandis* (Linn.) Osbeck]
Mango (*Mangifera indica* Linn.)	Salak [*Salacca zalacca* (Gaertn.) Voss]
Sugar apple (*Annona squamosa* Linn.)	Lychee/Litchi (*Litchi chinensis* Sonn.)
Passion fruit (*Passiflora edulis* Sims)	Rambutan (*Nephelium lappaceum* Linn.)
Mangosteen (*Garcinia mangostana* Linn.)	Carambola/Star fruit (*Averrhoa carambola* Linn.)
Sentul/Santol [*Sandoricum koetjape* (Burm. f.)]	Pitaya/Dragon fruit [*Hylocereus undatus* (Haw) Britt. & Rose.]
	Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai]
	Marian Plum/Plum Mango (*Bouea macrophylla* Griff)

starting to ripen such that pre-climacteric respiration disappears from the fruit. The pre-climacteric stage occurs at the mature green stage when is not suitable to harvest because the pericarp color and flavor of harvested fruit cannot be fully developed (Noichinda, 1992). Rambutan fruit, which is non-climacteric after harvest show a respiratory pattern like the climacteric rise, caused by water loss from the fruit (Kosiyachinda et al., 1987).

Internal ethylene concentration

The internal ethylene concentration (IEC) of fruit is very important for long periods of storage. In some fruits, after ethylene biosynthesis is initiated a small amount of endogenous ethylene can be released, but the remainder stays in the fruit cavity or in the cells because of the cell high density. Tropical fruits that produce high IECs during harvest include mangosteen (Noichinda, 1991), papaya (Fuggate et al., 2010) and durian (Ketsa and Pangkool, 1994). Successful long-term storage of tropical fruits is associated with the harvesting index which relates to the IEC. Detached “Pluk Mai Lie” papaya fruit at the color break stage ripen faster than attached fruit, showing high IEC (Fuggate et al., 2010). A whole

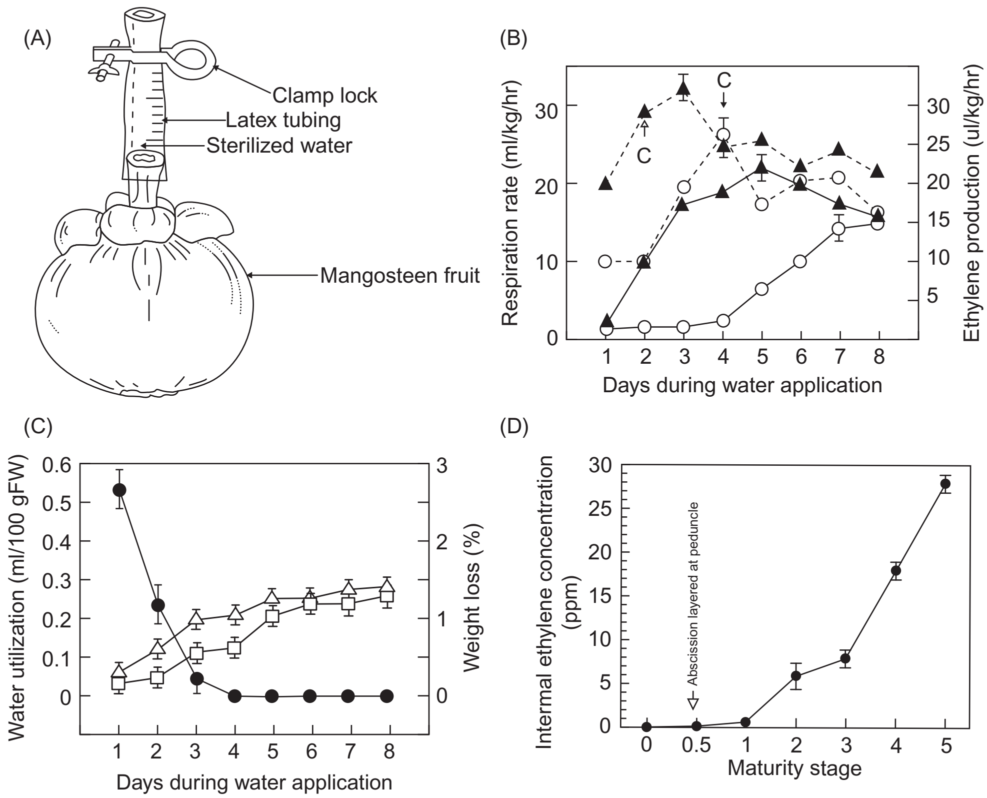

FIGURE 10.3

Illustration of mature green mangosteen fruit with continuous water infiltration via the peduncle (A) and the ethylene production (black lines) and respiration (dashed lines) of water infiltration (▲) and control (○) (B), water loss (□ = water infiltration and Δ = control) and water utilization (●) (C), compared with normal fruit, and internal ethylene concentration of normal fruit (0.5 = pale green, 1 = red pad, 2 = brown, 3 = red, 4 = purple, 5 = dark purple) (D) (Noichinda, 1992).

durian fruit comprising many segments varies widely in IEC. Incubating durian fruit at room temperature under low humidity of 65% RH induces high IEC accumulation, leading to husk dehiscence without accelerating ripening (Ketsa and Pangkool, 1994).

Ethylene sensitivity and response

Many fruits produce very low levels of endogenous ethylene such as non-climacteric fruit, but some are highly sensitive to both exogenous and endogenous ethylene, for induction of physiological disorders. Longkong is a non-climacteric fruit with a high sensitivity to ethylene. An ethylene level as low as at 0.5 ppm can induce fruit drop from the bunch. Postharvest ethylene inducing fruit drop is mostly generated by fungal growth on the fruit (Siriphanich et al., 2013).

Watermelons also produce small amounts of ethylene at rates in the range of 0.1−1.0 μl/ kg per h at 20°C. Despite these rates, watermelon fruits are extremely sensitive. Exposure to ethylene induces placental tissue softening, water soaking and over-ripening of the rind (Elkashif et al., 1989). For long-term storage of watermelons, ethylene in the atmosphere should be kept under 0.1 ppm. This type of fruit is sensitive to ethylene and should not be stored or shipped with produce emitting high levels of ethylene such as ripe durian and banana.

Fruit maturation

The maturation process of fruit is, in general, initiated by seed formation. Natural pulp ripening of the whole fruit depends individually on the maturation stage of each locule (i.e., mangosteen), segment, or even each layer on the same aril (i.e., durian). Thus, the maturity of a whole fruit is uneven. Pineapples develop from the fusion of fruitlets on the same inflorescence, while developing carpels are on a single flower for sugar apples. Uneven ripening of the pineapple fruit increases with fluctuations in respiratory patterns. Even though the pineapple is classified as a non-climacteric fruit, its ripening is similar to that of the climacteric sugar apple (Kosiyachinda and Young, 1975).

The storage of tropical fruits for distant markets must be concerned with the anatomy (stomata, lenticels), morphology (dimension, fruit structure: spin, spintern, shape, peduncles) and physico-biochemical properties (maturity, eating quality of climacteric and non-climacteric fruits). Non-climacteric fruits should be harvested at full maturity to accumulate high levels of organic acids and sugars inside while keeping the cell wall structure intact, to maintain a firm fruit texture for transportation. However, some non-climacteric fruits may require the induction of color changes (degreening) after harvest.

Harvesting index

Early and late harvesting

Peel color (i.e., rambutan, mangosteen, papaya and pineapple), structure and shape (i.e., durian, banana) are often used as criteria for a maturity index of many tropical fruits. However, duration of fruit development is a more precise tool for a maturity index. Harvesting time for a tropical fruit depends on both the shipping distance and the period of storage. Overseas consumers rarely enjoy the best flavor of an imported fruit because it is frequently harvested at an immature stage. For long-distance markets, fruits are usually harvested at early maturation, whereas for local or domestic markets, fresh commodities are customarily harvested fully mature, which allows the fruit to accumulate its full flavor, which is important for fresh consumption. General harvesting indices of some tropical fruits are shown in Table 10.3.

Finger angle shape can generally be used for determining banana fruit maturity. Maturing fruit become less angular and more rounded. Green bananas, harvested at early harvesting stage of three-quarter round (70−75% mature) at the

Table 10.3 Harvesting Indices of Selected Tropical Fruits

Fruit	Harvesting Index	
	Time	**Other Index**
"Khai" banana (AA)	40–45 DBR	{3/4} of angular fruit shape for distant markets
"Hom Thong" banana (AAA)	60–70 DBR	Almost rounded shape for local markets
"Rong-Rien" Rambutan	18 WFB	Pink peel color with still green spinterns
Mangosteen	70–80 DFS	Red pad fruit stage for distant markets
		Pink–purple peel for local markets
Longkong	6 MFB	20% green color leave on peel
Pummelo	7–8 MFB	Peel changes to yellowish green.
		Expanding oil glands on peel and scattered.
		≥ 8% soluble solids
"Kradoom" Durian	90–100 DFB	27% flesh dry weight
"Chanee" Durian	100–120 DFB	30% flesh dry weight
"Mon Thong" Durian	115–130 DFB	32% flesh dry weight
Pineapple	6–7 MFI	2–3 fruitlet rows turn yellow with dried bracts
	110–120 DFB	12% soluble solids
Litchi/Lychee	60–70 DFB	Fruit expanded with thinner peel
Longan	5 MFB	Fully expanding fruit and smooth peel
Mango	95–105 DFB	Fruit color changes
		Glossy rind surface
Sapota	6–7 MFB	Fruit color changes
		Dried filament
Papaya	130–140 DFB	A shine of yellow pad on fruit stylar end
Watermelon	5–6 WFB	Glossy rind surface
Jackfruit	9–10 MFB	Leaves on the peduncle turn yellow
		Outer prickles separated

DFB, days after full bloom; WFB, weeks after full bloom; DFS, days after fruit set; MFB, months after full bloom; DBR, days after blossom removal; MFI, months after flower induction.
Modified from Siriphanich and Romphophak (2000); CODEX STAN 182-1993; TAS 3-2003; TAS 13-2007.

pre-climacteric stage when IEC is low, and autocatalytic ethylene production has not yet been induced, have lower consumption quality due to a firm texture in the core and less flavor during ripening (Noichinda et al., 2006). Harvesting "Chanee" durian at 75% maturity causes a reduction in some volatiles, especially sulfur-containing compounds, compared to 100% abscised fruit (Maninang et al., 2011). Translucent pulp, with white-translucent flesh like glass, is frequently found in high levels in late harvested mangosteen fruit when fruit is ripened on the tree during the rainy season.

Although pummelo can be held on the tree as green storage, the longer mature fruit is held on the tree, the more granulation is generated, which lowers its marketable value. Over-maturing rambutan shows peel wilting and collapsed pulp tissue, resulting in juice expression between peel and pulp particularly in the "See Chompoo" cultivar (Kosiyachinda et al., 1987). Furthermore, in some mango cultivars, over-maturing fruit soften in the flesh, particularly the flesh around the seed, which turns a deeper yellow and becomes jelly-like. These disorder symptoms are usually found in the early stage of mango fruit ripening on tree.

Quality alterations with different fruit maturities

Pericarp color changes of mangosteen from green to purple black after harvest can be used as a harvest index when the fruit pericarp firmness is reduced (Palapol et al., 2009). The peel color harvest index for mangosteen starts at pale green, with development of red color on the fruit when an abscission zone of the peduncle is swollen, until it becomes a dark purple, which indicates superior eating quality (Table 10.4). Domestic harvesting trends use pale green with 10% red pad (Figure 10.2A; stage 2) requiring 6 days to reach the dark purple stage (Figure 10.2A; stage 6) at room temperature (Table 10.5). At the red pad stage, the quality and ripening of the fruit cannot be effectively maintained or delayed for export because the harvested fruit has already reached a climacteric rise stage with IEC over 0.5 ppm (Figure 10.3D). From mature pale green (stage 1) to red purple (stage 4), the pericarp of mangosteen contains yellow latex spots within the pericarp (Figure 10.2B), reducing the acceptable quality during transportation and storage. Fruit physically damaged during these periods will generate gamboge disorders.

The development of climacteric fruit is related to the biochemical changes of fruit softening, respiration, ethylene production, fruit pigmentation and flavor. Sucrose is the predominant sugar in the aril of rambutan, and this accumulates as the fruit matures, but sucrose and glucose sharply decrease in all maturity stages a few days after harvest. Fructose also increases sharply at all stages of fruit maturity. One day after harvest, fruit at breaker and orange red stages have a high invertase activity which converts sucrose to glucose and fructose. Glucose is further metabolized in respiration (Tongtao et al., 2013).

Table 10.4 Physio-Chemical Changes of Harvested Mangosteen Fruit at Various Stages Stored in Ambient Conditions (28–30°C, 64–68% RH)

	Day 1 After Harvest				After Peel Color Turns to Dark Purple			
Maturity Stage	**SS (%)**	**TA (%)**	**SS/TA**	**Flesh Texture/Color**	**SS (%)**	**TA (%)**	**SS/TA**	**Flesh Texture/Color**
Pale green	15.4	0.60	22.67	High firm/white*	18.3	0.52	35.19	Soft/translucent white
Red pad	15.7	0.59	26.61	High firm/white*	18.9	0.45	42.00	Soft/translucent white
Reddish brown	17.8	0.59	30.16	Slightly soft/white**	18.8	0.43	43.72	Soft/translucent white
Red purple	18.5	0.51	36.28	Soft/translucent white***	19.2	0.48	40.00	Succulent/translucent white
Purple	18.9	0.50	37.80	Soft/translucent white***	19.0	0.48	39.53	Succulent/translucent white
Dark purple	18.6	0.52	37.2	Succulent/translucent white				

**Rind and flesh cannot be separated from each other.*
***Some parts of aril flesh separated from the rind.*
****Rind and flesh is completely separated.*
From Noichinda (1992).

Table 10.5 Physio-Chemical Changes of Harvested Red Pad Stage Mangosteen Fruit Stored in Ambient Conditions (28–30°C, 64–68% RH)

Property	Days After Harvest					
	1	2	3	4	5	6
Rind color* (scores)	1.00	2.10	3.25	4.15	4.75	5
Weight loss (%)	1.20	2.75	3.40	5.50	5.70	6.20
Rind hardness (kg/cm^2)	3.47	3.45	3.30	3.19	2.27	2.20
Latex content** (%)	95	75	45	5	0	0
Total sugars (%)	17.20	17.35	18.52	19.87	20.31	20.00
Soluble solids (%)	15.50	15.95	16.30	17.80	18.50	18.85
Titratable acidity (%)	0.68	0.70	0.65	0.69	0.62	0.53
Flesh ascorbic acid (mg/100 g FW)	22.0	27.3	24.5	26.3	22.4	19.8

*Rind color: 0 = pale green, 1 = red pad, 2 = reddish brown, 3 = red purple, 4 = purple, 5 = dark purple.
**Latex content in rind pericarp calculated as percentage of latex on the cross-section surface 1 min after cutting.
From Noichinda (1992).*

D Physiological disorders

There are many physiological disorders that affect tropical fruits. Some fruits are susceptible to a single disorder, but many are affected by multiple disorders. Quality acceptance can be directly assessed from visual appearance, but internal quality and disorder are not noticed until the fruit is cut for sale or consumption.

Wet core

Wet core or water core is an internal fruit disorder in durian. Aril flesh areas connected to the seeds and the fruit core are very moist caused by over-watering just prior to harvest. Water is translocated from the mother tree through the placental xylem and accumulates at the connection of aril with the placenta. Thus, when durian trees accumulate too much water from rain as it becomes mature, the fruit develops the water core disorder (Nanthachai, 1994). The symptom of this disorder is that the flesh becomes water soaked and deteriorates faster than unaffected areas. Late-maturing durian varieties such as "Mon Thong", which matures during the heavy rainy season, are particularly susceptible to water core.

Flesh hardening

Hardened flesh, an internal disorder, is characterized as uneven fruit ripening or improper development of durian fruit aril during maturation. The hard aril flesh cannot soften normally and ripening will not occur even if is treated with exogenous ethylene. The end of each aril layer of the seed opposite to the placental connection turns reddish brown with a hard or leathery texture, and lacks flavor.

When durian trees respond by producing new emerging shoots after receiving excess water during late fruit development (Nanthachai, 1994), this is probably due to translocation of fruit nutrition (source) back to the mother plant to provide for the new shoots (strong sink). Local farmers observe this disorder visually by the failure of the spin tip to lose its green color as the husk turns yellowish green during fruit ripening.

Fruit dehiscence

Fruit dehiscence occurs frequently in some durian cultivars during late ripening. The abscission layer of each fruit segment is split at the end of the capsule (Figure 10.4A). Although low relative humidity and ethylene induction increase fruit dehusking, ethylene is more important than weight loss (Ketsa and Pangkool, 1994). Most ethylene production is associated with the husk, while the pulp produces ethylene at a very low rate (Siriphanich, 1996). Khurnpoon and Siriphanich (2005) reported that husk dehiscence in "Mon Thong" fruit, starting during late ripening on day 4 at room temperature. Although the increased activities of pectinmethyl esterase (PME) and polygalacturonase (PG) were related to increased levels of water-soluble pectin in the dehiscent abscission zone, they play only a minor role in the fruit dehusking process.

Peel browning

Polyphenol oxidase (PPO) and peroxidase (POD) are the two major enzymes involved in browning fresh produce. Rambutan, longkong and litchi fruits exhibit skin browning after harvest. Rambutan stomata on the spintern outnumber those on the peel by 2.5- to 5-fold. The rapid desiccation of the fruit leads to extensive browning/blackening of the spintern. PPO and POD activities in the spinterns are higher than those in the peel, but the PPO activity is not affected by RH (Yingsanga et al., 2008). During the browning of longkong fruit the respiration rate decreases slightly, in contrast to a progressive increase in ethylene production. Browning is initially induced by phenylalanine ammonia-lyase (PAL) and followed by PPO activity. Longkong peel collapses after harvest especially around any brown patches (Lichanporn et al., 2009). Litchi pericarp turns brown rapidly after harvest. Browning is closely associated with the degradation of anthocyanins, a reduction of ascorbic acid and an increase in PPO in the pericarp (Yueming, 2000).

Fruit drop

Banana fingers (individual fruit) dropping from the hands (bunches) during ripening are caused by physiological softening and weakening which separate fruits from the hands. Finger drop has been reported in "A" genome group of diploid (AA) (Prayurawong, 1999) and triploid cultivars (AAA) (Semple and Thompson, 1988; Imsabai et al., 2006). The disorder is reduced by incubating banana hands at low RH during ripening. Pectate lyase (PL) activity at the drop zone dramatically increases at high RH with a slight increase in PME, but little or no change

FIGURE 10.4

Physiological disorders of some tropical fruits: fruit dehusking in durian (A), Fruit splitting in sugar apple (B), gamboge on outer mangosteen rind (C), gamboge affecting the inner flesh (D), and translucent flesh in mangosteen fruit (E).

in PG (Saengpook et al., 2007). Longkong fruit in bunches are highly sensitive to ethylene with even a low concentration inducing fruit drop from the bunch (Siriphanich et al., 2013). Postharvest fungal infection and growth on the fruit during storage or transportation increases the ethylene concentration and induces fruit drop (Pluemjit et al., 2013). The separation site between the calyx and the fruit is much more responsive to physiological processes than the site between the peduncle and the calyx. PG and cellulase (CEL) activities increase after harvest at the separation site between the calyx and the fruit when induced by exogenous ethylene treatments (Taesakul et al., 2013).

Fruit splitting

During ripening, flesh of “Fai” sugar apples turns very soft soon after onset of ripening when the fruit berries on an aggregate fruit are easily separated from each other (Figure 10.4B). Fruit firmness decreases rapidly from 6.4 N to 0.5 N 2 days after harvest at ambient temperature. PME activity moderately increases from the first day after harvest while a sharp increase of the endo-PG activity occurs after the third day. PL plays a prominent role during the softening process of “Fai”, such that the activity rapidly increases at high rates and maximizes on the second day after harvest (Noichinda et al., 2010).

Pericarp hardening

In mangosteen, mechanical damage to the fruit from compression or impact bruising during harvest and handling leads to hardening of the pericarp. The pericarp will harden after an impact force at least 80 cm height within 1 h, whereas fruit treated with N_2 gas show lower POD activity with a loss of lignin and accumulation of high levels of phenolics (Ketsa and Atantee, 1998). Levels of *p*-Cuamaric acid and cinnapic acid in pericarp decrease rapidly after impact. Keeping fruit in a low O_2 environment can delay pericarp hardening (Bunsiri et al., 2003). Furthermore, apart from pericarp hardening (Ketsa and Atantee, 1998) other damage to the pericarp also induces pericarp browning (Tongdee and Suwanagul, 1989; Ketsa and Atantee, 1998).

Translucent flesh

Translucent flesh, an internal disorder, develops during mangosteen fruit ripening, such that aril firmness increases resulting in a crispy texture and a change in flesh color from white to translucent. This disorder may result from mechanical injury, nutrient imbalance, long storage at low temperature or excessive water uptake into the flesh. The disorder is usually found in the aril flesh of big carpels containing an apomatic seed (Figure 10.4E). The symptoms develop in the cell wall of parenchyma tissue of the aril, which becomes thicker by lignification. Mangosteen translucent flesh disorder is widespread, and appears to be related to excess water in the developing fruit on the tree during rain (Sdoodee and Limpun-Udom, 2002; Sdoodee and Chairawipa, 2005). In natural translucent flesh, white normal aril tissue contains higher numbers of intact protoplasts, which becomes translucent as these are lost. Translucent flesh contains less water-soluble and CDTA (1,2 cyclohexane diamine tetraacetic acid)-soluble pectins than normal flesh. During fruit ripening of mangosteen, the plants translocate excess water from the mother plants to the fruit through fruit xylem, the aril tissues are injured and then solute leaks out through the cell membrane. These changes are responsible for water-soluble pectin turning to highly water-insoluble pectin and giving firmer fruit flesh (Dangcham and Siriphanich, 2001). Water infiltration of postharvest treatment at 39 kPa for 5 min adds more water to both rind and flesh (Figure 10.3A, C), which induces higher ethylene production and respiration (Figure 10.3B). Water infiltration also influences the translucency of treated mangosteen fruit (Pankasemsuk et al., 1996), but the affected aril is soft, unlike the firm−crispy translucent flesh found normally. This uncharacteristic softening indicates that the disorder may be indirectly induced by other factors such as high accumulation of secondary wall of lignification. Internal physiological disorders are more likely to occur in smooth-surface than coarse-surface fruit at levels of 63% and 19%, respectively. Fruits exhibit a high specific gravity above 1.0 with a high probability of translucent flesh inside (Chaisrichonlathan and Noomhorm, 2011).

Gamboge/latex leak

Damaged pericarp of mangosteen induced by physical impact during maturation is responsible for latex leaking called "gamboge", both on the outer (Figure 10.4C) and in the inner pericarp of the flesh (Figure 10.4D). The latex covers the flesh aril leading to a yellow color and a bitter taste. The yellow latex secretory ducts are found in the exocarp, mesocarp and endocarp of the fruit with secretory ducts of largest diameter being found in the endocarp. The secretory ducts connect from the peduncle to the fruit. Yellow latex collected from the outer part of the fruit, young fruit pericarp, mature and young arils contains terpenoids, flavonoids and tannins, but not alkaloids, except in the young aril containing sterols (Dorly et al., 2011). Reduction of yellow latex spots both on the outer and inside the fruit pericarp was demonstrated by applying $CaCl_2$ spray during fruit development on trees. Latex disorders were significantly reduced both on the outer fruit and inside fruit on the aril (Dorly et al., 2011).

Jelly flesh

Jelly flesh of mango fruit is an internal fruit breakdown resulting from over ripening of the flesh around the seed which is surrounded by the normal firm flesh. Flesh tissues surrounding the hard endocarp turn into a transparent, gelatinous substance with a yellow color. The affected flesh matures more rapidly than healthy mesocarp and produces a deeper yellow color (Lizada et al., 1984). It generally occurs when mango fruit ripens on the tree, and may involve fermentation of the flesh surrounding the seed. Mango fruit gradually generates a cuticle wax covering the peel during fruit development to prevent water loss from the flesh which also may prevent gas transmission into late maturing fruit leading to fermentation in the deep inner tissues.

Granulation

Granulation is an internal disorder of the juice sacs of citrus near the stem end of the fruit. In fruit segments, some juice sacs become a cloudy white color, hard and dry. This disorder may be caused by improper maturation or improper conditions of fruit development. Over-mature citrus including mandarin, lime and pummelo develop juice sac granules. Granulated fruit show lower levels of phenolics and PPO activity when compared with normal fruit (Sharma et al., 2006).

Pummelo fruit maturing in the rainy season have a greater chance of granulation inside the fruit (Thongleaw and Phuwatanon, 2011). When the water supply for pummelo trees is high, new shoots emerge. These new shoots represent a high potential sink, which can deplete stored nutrients from the source such as mature fruits. The translocated nutrients from fruit to new shoots may be responsible for generating the granules. Furthermore, She et al. (2009) reported that aged pummelo plants, compared to optimum-age plants, tend to produce high amounts of granulated juice sacs in maturing fruit. An increase in oxidative substances in the juice sac, including H_2O_2, is responsible for POD induction and subsequent lignification.

Uneven fruit ripening

Differing maturity stages of different tissues or segments within the same whole fruit leads to a variation in fruit maturation and ripening. The rind of many of tropical fruits such mangosteen, longkong, and durian develops from the ovary wall at the pericarp. The edible part of the fruit is a special tissue developed from the seed. Both the rind and the aril develop by independent metabolic processes. Thus, there are variations of fruit ripening within the whole fruit. Uneven ripening is often found in "Mon Thong" durian flesh, but the defect cannot be detected visually from the external appearance (Chaiprasart and Siriphanich, 2000). Furthermore, fused fruits such as pineapple and sugar apple are derived from many fruitlets or berries which are responsible for uneven ripening of the whole fruit. Uneven fruit ripening may be overcome by harvesting at the proper maturity and treating with ethylene or calcium carbide (CaC_2) for regular ripening.

Mixed ripening

Some fingers in banana hands turn yellow before the other fruit; this is known as "mixed-ripe" and it is an important problem when exporting fruit to Europe or the United States. The export banana must stay green during shipment to comply with quarantine regulations for pest control. They are then artificially ripened by ethylene treatment at the destination. High temperatures during field transport, packing, storage and market transport can lead to over-mature fingers in hands turning from green to yellow peels (Daniells, 1991).

Senescent spotting

Banana fruit in some varieties develop senescent brown/black spots during peel color change at later stages of fruit ripening. These black spots are scattered across the fruit, and expand in size during distribution and decrease marketable value of ripe bananas. The spot does not arise disease or infection but from physiological processes, which can be reduced by modified atmospheres, surface coating, low temperature and heat treatment (Ketsa, 2000; Trakulnaleumsai et al., 2006). The symptoms are related to high O_2 levels in the atmosphere which leads to lower activities of PAL and PPO. However, Maneenuam et al. (2007) reported that banana senescent spotting symptoms are not related to the PPO and PAL activities, but to a decrease in dopamine in banana peel.

Placental water soaking

Watermelon fruit is very sensitive to ethylene, inducing placental water soaking (Elkashif et al., 1989). Exogenous ethylene will induce placental tissue softening and water soaking, electrolyte leakage, rind softening and enhanced phospholipid degradation in watermelons (Elkashif and Huber, 1988; Karakurt and Huber, 2002; Mao et al., 2004).

E Climate and agricultural practice

Different production locations and growing seasons also affect the quality of tropical fruits. Mangosteen and durian fruits harvested in the early season show better fruit quality than those harvested in the middle or late seasons, which corresponds to heavy rain in tropical zones. High levels of water in fruit from this period contribute to the development of fruit disorders such as translucent flesh and latex leaks in mangosteen and wet core in durian. Hardened pulp of durian occurs when fruit is maturing on the tree while new shoots are emerging and developing. Moreover, different growing seasons are associated with different types of pests and insects. Fruit supplied with generous amounts of nitrogen fertilizer will decay easily. Use of good agricultural practices will help to control some defects in the field. Furthermore, field heat could induce physiological changes in harvested fruits. Because fruits are composed of more than 80% water, a reduction of fruit temperature could reduce energy requirements from refrigeration units. Harvesting at an optimum maturity stage leads to the best quality and the longest postharvest life.

The fruit quality of “Khao Yai” pummelo harvested from orchards in Thailand in January differs from that harvested in April (in season). Pummelo fruits harvested in April have better overall quality than those harvested in January. Fruit harvested in April are darker and smaller with a thinner peel, fewer granules, a higher soluble solids (SS)/titratable acidity (TA) ratio and better preference scores (Thongleaw and Phuwatanon, 2011). “Pluk Mai Lie” papaya fruit ripened on trees develop a redder peel than those harvested at breaker color and ripened at room temperature. The production of total esters, highly correlated with a loss of firmness and an increase in cavity ethylene accumulation, is about 10-fold higher in fruit ripened off the tree (Fuggate et al., 2010). Mangosteen fruit ripened on the tree will develop a red calyx, which is not characteristic of fruit ripened after harvest (Kataoka et al., 2008). The red coloration of the calyx results in the reduction of the grade of mangosteen for export.

III Standardization

Standardization is a tool for harmonizing the compulsory quality, which is required of commercial products. In general, good quality attributes for fresh tropical fruits include an attractive appearance, cleanliness, freedom from pests and damage caused by pests, freedom from defects, acceptable shape, color and flavor.

However, there may be other requirements specific to a particular commodity, variety or commercial type. A major problem for sorting quality fresh tropical fruit is a suitable method of quality assessment for internal physiological disorders (see also Chapter 13). The current practice is detection of the disorder by experienced inspectors. Nondestructive techniques are needed for better detection.

Rambutan fruit contain special morphological organs as they contain numerous spinterns that become habitats for some pests. Rambutan must be virtually free of pests and damage caused by postharvest handling (CODEX STAN 246-2005). Mangosteen fruit must come with the calyx and pedicel intact, free of latex and free of blemishes such as hard pericarp, translucent and gamboge aril (CODEX STAN 204-1997). Pineapple fruit should be at least 12.0° Brix. Fruit must be without condensation or internal browning following removal from cold storage (CODEX STAN 182-1993). Durians should carry a minimum of three to four fertile locules. Thorns should be well developed with no splitting of the thorn end. Quality criteria include pulp with sweet flavor and thick, yellow, fiberless and firm pulp. (TAS 3-2003). Pummelos must be properly mature with a total soluble solid content above 8.0° Brix. Fruit must not exhibit a cloudy white color, be hard and dry or granulated (TAS 13-2007).

IV Postharvest quality improvement and maintenance

A Quality improvement

Improvement of fruit ripening quality with artificial ripening (AR)

Most tropical climacteric fruit require artificial ripening after harvest to improve their quality. Both qualitative and quantitative characteristics are improved. The AR system assists management for fruit storage, transportation and marketing. In the past, local Asian distributors used calcium carbide (CaC_2) for AR. At present, ethylene is used to hasten ripening, using compounds such as catalytically-generated ethylene gas and ethephon (2-chloroethyl phosphonic acid). However, these postharvest uses of ethephon have not yet been approved by USDA and, thus, such treatment is not suitable for fruit to be exported to the United States. Commercial ripening in Thailand uses CaC_2 at 1−5 g/kG fruit weight for most fruits. AR helps to even the ripening process within the whole fruit to provide more consistent quality, including full external and internal color development, while maintaining fruit firmness, full flavor development and an increase of antioxidants in some fruits.

Thai consumers, unlike the Chinese, prefer ripe durians that maintain a green color of the husk because yellowish or brownish husks are not regarded as fresh. Thus, in Thailand, AR of durians is carried out by a quick dip of the fruit peduncle into ethephon solution to prevent husk color changes. Mangosteen can be harvested at various maturity stages from red to brown pad resulting in non-uniformity of fruit peel color at the collection center. Application of

250−500 ppm ethephon or 5−10 g/kG CaC_2 for 1 day can lead to uniform color of the rind. Achieving uniform color by AR has no effect on the taste (SS/TA) or fruit firmness (Piriyavinit and Ketsa, 2008).

Exogenous ethylene treatment of bananas improves the quality of the ripe fruit by inducing full color change of the peel, maintaining firmness of ripe pulp, and increasing pulp yellowing due to increases in carotenoids and flavonoids, which also function as antioxidants. Apart from a reduction of the ripening time, ethylene treatment reduces fruit waste particularly due to disease (Noichinda et al., 2014). Unfortunately ethephon spraying on rambutan bunches during maturation on the tree to induce fruit drop can lead to blackening of the spinterns of harvested fruit (Yuktanun and Siriphanich, 1993).

Enhancing antioxidant development

Total polyphenols, in particular caffeic acid and quercetin, are the main antioxidants present in ripe "Mon Thong" durian. Antioxidant capacity is lower in the mature and overripe fruit (Arancibia-Avila et al., 2008; Ashraf et al., 2010). Pummelo (*Citrus grandis* [L.] Osbeck) are generally separated into two groups: white and pink flesh. Pink cultivars have greater antioxidant capacity than white cultivars as shown by DPPH [di(phenyl)-(2,4,6-trinitrophenyl)iminoazanium] and FRAP [ferric ion reducing antioxidant power] assays (Pichaiyongvongdee and Haruenkit, 2009a). Naringin and limonin, which produce a bitter taste, are produced throughout the pummelo fruit, especially in the seeds (Pichaiyongvongdee and Haruenkit, 2009b; Zhang et al., 2011). Improvement of flavor quality can be achieved by treatment with 200 ppm exogenous ethylene. "Thongdee" pummelo fruit treated with ethylene showed a 78% reduction of limonin content in fruit, including fruit juice, while slightly decreasing naringin content. This treatment showed no additional effect on other flavonoids or antioxidant capacity (Pichaiyongvongdee and Haruenkit, 2011). Conversely, Nishikawa et al. (2002) reported that "Suisho-buntan" (*Citrus grandis* [L.] Osbeck) fruit treated with 20−40 ppm ethylene for 72 h resulted in degreening of the fruit with no effect on the amount of naringin and other flavor compounds.

B Storage

An understanding of the CP and microatmospheric gases is critical for controlling climacteric fruit during the pre-climacteric period, as hastening the climacteric rise also shortens the storage life. The CP is controlled by both endogenous and exogenous ethylene, which triggers autocatalytic ethylene production in climacteric fruits depending on the sensitivity of the specific tropical fruit. The concentrations of O_2 and CO_2 surrounding fruits affect the period of CP. Thus, the control of climacteric rise may be achieved by some handling procedures. Fruits should be harvested a maturity stage when the fruit IEC is low. Harvested fruits should not be exposed to exogenous or wound ethylene. Furthermore, fruits should be stored under a modified atmosphere (MA) of high CO_2/low O_2 ratio to minimize respiration and ethylene production.

Cold storage

Low temperature storage can slow down metabolic processes such as respiration and ethylene production by suppressing ripening-related enzymes. Tropical fruits are perishable crops which have a short shelf life (3−5 days after harvest at ambient conditions). The most effective way to maintain the quality of tropical fruits is to store them at temperatures which are as low as possible. The storage time depends on respiratory and ethylene production rates. Most storage periods of tropical fruit are 1−4 weeks at optimal low temperatures (Table 10.6). Storage below the optimal storage temperature induces the development of CI symptoms, which decreases the market value.

"Rong-Rien" rambutan fruit pre-cooled in 10°C water and stored at 13°C, 90−95% RH shows the greatest reduction in browning, whereas 2°C hydrocooling induced CI with an increase in surface discoloration and resulted in a shelf life of 4 to 6 days (Nampan et al., 2006).

Table 10.6 Optimum Temperature and Relative Humidity for Low Temperature Storage of Selected Tropical Fruits

Fruit	Optimum Temperature (°C)	Relative Humidity (%)	Storage Life (Weeks)
"Khai" banana (AA)	13 ± 1	90−95	4−6
"Hom Thong" banana (AAA)	13 ± 1	90−95	4−6
Rambutan ("Rong-Rien")	13 ± 1	95	2−3
Mangosteen	13 ± 1	90−95	3−4
Longkong	14−15	90−95	2−3
Pummelo	5 ± 1	90−95	12−16
Durian	14 ± 1	80−90	2−3
Smooth Cayene Pineapple	10 ± 3	85−90	2−4
Queen Pineapple	14 ± 1	85−90	1−2
Litchi/Lychee	1.5	90−95	3−5
Longan	5 ± 1	90−95	5−6
Mango	13 ± 1	85−90	2−3
Sapota	12 ± 1	90−95	2−3
Watermelon	13 ± 2	85−90	2−3
Papaya	14 ± 1	85−90	2−3

Modified from Siriphanich and Romphophak (2000).

The firmness of mature green mangosteen fruit (5% red pad) rapidly decreases at room temperature over 4 days, while slowly decreasing at 13°C storage. Due to PG and PME activities, the water soluble pectin in the aril increases in fruit stored at temperatures higher than at 13°C (Noichinda et al., 2007). The relationship between decreasing aril firmness and increasing PG and PME has been explained by a mathematical model. In the first 20 h PME activity rapidly decreases as the enzyme substrate complex (ES) sharply increases in concentration, followed by a sudden decline in ES after 30 h of storage at room temperature (Noichinda et al., 2013c). The softening process of mangosteen flesh is related not only to PME and PG concentrations, but also to other enzymes such as CEL, hemicellulase β-galacturonase and PL which play an important role in the softening process of mangosteen arils (Sirisukchaitavorn et al., 2010).

Modified atmosphere (MA) storage

Low O_2 at 10% combined with 5−15% CO_2 effectively reduces respiration and ethylene production in durian to delay fruit ripening at 22°C (Tongdee et al., 1990). Rambutan fruit stored at 12°C has 8 days' storage life when stored in 40 μm low-density polyethylene (LDPE) bags. Alternatively, polyvinyl chloride (PVC) or polyvinyl dichloride (PVDC) without perforated holes extends the storage life to 16 days (Srilaong et al., 2002; Ponrot et al., 2006). Rambutan stored under a controlled atmosphere of 10−15% CO_2 has 20 days of storage when compared with the control of only 8 days. Fruit stored at 1% O_2 show no visible injury, but off flavor developed in 5 days, while 20 and 40% CO_2 caused skin and spintern browning. The most suitable conditions were >2% O_2 and 5−10% CO_2 as low O_2 is more likely to prevent disease than high CO_2 (Ratanachinakorn et al., 2005). Rambutan fruit packed in four- and six-well plastic trays (semi-closed) and stored at 12°C showed that four-well trays are superior and will keep the fruit for 11 days, limiting disease occurrence (Srilaong et al., 2004). MAP (Modified Atmosphere Packaging) will reduce inside O_2 and increase CO_2 resulting in quality maintenance of the fresh produce such as inhibition of senescent spotting of banana peel (Choehom et al., 2004). Mangosteen fruit individually wrapped with 40 μm polyethylene film maintained a storage life to 24 days at 13°C in contrast to only 16 days for un-wrapped fruit (Pranamornkith et al., 2003). The pericarp color of mangosteen fruit with a pale-green husk and red pad turns to dark purple within 4−5 days at ambient temperature (25−30°C), but the fruit can be stored in a perforated polyethylene bag at 13°C for four weeks (Choehom et al., 2003).

Mangosteen fruit coated with commercial materials has brighter peel during storage (Jitareerat et al., 2004). In Thailand, chitosan is sprayed on fruit during box packing for export of mangosteen to prevent calyx browning and water loss (Figure 10.5A). Dipping rambutan fruit for 5 minutes in polyethylene wax at various concentrations can reduce weight loss and delay browning at 25°C and 60−65% RH, but these fruit develop off flavors. Application of 0.1−0.5% sucrose fatty acid esters had no effect on water loss and browning (Yingsanga

FIGURE 10.5

Commercial practice for export of chitosan spraying in mangosteen fruit (A) and curcuma dying in durian fruit (B).

et al., 2012). Coating with sucrose fatty acid esters at 1% reduces 7% to 14% weight loss of durian and induces high internal CO_2 levels that delay fruit dehusking (Sriyook et al., 1994). Use of Sta-Fresh 2952 wax and Sta-Fresh 7055 wax to coat pineapple fruit of the cultivar "Paris" alleviates CI and delays changes in firmness, flesh color, weight loss and soluble protein content (Hu et al., 2011).

Chemical treatments

1-MCP treatments

1-Methylcyclopropene (1-MCP) has been applied to tropical fruit to extend the storage life. Pericarp color of mangosteen, used as a criterion for grading, develops rapidly after harvest. The use of 4 μl/l 1-MCP for 3 h at room temperature (28−30°C) on fruit with scattered pink spots (stage 1) to reddish pink (stage 3) delays color development for 3 days at room temperature, but cannot inhibit other ripening processes because harvesting at pale-green husks with red pad is the stage of the climacteric rise (Koslanund et al., 2005; Bayogan et al., 2010; Korpphaiboon et al., 2011). 1-MCP fumigation of "Nam Dokmai" mango at 250 ppb for 24 h at 25°C before 20°C storage reduced respiration and ethylene production, while delaying color change in mango and increasing shelf life from 10 to 15 days (Penchaiya et al., 2006). Piriyavinit et al. (2011) found that 1-MCP treatment reduced ACC(1-Aminocyclopropane-1-carboxylic acid) content, ACS and ACO activities in mangosteen pericarp, but showed no effect on ACC content and ACS activity in the flesh. Furthermore 1-MCP and ethephon can be applied to fruit at the pre-climacteric stage to delay harvest of mangosteen fruit by 1 or 2 weeks (Lerslerwong et al., 2013).

Unfortunately, 1-MCP can affect aroma generation in some treated fruit. 1-MCP fumigation affects aroma generation of ripe durian fruit such that only diethyl disulfide could be detected from "Chanee" treated with the compound compared to an untreated control, which generated numerous sulfur-containing compounds (Maninang et al., 2011). Moreover, because of its function as an ethylene response inhibitor, 1-MCP can inhibit the production of esters, which are generated by ethylene-dependent processes in many climacteric fruits (Flores et al., 2002; Defilippi et al., 2005; Balbontín et al., 2010). Thus, use of 1-MCP to prolong shelf life must consider effects on flavor quality of treated fruit.

Other chemicals

Gibberellic acid (GA_3) has been applied to mangosteen fruit preharvest and postharvest. Treatment with 50−100 ppm GA_3 at preharvest delays the harvest date by 4 days. Postharvest treatment of 1000 ppm GA_3 extends the storage life at 15°C from 6 to 13 days by delaying the softening of the aril (Promtongruk and Lerslerwong, 2012). However, Noichinda (1991) found that GA_3 dipping at 50−100 ppm could preserve the freshness and greenness of the mangosteen calyx after harvest, but GA_3 treatments at or above 100 ppm induced development of the red calyx. Spraying durian fruit with 100 ppm GA_3 delayed husk dehiscence of ripe durian, but allowed pulp ripening to continue (Sriyook et al., 1994). "Dashehari" Mango fruit postharvest treated with 100−400 mg/l GA_3 showed a delay in ripening with increasing concentrations of total acid and ascorbic acid in the fruit and more chlorophyll in the peel (Khader, 1991).

In addition to reducing the incidence of postharvest diseases, dipping with 0.1 and 1% $CaCl_2$ for 5 min induces stomata closure in rambutan fruit spinterns when stored at 13°C and 90−95% RH (Wongs-Aree and Kanlayanarat, 2004). Siriphollakul et al. (2006) reported that abscisic acid (ABA) and salicylic acid (SA) treatments delayed pericarp browning in rambutan and SA treatments also retarded the loss of anthocyanins. Sapota fumigated fruit with high CO_2 at low temperatures to reduce astringency and maintain a firm texture during ripening (Chantaksinopas, 1987). Chinese consumers prefer a ripe durian with yellowish-green husks. Consequently, some Thai exporters commercially dye durian husks by dipping the fruit in curcuma solution to maintain a yellow color for export to China (Figure 10.5B).

C Disorders associated with postharvest treatments

Some fresh fruits may not show evidence of disorders immediately after removal from storage (low temperature, irradiation, chemical treatments). Stored fruits may not develop the symptoms of CI, color change or fruit drop until they are acclimatized to room temperature.

Chilling injury (CI)

Most tropical fruits are sensitive to low-temperature storage leading to CI symptoms. Development of CI is a very complex process whose mechanisms are not fully understood. Factors affecting the development of CI in susceptible fruits include the level of saturation of fatty acids in cell membranes, lipid peroxidation, the presence of polyamines and cell wall composition (Sevillano et al., 2009).

FIGURE 10.6

Development of chilling injury symptoms of red pad mangosteen fruit stored at 8°C for 15 days. Fruit expressed yellow latex in the pericarp with fresh green calyx on Day 0, started peel browning on Day 3 and full browning on Day 9, showed obvious calyx drying on Day 12, and seed browning and flesh translucence on Day 15.

CI occurs in mangosteen fruit when stored under 12°C, with symptoms including a hardening pericarp, aril browning and off-flavor development (Choehom et al., 2003). CI in mangosteen is associated with an increase of polyamines, putrescine and spermidine in the chilled pericarp (Kondo et al., 2003a). The same investigators found that the application of another polyamine, spermine, reduces CI symptoms such as browning and hardening of the skin that induces high content of ABA in the pericarp (Kondo et al. 2003b). Dangcham et al. (2008) reported that mangosteen stored at 6°C had greater pericarp firmness, and lignin as phenolics, especially *p*-coumaric acid, was reduced.

Mangosteen pericarp hardening is associated with an increase of electrolyte leakage during storage at 8°C for 6 days. Red pad fruit of mangosteen stored at 8°C for 15 days showed pericarp hardening and discoloration, dried calyx and rind attached to the flesh as shown in Figure 10.6 (Noichinda et al., 2013a). Discoloration of mangosteen pericarp was not directly related to the PPO activity, but to a reduction in anthocyanin accumulation (Noichinda et al., 2013a). An increase in hardening and lignin content of the pericarp is due to increases in PAL and POD activities of the lignification process (Dangcham et al., 2008). The calyx and peel surface of mangosteen fruit stored at 8°C become slightly browner in color and the peel hardness increases moderately. Furthermore, the eating quality is affected by a decrease in sugar composition due to a dramatic degradation of sucrose by increased invertase activity. Mangosteen fruit kept in a corrugated box 25.5 × 22.5 × 22.5 cm with four perforations (0.5 inches in diameter), then covered with two layers of paper inside, exhibited less CI for 22 days at 8°C, without sucrose degradation (Noichinda et al., 2013b).

Salunkhe and Desai (1984) reported that durian could be stored at 4−5°C for 30−35 days. In contrast, Romphophak and Palakul (1990) found that "Chanee" durian fruit could be stored at 5°C for 3 weeks. Furthermore, durian pulp lost the ability to ripen, convert starch to sugars, and failed to generate aromatic volatiles after 1 week in storage at low temperatures (Siriphanich, 1996). Visible CI can be noticed in 2 weeks as the peel turns black or dark brown, especially the groove between thorns (Brooncherm and Siriphanich, 1991).

Cellulose concentration may strongly affect pulp firmness of chilled rambutan. Cellulose comprises about 80% of the rambutan rind cell wall and about 60% of the pulp cell wall. Greater softening of rambutan peel was observed during storage at 8°C than at 13°C for a smiliar period. Sodium hexametaphosphate-soluble pectin substances (HMP) of the CI peel of fruit stored at 8°C are lower than those at 13°C (Kondo et al., 2002).

Low temperature storage induces internal browning in pineapple fruit. Most cultivars of pineapple generally develop symptoms of internal browning (IB), a form of CI, during further storage at room temperature (20−25°C) following several weeks of storage below 15°C (Smith, 1983; Paull and Rohrbach, 1985; Nukulthornprakit and Siriphanich, 2005; Youryon et al., 2008). Figure 10.7 shows how the symptoms develop in the core and the surrounding flesh of "Queen" pineapple fruit stored at 13°C for 2 weeks. The market life of fresh pineapple fruit is short and storage at low temperatures to extend shelf life is limited by the development of IB. The outside appearance is related to the generation of IB in pineapple fruit with an increase in pink color of the dorsal of crown leaves and groove of fruitlets (Figure 10.7, at pencil points).

IB symptoms in pineapple fruit cv. Pattavia stored at 10°C, 85% RH are observed in the pulp adjacent to the core for as long as 21 days after storage. Methyl jasmonate (MeJA) fumigation of pineapple fruit at 10^{-5}−10^{-3} M is reported to reduce CI and weight loss compared to the control treatment (Nilprapruck et al., 2008). IB in pineapple may be caused by an imbalance of

FIGURE 10.7

Visual appearances and internal browning symptoms of "Queen" pineapple stored at 13° C for 2 weeks.

some elements in the cell. Peduncle infiltration of a 0.2 M solution of $CaCl_2$ a day before storage is the predominant means of preventing IB in "Queen" pineapple stored at above the critical low temperature point (13° C) (Youryon et al., 2008; Youryon et al., 2013).

PAL and PPO are both enzymes involved in the browning senescence of CI processes. CI symptoms in banana peel include increases in PAL and PPO activities and highly correlated decreases of total free phenolic compounds (Nguyen et al., 2003). CI symptoms in mango appear as a gray to brown discoloration of the peel, followed by color changes in the pulp and endocarp. Peel and pulp color changes are related to increases free phenolics, but peel symptoms are related to PAL activity (Chidtragool et al., 2011), low ascorbic acid content, low total antioxidant capacity and activity of oxidative scavenging enzymes (Chongchatuporn et al., 2013). In papaya, surface pitting on the peel of fruit in the half-ripe stage occurred after 15 days of storage at 5°C. Glutathione in the chilling peel and pulp remained stable, but ascorbic acid was markedly reduced (Wongs-Aree et al., 2007).

CO_2/O_2 injury

Long-term storage of tropical fruit under low O_2 and/or high CO_2 conditions could be responsible for disorders associated with the storage conditions. Ripe bananas stored under anaerobic conditions of less than 1% O_2 or 100% N_2 develop a pronounced off-flavor due to the presence of ethanol with little typical fruit flavor due to a low concentration of esters. Low ester production, especially acetate esters, may be due to the lack of acetyl CoA substrate due to the inhibition of either the conversion of pyruvate or the β-oxidation of fatty acids under anaerobic conditions (Wendakoon et al., 2004). Furthermore, storage under high CO_2 at 6% CO_2 atmospheres for 6 days induces brown spotting on baby banana peels (Noichinda et al., 2006). CO_2 levels above 10% in storage atmospheres for 1 week can induce peel blackening of sugar apple, while the white pulp accumulates a pink coloration (Chunprasert et al., 2006).

Postharvest quarantine treatment

Hot vapor treatment

Mangoes exported to Japan and the Republic of Korea must be treated with vapor heat treatment to a pulp temperature of 46°C held constant for 10 min. The vapor treatment induces physiological breakdown in the inner mesocarp of the ripe fruit. The disorder, related to a depletion of the internal oxygen levels in the fruit, shows white, starchy and tough lesions. In severe cases, the symptoms generate fermented odors and flavors (Esguerra et al., 1990). The affected flesh does not ripen even when treated with exogenous ethylene.

Irradiation

In 1986, the Food and Drug Agency (FDA) of the United States approved irradiation doses up to 1000 grays (Gy) for the preservation and disinfestation of fresh fruits and vegetables. The disorders caused by the irradiation of fresh fruits include altered ripening, pitting, darkening, discoloration, scalding, softening, loss of flavor or aroma, higher disease incidence, lower vitamin C and organic acids.

Although gamma irradiation at 0.5 and 1.0 kGy did not affect internal browning, peel color changes and disease incidence of treated "Queen" pineapple fruit stored at 13°C, the irradiation significantly reduced the SS/TA ratio and DPPH scavenging antioxidant activity in the fruit (Uthairatanakij et al., 2013). Weight loss in durians irradiated at 300 Gy kept for 14 days was significantly less than those in non-irradiated controls and of durians irradiated at 700 Gy (Charoen et al., 2007). Furthermore, gamma irradiation at 400 Gy resulted in the induction of peel browning of treated litchi fruit, but did not affect other quality markers such as the ascorbic acid, TA, SS, and phenolic compounds. Packing in PET (polyethylene terephthalate) tray covered with an active bag (Equilibrium Modified Atmosphere film) reduced pericarp browning and maintained the quality of gamma-irradiated litchi fruit kept at 4°C for 28 days (Jitareerat et al., 2013).

V Conclusions

The quality of tropical fruits can be assessed starting from the preharvest practices such as bagging, fruit trimming, or supplying water, through to postharvest logistics and management. Along with attractive visual appearence, exotic fruits morphologically exhibit differences in physiological disorders after harvest. Many tropical fruits acquire different physiological metabolic processes between pulp and rind throughout fruit maturation. Fully maturing fruit with the best flavor is demanded by domestic markets, whereas, in general, fruit at the preclimacteric stage containing low levels of internal ethylene is technically required for distant markets. Furthermore, purchase quality improvement of fruits can be done effectively by harvesting fruit at moderate maturity followed by artificial ripening using ethylene-releasing agents. Low temperature is a powerful tool for long storage but temperatures lower than 13°C usually induce chilling injury symptoms in many tropical fruits. Nondestructive assesment needs to be quickly carried out to separate fruits having such internal disorders from healthy fruits. Consequently, the study of physiological changes of fruit development on and off trees will provide a better understanding that could significantly improve the quality of fruit.

Bibliography

Aoki, H., Kieu, N.T., Kuze, N., Tomisaka, K., van Chuyen, N., 2002. Carotenoid pigments in GAC fruit (*Momordica cochinchinensis* SPRENG). Biosci., Biotechnol., Biochem. 66, 2479–2482.

Arancibia-Avila, P., Toledo, F., Park, Y.-S., Jung, S.-T., Kang, S.-G., Heo, B.G., et al., 2008. Antioxidant properties of durian fruit as influenced by ripening. LWT – Food. Sci. Technol. 41, 2118–2125.

Ashraf, M.A., Maah, M.J., Yusoff, I., 2010. Estimation of antioxidant phytochemicals in four different varieties of durian (*Durio zibethinus* Murray) fruit. Middle-East J. Sci. Res. 6, 465–471.

Balbontín., C., Gaete-Eastman, C., Fuentes, L., Figueroa, C.R., Herrera, R., Manriquez, D., et al., 2010. *VpAAT1*, a gene encoding an alcohol acyltransferase, is involved in ester biosynthesis during ripening of mountain papaya fruit. J. Agric. Food Chem. 58, 5114–5121.

Bayogan, E.R.V., Apolinario, A.L.D., Delgado, D.R.V., Anabesa, M.S., 2010. Shelf life of Mangosteen (*Garcinia mangostana* L.) fruit as influenced by 1-methylcyclopropene, treatment duration, and maturity. Acta Hortic. 875, 97–104.

Brooncherm, P., Siriphanich, J., 1991. Postharvest physiology of durian pulp and husk. Kasetsart J. (Nat. Sci.) 25, 119–125 (in Thai with English abstract).

Bunsiri, A., Ketsa, S., Paull., R.E., 2003. Phenolics metabolism and lignin synthesis in damaged pericarp of mangosteen fruit after impact. Postharvest Biol. Technol. 29, 61–71.

Chan, Y.K., Eeckenbrugge, G.C., Sanewski, G.M., 2003. Breeding and variety improvement. In: Bartholomew, D.P., Paull, R., Rohrbach, K.G. (Eds.), The Pineapple: Botany, Production and Uses. CABI Publishing, Wallingford, pp. 33–56.

Chaiprasart, P., Siriphanich, J., 2000. Enzymes and intermediates in ethylene production in two cultivars of durian fruits. Agri. Sci. J. 31, 35–42 (in Thai with English abstract).

Chaisrichonlathan, P., Noomhorm, A., 2011. Effects of harvesting seasons and maturity stages on internal characteristics of the mangosteen having different surface properties. Int. J. Food. Sci. Technol. 46, 717–723.

Chantaksinopas, S. 1987. Ripening, Postharvest Changes under Temperature and Carbon Dioxide for Removing Astringent in Sapota (*Achras sapota* Linn.). Ms. Thesis, Department of Horticulture. Kasetsart University (in Thai with English abstract).

Charoen, S., Sajjabut, S., Aemsiri, J., Limohpasmanee, V., Segsarnviriya, S., 2007. Effect of gamma radiation on the qualities of durians for export. Agri. Sci. J. 38, 243–246 (in Thai with English abstract).

Chidtragool, S., Ketsa, S., Bowen, J., Ferguson, I.B., van Doorn, W.G., 2011. Chilling injury in mango fruit peel: Cultivar differences are related to the activity of phenylalanine amonialyase. Postharvest Biol. Technol. 62, 59–63.

Choehom, R., Ketsa, S., van Doorn, W.G., 2003. Chilling injury in mangosteen fruit. J. Hortic. Sci. Biotechnol. 78, 559–562.

Choehom, R., Ketsa, S., van Doorn, W.G., 2004. Senescent spotting of banana peel is inhibited by modified atmosphere packaging. Postharvest Biol. Technol. 31, 167–175.

Chongchatuporn, U., Ketsa, S., van Doorn, W.G., 2013. Chilling injury in mango (*Mangifera indica*) fruit peel: Relationship with ascorbic acid concentrations and antioxidant enzyme activities. Postharvest Biol. Technol. 86, 409–417.

Chunprasert, A., Uthairatanakij, A., Wongs-Aree, C., 2006. Storage quality of 'Neang' sugar apple treated with chitosan coating and MAP. Acta Hortic. 712, 857–863.

CODEX STAN 182-1993. Codex Standard for Pineapples.

CODEX STAN 204-1997. Codex Standard for Mangosteens (AMD. 1-2005).

CODEX STAN 246-2005. Codex Standard for Rambutan.

Daniells, J.W., 1991. How to avoid with mixed-ripe problems with bananas. Queensland Fruit and Vegetables NEWS 62, 12–13.

Dangcham, S., Bowen, J., Ferguson, I.B., Ketsa, S., 2008. Effect of temperature and low oxygen on pericarp hardening of mangosteen fruit stored at low temperature. Postharvest Bio. Technol. 50, 37–44.

Dangcham, S. and Siriphanich J. 2001. Mechanism of flesh translucent disorder development of mangostenn fruits (*Garcinia mangostana* L.). In Proceeding of the thirty-nineth Kasetsart University Annual Conference. (Plant section), Bangkok, pp. 483–489 (in Thai with English abstract)

Defilippi, B.G., Kader, A.A., Dandekar, A.M., 2005. Apple aroma: alcohol acyltransferase, a rate limiting step for ester biosynthesis, is regulated by ethylene. Plant. Sci. 168, 1199–1210.

Dorly, S., Tjitrosemito, R., Poerwanto, Juliarni, 2008. Secretory duct structure and phytochemistry compounds of yellow latex in mangosteen fruit. HAYATI J. Biosci. 15, 99–104.

Dorly, S., Tjitrosemito, J.A.T., da Silva, R., Poerwanto, D., Efendi, Barasa, F., 2011. Calcium spray reduces yellow latex on mangosteen fruits (*Garcinia mangostana* L.). J. Fruit Ornam. Plant Res. 19, 51–65.
Elkashif, M.E., Huber, D.J., Brecht, J.K., 1989. Respiration and ethylene production in harvested watermelon fruit: Evidence for nonclimacteric respiratory behavior. J. Am. Soc. Hortic. Sci. 114, 81–85.
Elkashif, M.E., Huber, D.J., 1988. Electrolyte leakage, firmness and scanning electron microscopic studies of watermelon fruit treated with ethylene. J. Am. Soc. Hortic. Sci. 113, 378–381.
Esguerra, E.B., Brena, S.R., Reyes, M.U., Lizada, M.C.C., 1990. Physiological breakdown in vapor heat-treated 'Carabao' mango. Acta Hortic. 269, 425–434.
Flores, F., Yahyaoui, F.E., de Billerbeck, G., Romojaro, F., Latche, A., Bouzayen, M., et al., 2002. Role of ethylene in the biosynthetic pathway of aliphatic ester aroma volatiles in Charentais cantaloupe melons. J. Exp. Bot. 53, 201–206.
Fuggate, P., Wongs-Aree, C., Noichinda, S., Kanlayanarat, S., 2010. Quality and volatile attributes of attached and detached 'Pluk Mai Lie' papaya during fruit ripening. Sci. Hortic. 126, 120–129.
Hu, H., Li, X., Dong, C., Chen, W., 2011. Effects of wax treatment on quality and postharvest physiology of pineapple fruit in cold storage. Afr. J. Biotechnol. 10, 7592–7603.
Imsabai, W., Ketsa, S., van Doorn, W.G., 2006. Physiological and biochemical changes during banana ripening and finger drop. Postharvest. Bio. Technol. 39, 211–216.
Jitareerat, P., Uthairatanakij, A., Photchanachai, S., Srilaong, V., Chookhongka, N., 2004. Effect of coating materials on mangosteen fruit quality. In: Proceeding of the APEC Symposium on Quality Management in Postharvest Systems, Bangkok, pp. 173–177.
Jitareerat, P., Uthairatanakij, A., Photchanachai, S., Srilaong, V., 2013. Effect of packaging on postharvest disease development and quality of gamma irradiated litchi fruits. Acta Hortic. 973, 145–149.
Jung, H.-A., Su, B.-N., Keller, W.J., Mehta, R.G., Kinghorn, A.D., 2006. Antioxidant xanthones from the pericarp of *Garcinia mangostana* (mangosteen). J Agric Food Chem 54, 2077–2082.
Karakurt, Y., Huber, D.J., 2002. Cell wall degrading enzymes and pectin solubility and depolymerization in immature and ripe watermelon (*Citullus lanatus*) fruit in response to exogenous ethylene. Physiol. Plant. 116, 98–405.
Khader, S.E.S.A., 1991. Effect of preharvest application of GA_3 on postharvest behavior of mango fruits. Sci. Hortic. 47, 317–321.
Kataoka, I., Kozai, N., Yonemoto, Y., 2008. Preliminary survey on the undesirable red coloration of calyx of mangosteen fruit. Report of the Integrated Management of Tropical Fruits, Durian and Mango Steen. JIRCAS, Chanthaburi, pp. 59–64.
Ketsa, S., 2000. Development of control of senescent spotting in banana. Food. Preserv. Sci. 26, 173–177.
Ketsa, S., Atantee, S., 1998. Phenolics, lignin, peroxidase activity and increased firmness of damaged pericarp of mangosteen fruit after impact. Postharvest. Bio. Technol. 14, 117–124.
Ketsa, S., Pangkool, S., 1994. The effect of humidity on ripening of durians. Postharvest. Bio. Technol. 4, 159–165.

Khurnpoon, L., Siriphanich, J., 2005. Changes in pectin fractions and enzyme activities during husk dehiscence of Monthong durians. Acta Hortic. 687, 187–192.

Kondo, S., Nimitkiatklai, H., Kanlayanarat, S., 2002. Effect of chilling injury on cell wall metabolism during storage of rambutan fruit. Jpn. J. Trop. Agri. 46, 259–264.

Kondo, S., Ponrod, W., Sutthiwal, S., 2003a. Polyamines in developing mangosteens and their relationship to postharvest chilling injury. J. Jpn. Soc. Hort. Sci. 72, 318–320.

Kondo, S., Ponrod, W., Kanlayanarat, S., Hirai, N., 2003b. Relationship between ABA and chilling injury in mangosteen fruit treated with spermine. Plant Growth Regul. 39, 119–124.

Korpphaiboon, A., Siriphanich, J., Palapol, Y., 2011. Application of 1-methylcyclopropene (1-MCP) to control mangosteen fruit ripening for export. Agri. Sci. J. 42, 39–42 (in Thai with English abstract).

Kosiyachinda, S., Lam, P.F., Mendoza Jr., D.B., Broto, W., Wanichkul, K., 1987. Maturity indices for harvesting of rambutan. In: Lam, P.F., Kosiyachinda, S. (Eds.), Rambutan: Fruit Development, Postharvest Physiology and Marketing in ASEAN. ASEAN Food Handling Bureau, Kuala Lumpur, pp. 32–38.

Kosiyachinda, S., Young, R.E., 1975. Ethylene production in relation to the initiation of respiratory climacteric in fruit. Plant. Cell. Physiol. 16, 595–602.

Koslanund, R., Dejnumbunchachai, W., Jumradshine, P., Williams, S., 2005. Application of 1-methylcyclopropene (1-MCP) to prolong shelf life of mangostenn (*Garcinia mangostana* L.). In: Proceeding of the APEC Symposium on Assuring Quality and Safety of Fresh Produce, Bangkok, pp. 243–245.

Landrigan, M., Morris, S.C., Eamus, D., McGlasson, W.B., 1996. Postharvest water relationships and tissue browning of rambutan fruit. Sci. Hortic. 66, 201–208.

Lerslerwong, L., Rugkong, A., Imsabai, W., Ketsa, S., 2013. The harvest period of mangosteen fruit can be extended by chemical control of ripening – A proof of concept study. Sci. Hortic. 157, 13–18.

Lichanporn, I., Srilaong, V., Wongs-Aree, C., Kanlayanarat, S., 2009. Postharvest physiology and browning of longkong (*Aglaia dookkoo* Griff.) fruit under ambient conditions. Postharvest Bio. and. Technol. 52, 294–299.

Lizada, M.C.C., Kosiyachinda, S., Mendoza, D.B., 1984. Physiol disorders of mango. In: Mendoza, D.B., Wills, R.B.H. (Eds.), Mango. Association of South-east Asian nations (ASEAN) Food Handling Bureau, Kuala Lumpur, pp. 68–74.

Maneenuam, T., Ketsa, S., van Doorn, W.G., 2007. High oxygen levels promote spotting in banana fruit. Postharvest. Bio. Technol. 43, 128–132.

Maninang, J.S., Wongs-Aree, C., Kanlayanarat, S., Sugaya, S., Gemma, H., 2011. Influence of maturity and postharvest treatment on the volatile profile and physiological properties of the durian (*Durio zibethinus* Murray) fruit. Int. Food Res. J. 18, 1067–1075.

Mao, L., Karakurt, L., Huber, D.J., 2004. Incidence of water-soaking and phospholipid catabolism in ripe watermelon (*Citrullus lanatus*) fruit: Induction by ethylene andprophylactic effects of 1-methylcyclopropene. Postharvest. Bio. Technol. 33, 1–9.

Nampan, K., Techavuthiporn, C., Kanlavanarat, S., 2006. Hydrocooling improves quality and storage life of Rong-Rein rambutan (*Nephellium lappaceum* L.) fruit. Acta Hortic. 712, 763–770.

Nanthachai, S., 1994. Durian: Fruit Development, Postharvest Physiology, Handling and Marketing in ASEAN. ASEAN Food Handling Bureau, Kuala Lumpur.

Nerd, A., Gutman, F., Mizrahi, Y., 1999. Ripening and postharvest behaviour of fruit of two *Hylocereus* species (Cactaceae). Postharvest. Bio. Technol. 17, 39−45.

Nguyen, T.B.T., Ketsa, S., van Doorn, W.G., 2003. Relationship between browning and the activities of polyphenol oxidase and phenylalanine ammonia lyase in banana peel during low temperature storage. Postharvest. Bio. Technol. 30, 187−193.

Nilprapruck, P., Pradisthakarn, N., Authanithee, F., Keebjan, P., 2008. Effect of exogenous methyl jasmonate on chilling injury and quality of pineapple (*Ananas comosus* L.) cv. Pattavia. Silpakorn Univ. Sci. Technol. J. 2, 33−42 (in Thai with English abstract).

Nishikawa, K., Okabayashi, H., Mitiku, S.B., Sawamura, M., 2002. Bitter and volatile compounds in ethylene-treated *Citrus grandis* [L.] Osbeck fruits. J. Jpn. Soc. Hortic. Sci. 71, 292−296.

Noichinda, S., 1991. Effect of GA_3 on mangosteen (*Garcinia mangostana* L.) fruit at turning stage. Ms. special problem, Department of Horticulture, Kasetsart University, Bangkok (in Thai with English abstract).

Noichinda, S., 1992. Effect of modified atmosphere condition on quality and storage-life of mangosteen. Ms. Thesis, Department of Horticulture, Kasetsart University, Bangkok (in Thai with English abstract).

Noichinda, S., Bodhipadma, K., Leung, D.W.M., 2006. Modified atmosphere during storage of ‘Khai’ bananas in polyethylene bags: Implications for export and nationwide transportation. J. KMITNB 16, 14−17.

Noichinda, S., Bodhipadma, K., Singkhornart, S., Ketsa, S., 2007. Changes in pectic substances and cell wall hydrolase enzymes of mangosteen (*Garcinia mangostana* L.) fruit during storage. New Zeal J Crop Hort 35, 229−233.

Noichinda, S., Bodhipadma, K., Jirapong, C., Panaaphichon, S., Wongs-Aree, C., 2013a. The physiology of chilling injured mangosteen fruit. In: Proceeding of the International Symposium on Quality Management of Fruits and Vegetables for Human Health, Bangkok (in print).

Noichinda, S., Bodhipadma, K., Katevorakitti, T., and Wongs-Aree C., 2013b. Changes in sugar component and its enzyme activity in cold stored mangosteen fruit. In Proceeding of the International Symposium on Quality Management of Fruits and Vegetables for Human Health, Bangkok (in print).

Noichinda, S., Bodhipadma, K., Koonprasert, S., Wongs-Aree, C., 2013c. Kinetics of pectin methylesterase activity on mangosteen aril firmness during low temperature storage. In: Proceeding of the International Symposium on Quality Management of Fruits and Vegetables for Human Health, Bangkok (in print).

Noichinda, S., Bodhipadma, K., Dansakul, P., Sangudom, T., Wongs-Aree, C., 2014. The induction of antioxidants in ripe ‘Hom Thong’ bananas (*Musa*, AAA Group) by calcium carbide treatment. Acta. Hortic (in process).

Noichinda, S., Bodhipadma, K., Wongs-Aree, C., Komkhuntod, R., Sirisukchaitavorn, H., Rachakhome, P., et al., 2010. Evaluation of antioxidant properties in naturally and artificially ripened sugar apple (*Annona squamosa* L.) fruits. Acta Hortic. 875, 377−381.

Nukulthornprakit, O., Siriphanich, J., 2005. Hydrogen peroxide and ascorbic acid contents, superoxide dismutase and catalase activities in Smooth Cayenne and Queen pineapples during cold storage. Acta Hortic. 682, 611−615.

Palapol, Y., Ketsa, S., Stevenson, D., Cooney, J.M., Allan, A.C., Ferguson, I.B., 2009. Colour development and quality of mangosteen (*Garcinia mangostana* L.) fruit during ripening and after harvest. Postharvest Bio. Technol. 51, 349–353.

Pankasemsuk, T., Garner Jr., J.O., Matta, F.B., Silva, J.L., 1996. Translucent flesh disorder of mangosteen fruit (*Garcinia mangostana* L.). HortScience 31, 112–113.

Paull, R.E., Rohrbach, K.G., 1985. Symptom development of chilling injury in pineapple fruit (*Ananas comosus*). J. Am. Soc. Hortic. Sci. 110, 100–105.

Penchaiya, P., Jansasithorn, R., Kanlayanarat, S., 2006. Effect of 1-MCP on physiological changes in mango 'Nam Dokmai'. Acta Hortic. 712, 717–721.

Pichaiyongvongdee, S., Haruenkit, R., 2009a. Investigation of limonoids, flavanones, total polyphenol content and antioxidant activity in seven Thai pummelo cultivars. Kasetsart J. (Nat. Sci.) 43, 458–466.

Pichaiyongvongdee, S., Haruenkit, R., 2009b. Comparative studies of limonin and naringin distribution in different parts of pummelo [*Citrus grandis* (L.) Osbeck] cultivars grown in Thailand. Kasetsart J. (Nat. Sci.) 43, 28–36.

Pichaiyongvongdee, S., Haruenkit, R., 2011. Effect of ethylene treatments on limonin reduction in Thai pummelo [*Citrus grandis* (L.) Osbeck] fruit. Kasetsart J. (Nat. Sci.) 45, 1105–1114.

Piriyavinit, P., Ketsa, S., 2008. Effect of 2-chloroethanlphosphoic acid (ethephon) and calcium carbide on ripening of mangosteen fruit after harvest. Agri. Res. J. 26, 48–60 (in Thai with English abstract).

Piriyavinit, P., Ketsa, S., van Doorn, W.G., 2011. 1–MCP extends the storage and shelf life of mangosteen (*Garcinia mangostana* L.) fruit. Postharvest. Bio. Technol. 61, 15–20.

Pluemjit, O., Siriphanich, J. Farungsang, N., 2013. Postharvest abscission in longkong is due to ethylene production induced by fungal growth. In: Abstract Book of the eleventh National Postharvest Technology Conference, Petchaburi, p. 20.

Ponrot, W., Niyomlao, W., Kanlayanarat, S., 2006. Modified atmospheres affect the quality and storage life of rambutan fruit (*Nephellium lappaceum* L.). Acta Hortic. 712, 667–669.

Pranamornkith, T., S. Kanlayanarat and A. Uthairatanakij 2003. Effect of polyethylene film packaging on the storage life of mangosteen fruit (*Garcinia mangostana* L.). In: Proceeding of the APEC Symposium on Postharvest Handling Systems, Bangok, pp. 377–381.

Prayurawong, A., 1999. Effect of temperature and relative humidity on ripening and finger drop of 'Kluai Khai' (*Musa* AA Group). Ms.Thesis, Department of Horticulture. Kastsart University, Bangkok (in Thai with English abstract).

Promtongruk, O., Lerslerwong., L., 2012. Effects of pre and post-harvest gibberellic acid and 1-methylcyclopropene applications on harvest date and storage life of mangosteen fruits. Agri. Sci. J. 43, 392–395 (in Thai with English abstract).

Ratanachinakorn, B., S. Nanthachai and N. Nanthachai 2005. Effect of different atmospheres on the quality of 'Rong Rian' rambutan. In: Proceedings of the Second International Symposium on Lychee, Longan, Rambutan and Other Sapindaceae Plants, Bangkok, pp. 211–216.

Ramage, C.M., Sando, L., Peace, C.P., Carroll, B.J., Drew, R.A., 2004. Genetic diversity revealed in the apomictic fruit species *Garcinia mangostana* L. (mangosteen). Euphytica 136, 1–10.

Romphophak, T., Palakul, S., 1990. Quality of 'Chanee' durian (*Durio zibethinus*) stored at 5°C. Acta Hortic. 269, 213–216.

Saengpook, C., Ketsa, S., van Doorn, W.G., 2007. Effects of relative humidities on banana fruit drop. Postharvest Bio. Technol. 45, 151–154.

Salunkhe, D.K., Desai, B.B., 1984. Postharvest Biotechnol. Fruits, vol. 2. CRC Press, Inc., Boca Raton, Florida.

Samson, J.A., 1986. Trop Fruits, second ed. Longman, New York.

Sdoodee, S., Limpun-Udom, S., 2002. Effect of excess water on the incidence of translucent flesh disorder in mangosteen (*Garcinia mangostana* L.). Acta Hortic 575, 813–820.

Sdoodee, S., Chairawipa, R., 2005. Regulating irrigation during pre-harvest to avoid the incidence of translucent flesh disorder and gamboge disorder of mangosteen fruits. Songklanakarin J. Sci. Technol. 27, 957–965.

Semple, A.J., Thompson, A.K., 1988. Influence of the ripening environment on the development in finger drop in bananas. J. Sci. Food. Agri. 46, 139–146.

Sevillano, L., Sanchez-Ballesta, M.T., Romajaro, F., Flores, F.B., 2009. Physiological, hormonal and molecular mechanisms regulating chilling injury in horticultural species. Postharvest technologies to reduce its impact. J. Sci. Food. Agri. 89, 555–573.

Sharma, R.R., Singh, R., Saxena, S.K., 2006. Characteristics of citrus fruits in relation to granulation. Scienctia Hortic. 111, 91–96.

She, W., Pan, D., Lin., H., 2009. Relationship between granulation and active oxygen metabolism of juice sac in pummelo fruit during maturation. Scientia Agri. Sinica 42, 1737–1743.

Siriphanich, J., 1996. Storage and transportation of tropical fruits: A case study on durian. In: Proceeding of the International Conference on Tropical Fruits, Kuala Lumpur, pp. 439–451.

Siriphanich, J., Palapol, Y., Kerddonfag, N., Leeangulsatian, N., Kunprom, J., Labboriboon, P., 2013. Longkong export trial to China by sea. In: Abstract Book of the eleventh National Postharvest Technology Conference, Petchaburi (English abstract), p. 18.

Siriphanich, J., Romphophak, T., 2000. Postharvest Handling of Fruits and Vegetables. Agricultural Extension and Training Centre Publising, University of Kasetart, Nakhon Pathom, Thailand, 89 pp. (in Thai).

Siriphollakul, P., Niyomlao, W., Kanlayanarat, S., 2006. Antitranspirants maintain freshness and improve storge life of rambutan (*Nephellium lappaceum* L.) fruit. Acta Hortic. 712, 611–616.

Sirisukchaitavorn, H., Noichinda, S., Bodhipadma, K., Wongs-Aree, C., 2010. Changes in pectate lyase, xylanase and cellulase activities in different peel color development of normal and translucent mangosteen (*Garcinia mangostana* L.) fruits. Agri. Sci. J. 41, 709–712.

Somsri, S., 2008. Thai durians and the breeding: case study of hybrid cultivars of 'Chanthaburi 1', 'Chanthaburi 2', and 'Chantaburi 3'. AFACI5/2008. Department of Agri, Ministry of Agri and Cooperatives, Thailand (in Thai).

Smith, L.G., 1983. Cause and development of blackheart in pineapples. Trop. Agri. 60, 31–35.

Srilaong, V., Kanlanarat, S., Tatsumi, Y., 2002. Changes in commercial quality of 'Rong-Rein' Rambutan in modified atmosphere packaging. Food. Sci. Technol. Res. 8, 337–341.

Srilaong, V., Uthairatanakij, A., Jitareerat, P., Kanlayanarat, S., 2004. Effects of plastic tray packaging on quality of 'Rong-Rien' rambutan. In: Proceeding of the APEC Symposium on Quality Management in Postharvest Systems, Bangkok, pp. 195−199.

Sriyook, S., Siriatiwat, S., Siriphanich, J., 1994. Durian fruit dehiscence −Water status and ethylene. HortScience 29, 1195−1198.

Stewart, R.J., Sawyer, B.J.B., Robinson, S.P., 2002. Blackheart development following chilling in fruit of susceptible and resistant pineapple cultivars. Aust. J. Exp. Agri. 42, 195−199.

Taesakul, P., Siriphanich, J. Pluemjit, O., 2013. Changes in enzyme activities at the abscission sites of longkong fruits. In: Abstract Book of the eleventh National Postharvest Technology Conference, Petchaburi, p. 19 (English abstract).

Taniguchi, G., Sanewski, G.M., Bartholomew, D.P., Paull, R.E., 2008. Characteristics of the pineapple research institute of Hawaii hybrids 73-50 and 73-114. Pineapple News 15, 27−37.

TAS 3-2003. Thailand Agricultural Standard for Durian. National Bureau of Agricultural Cpmmodity and Food Standards, Ministry of Agriculture and Cooperatives. ISBN: 974-403-141-7.

TAS 13-2007. Thailand Agricultural Standard for Pummelo. National Bureau of Agricultural Cpmmodity and Food Standards, Ministry of Agriculture and Cooperatives. ISBN 978-974-403-468-7.

Thongleaw, S., Phuwatanon, L., 2011. Relationship between harvesting season and fruit quality of 'Khao Yai' pummelo. Agri. KMITL J. 29, 33−36 (in Thai with English abstract).

Tongdee, S.C., Suwanagul, A., 1989. Postharvest mechanical damage in mangosteen. ASEAN. Food J. 4, 151−155.

Tongdee, S.C., Suwanagul, A., Neamprem, S., 1990. Durian fruit ripening and the effect of variety, marurity stage at harvest, and atmosphere gases. Acta Hortic. 269, 323−334.

Tongtao, S., Srilaong, V., Kanlayanarat, S., Noichinda, S., Bodhipadma, K., Khumjareon, S., 2013. Sugar components and invertase activity in different maturity stages of 'Rongrien' rambutan. Acta Hortic. 1011, 81−85.

Trakulnaleumsai, C., Ketsa, S., van Doorn, W.G., 2006. Temperature effects on peel spotting in 'Sucrier' banana fruit. Postharvest Bio. Technol. 39, 285−290.

Uthairatanakij, A., Jitareerat, P., Srilaong, V., Photchanachai, S., 2013. Effect of gamma irradiation dose on postharvest quality and antioxidant activity of 'Trad Si Thong' pineapple. Acta Hortic. 1012, 829−835.

Utsunomiya, N., 1989. Structure, constituents and postharvest of tropical fruits in southeast Asia. Jpn. J. Trop. Agri. 33, 203−207 (in Japanese with English abstract).

Wendakoon, S.K., Ueda, Y., Imahori, Y., Ishimaru, M., 2004. Inhibition of acetate ester biosynthesis in banana (*Musa sapientum* L.) fruit pulp under aneaerobic conditions. J. Agri. Food Chem. 52, 1615−1620.

Wongs-Aree, C., Jitareerat, P., Ketsa, S., 2007. Characteristics of ripe papaya stored at low temperature. Acta Hortic. 738, 183−188.

Wongs-Aree, C., Kanlayanarat, S., 2004. $CaCl_2$ applications on storage quality of rambutan. Acta Hortic. 687, 213−218.

Wongs-Aree, C., Noichinda, S., 2011. Sugar apple (*Annona squamosa* L.) and atemoya (*A. cherimola* Mill. x *A. squamosa* L.). In: Yahia, E.M. (Ed.), Postharvest biology and technology of tropical and subtropical fruits, vol 4: Mangosteen to white sapote. Woodhead Publishing Limited, Cambridge, pp. 399–426.

Yingsanga, P., Srilaong, V., Kanlayanarat, S., Noichinda, S., McGlasson, W.B., Kabanoff, E., 2006a. Morphological differences associated with water loss in rambutan fruit cv. 'Rongrien' and 'See-Chompoo'. Acta Hortic. 712, 453–459.

Yingsanga, P., Srilaong, V., Kanlayanarat, S., McGlasson, W.B., Kabanoff, E., 2006b. Microscopy studies of the morphology of fruit of 'Rongrien' rambutan method. Acta Hortic. 712, 461–466.

Yingsanga, P., Srilaong, V., Kanlayanarat, S., Noichinda, S., McGlasson, W.B., 2008. Relationship between browning and related enzymes (PAL, PPO and POD) in rambutan fruit (*Nephelium lappaceum* Linn.) cvs. Rongrien and See-Chompoo. Postharvest. Bio. Technol. 50, 164–168.

Yingsanga, P., Srilaong, V., Kanlayanarat, S., McGlasson, W.B., Noichinda, S., 2012. Efficacy of polyethylene wax, sucrose fatty acid ester and lime dips in delaying post-harvest browning of rambutan. Acta Hortic. 943, 173–180.

You-Lin, T., Yu-Chan, Z., Xing-Jie, T., 1997. A study on factors inducing and controlling postharvest blackheart in pineapples. Acta Hortic. 425, 595–603.

Youryon, P., Wongs-Aree, C., McGlasson, W.B., Glahan, S., Kanlayanarat, S., 2008. Internal browning occurrences of 'Queen' pineapple under various low temperatures. Acta Hortic. 804, 555–560.

Youryon, P., Wongs-Aree, C., McGlasson, W.B., Glahan, S., Kanlayanarat, S., 2013. Alleviation of internal browning in pineapple fruit by peduncle infiltration with solutions of calcium chloride or strontium chloride under mild chilling storage. Int. Food. Res. J. 20, 239–246.

Yueming, J., 2000. Role of anthocyanins, polyphenol oxidase and phenols in lychee pericarp browning. J. Sci. Food. Agri. 80, 305–310.

Yuktanun, S., Siriphanich, J., 1993. Applications of NAA and ethephon for harvesting 'Rong-Rien' rambutan fruit. Postharvest. Hortic. Newsletter 3, 12–15.

Zhang, M., Duan, C., Zang, Y., Huang, Z., Liu, G., 2011. The flavonoid composition of flavedo and juice from the pummelo cultivar (*Citrus grandis* (L.) Osbeck) and the grapefruit cultivar (*Citrus paradisi*) from China. Food Chem. 129, 1530–1536.

CHAPTER

11 Microbial Quality and Safety of Fresh Produce

Elazar Fallik

ARO – The Volcani Center, Department of Postharvest Science of Fresh Produce, Bet Dagan, Israel

I Introduction

Fresh produce is an important part of a healthy diet. Its consumption is known to have health-protective effects against a range of illnesses and health problems such as cancers and cardiovascular diseases (Havens et al., 2012; McGill et al., 2013). In many countries, fresh produce consumption is encouraged through campaigns initiated by governmental health agencies; they recommend consumption of at least five servings of fruit and vegetables daily (Abadias et al., 2008).

Consumers generally express their concerns about food safety but, nevertheless, relatively very few of them appear to be expressing their concerns by changing their food buying and consumption behaviors. Food safety is the inverse of food risk; it can be expressed as the probability of not suffering some disorder as a result of consuming a specific food. In general, consumers' concerns are based on factors such as natural contaminants, agro-chemicals, veterinary drugs and packaging materials (Lynch et al., 2009; Strawn et al., 2011; Ergonul, 2013). However, bacterial pathogens that cause decay/spoilage are considered, overall, to represent the most important food safety issue for fresh produce, followed by foodborne viruses (Table 11.1), pesticide residues and mycotoxins (Scharff, 2012). Perceived consumer food safety issues such as those raised by pesticide residues, resistance to antimicrobial treatments, wax coatings, nanomaterials and genetically modified organisms are increasingly raising concerns in the fresh produce supply chain (Domingo and Gine Bordonaba, 2011; Magnuson et al., 2011).

Factors leading to increased microbial contamination are numerous. In the field, contaminating factors include soil, irrigation water, animals, insects and handling by workers. During harvest, sources of contamination include workers, tools, bins, crates and transport vehicles (Gutierrez-Rodrıguez et al., 2012; Forslund et al., 2012; Harris et al., 2012). Processing, transportation, distribution and/or retail display also contribute to the contamination problem (Golan and Unnevehr, 2008). Also, it was recognized that the most common food-handling deficiencies involved were the following: serving contaminated foods; inadequate

Postharvest Handling.

Table 11.1 Pathogenic Microorganisms Responsible for Foodborne Illness

Organism	Onset Time After Ingesting	Signs and Symptoms	Duration	Food Sources
Bacillus cereus	10–16 h	Abdominal cramps, watery diarrhea, nausea	24–48 h	Meats, stews, gravies, vanilla sauce
Campylobacter jejuni	2–5 days	Diarrhea, cramps, fever, and vomiting; diarrhea may be bloody	2–10 days	Raw and undercooked poultry, unpasteurized milk, contaminated water
Clostridium botulinum	12–72 h	Vomiting, diarrhea, blurred vision, double vision, difficulty in swallowing, muscle weakness. Can result in respiratory failure and death	Variable	Improperly canned foods, especially home-canned vegetables, fermented fish, baked potatoes in aluminum foil
Clostridium perfringens	8–16 h	Intense abdominal cramps, watery diarrhea	Usually 24 h	Meats, poultry, gravy, dried or precooked foods, time and/or temperature-abused foods
Cryptosporidium	2–10 days	Diarrhea (usually watery), stomach cramps, upset stomach, slight fever	May be remitting and relapsing over weeks to months	Uncooked food or food contaminated by an ill food handler after cooking, contaminated drinking water
Cyclospora cayetanensis	1–14 days, usually at least 1 week	Diarrhea (usually watery), loss of appetite, substantial loss of weight, stomach cramps, nausea, vomiting, fatigue	May be remitting and relapsing over weeks to months	Various types of fresh produce (imported berries, lettuce, basil)
E. coli (Escherichia coli) producing toxin	1–3 days	Watery diarrhea, abdominal cramps, some vomiting	3–7 or more days	Water or food contaminated with human feces
E. coli O157:H7	1–8 days	Severe (often bloody) diarrhea, abdominal pain and vomiting. Usually, little or no fever is present. More common in children four years of age or younger. Can lead to kidney failure	5–10 days	Undercooked beef (especially hamburger), unpasteurized milk and juice, raw fruits and vegetables (e.g., sprouts), and contaminated water

Hepatitis A	28 days average (15–50 days)	Diarrhea, dark urine, jaundice, and flu-like symptoms, i.e., fever, headache, nausea, and abdominal pain	Variable, 2 weeks to 3 months	Raw produce, contaminated drinking water, uncooked foods and cooked foods that are not reheated after contact with an infected food handler; shellfish from contaminated waters
Listeria monocytogenes	9–48 h for gastrointestinal symptoms, 2–6 weeks for invasive disease	Fever, muscle aches, and nausea or diarrhea. Pregnant women may have mild flu-like illness, and infection can lead to premature delivery or stillbirth	Variable	Unpasteurized milk, soft cheeses made with unpasteurized milk, ready-to-eat deli meats
Noroviruses	12–48 h	Nausea, vomiting, abdominal cramping, diarrhea, fever, headache. Diarrhea is more prevalent in adults, vomiting more common in children	12–60 hrs	Raw produce, contaminated drinking water, uncooked foods and cooked foods that are not reheated after contact with an infected food handler; shellfish from contaminated waters
Salmonella	6–48 h	Diarrhea, fever, abdominal cramps, vomiting	4–7 days	Eggs, poultry, meat, unpasteurized milk or juice, cheese, contaminated raw fruits and vegetables
Shigella	4–7 days	Abdominal cramps, fever, and diarrhea. Stools may contain blood and mucus	24–48 h	Raw produce, contaminated drinking water, uncooked foods and cooked foods that are not reheated after contact with an infected food handler
Staphylococcus aureus	1–6 h	Sudden onset of severe nausea and vomiting. Abdominal cramps. Diarrhea and fever may be present	24–48 h	Unrefrigerated or improperly refrigerated meats, potato and egg salads, cream pastries
Vibrio parahaemolyticus	4–96 h	Watery (occasionally bloody) diarrhea, abdominal cramps, nausea, vomiting, fever	2–5 days	Undercooked or raw seafood, such as shellfish
Vibrio vulnificus	1–7 days	Vomiting, diarrhea, abdominal pain, bloodborne infection. Fever, bleeding within the skin, ulcers requiring surgical removal. Can be fatal to persons with liver disease or weakened immune systems	2–8 days	Undercooked or raw seafood, such as shellfish (especially oysters)

Source: www.fda.gov/downloads/Food/ResourcesForYou/consumers/UCM187482.

cooking, heating and re-heating; obtaining foods from unsafe sources; inappropriate cooling and storage; and allowing too much time between preparation and consumption (Badrie et al., 2006). The same survey also found that most working surfaces and kitchen tools were contaminated with both nonpathogenic and potentially pathogenic microorganisms (Jevsnik et al., 2013). A different study suggested that the introduction of proper food safety education and training courses for food handlers, periodic evaluation of food handlers' knowledge and of food safety training course materials and better pay for food handlers would all improve the status of food safety in food service establishments (Osaili et al., 2013).

In the EU in 2009 and 2010, 4.4 and 10%, respectively, of the verified foodborne pathogen outbreaks were linked with consumption of vegetables, fruits, berries, juices and juice products (EFSA/ECDC, 2012). One of the largest reported outbreaks of hemolytic uremic syndrome (HUS) and bloody diarrhea caused by the Shiga toxin-producing *Escherichia coli* (STEC) O104:H4 occurred in Germany and France in 2011 (Soon et al., 2013). There were also unpublished reports of similar cases in Georgia in 2009, one in France in 2004 and one in Finland in 2010 (Scheutz et al., 2011). Such outbreaks have, in addition to their very severe consequences for public health, also a significant economic impact (WHO, 2011a,b). Therefore, the goal of this chapter is to summarize the latest information – accumulated during the past five years – on pre-storage treatments designed to reduce, or eliminate, spoilage microorganisms and foodborne pathogens on fresh and fresh-cut products, and on sophisticated and very accurate, sensitive and fast detection methods.

II Treatments to maintain microbial quality

In the food industry there is widespread debris that is liable to promote the accumulation of microorganisms and to encourage biofilm formation. Therefore, regular cleaning is required to prevent contamination of food products. Application of a good cleaning process that removes any food residues and other compounds that may promote bacterial proliferation and biofilm formation is particularly effective (Simoes et al., 2010). Many different chemical products, including surfactants or alkali products, may be used for cleaning or to suspend and dissolve food debris, by decreasing surface tension, emulsifying fats and denaturing proteins (Srey et al., 2013).

Washing with plain water is a common practice to reduce the initial microbial load of fresh produce (Keskinen and Annous, 2011; Barrera et al., 2012; Van Haute et al., 2013). A different type of washing uses electrolyzed oxidizing (EO) water, which is generated by electrolyzing a NaCl solution to release free chlorine into the water. EO water was reported to be effective in reducing *E. coli* O157:H7 populations on various produce (Pangloli et al., 2009) but, used alone, it is sometimes not sufficient to reduce microbial populations below the desirable safe level; therefore various sanitizing agents are added to the wash water to kill surface microorganisms. Antimicrobial agents are used in the disinfection process in order to kill microorganisms and thereby reduce their surface population, along with microbial growth on the surfaces. However, the effectiveness of disinfectants is limited by the presence of organic materials, including fats, carbohydrates and protein-based materials (Barrera et al., 2012); furthermore, disinfectant effectiveness may also be influenced by pH, temperature, water hardness, chemical inhibitors, concentration and contact time (Kuda et al., 2008; Srey et al., 2013). Among many types of disinfecting treatments are chemical treatments based on chlorine, hydrogen peroxide, ozone, peracetic acid, among others, as well as physical treatments (Chmielewski and Frank, 2007; Olaimat and Holley, 2012). The following paragraphs describe and discuss some of these treatments.

A Sodium hypochlorite

Sodium hypochlorite (NaClO) is a chemical compound used for bleaching or disinfection; for disinfecting surfaces it has been applied at concentrations (total active ingredient of 50−200 ppm for 1−2 min; pH values between 6 and 7.5 ensure the presence of chlorine in the hypochlorous acid formed but do not promote excessive corrosion of equipment (Fukuyama et al., 2009; Araújo et al., 2011). Sodium hypochlorite was reported to be an effective disinfectant for biofilm inactivation (Ozdemir et al., 2010). However, in the fresh-cut produce industry there is concern about the use of NaClO because of its low effectiveness in the presence of organic matter, and the formation of byproducts, such as chloroform and haloacetic acids, that are known to be carcinogenic or mutagenic, or potentially so (Hrudey, 2009). Furthermore, the high chlorine level in the bleach solution may result in a strong chlorine odor in the fresh produce, corrosion of equipment, irritation to skin or mucous membranes, and other adverse impacts on the environment or on users' health. Therefore, the use of chlorine for washing fresh-cut produce is prohibited altogether in some European Union countries such as Belgium, Denmark, Germany and The Netherlands, and also in Switzerland (Rico et al., 2007; Artes et al., 2009). Kerr (2009) observed that the most effective sanitizer for reducing *Bacillus cereus* spores on melon rind was undiluted sodium hypochlorite (6.00% NaOCl); products containing NaOCl at 1.84−2.40% achieved 2.75−3.40 log reduction over 180 min.

B Hydrogen peroxide (H_2O_2)

Hydrogen peroxide (H_2O_2) is classified as Generally Regarded As Safe (GRAS) for use in food products. It is a strong oxidizer and is proposed as an alternative means of decontaminating fruits and vegetables, because of its low toxicity and safe decomposition products. It is effective against a wide range of bacteria, yeasts, molds, viruses and spore-forming organisms (Toté et al., 2010); it has been shown to damage bacterial proteins, DNA and cellular membranes of microbial cells, and to remove protein from the coats of bacterial spores; its action is affected by organic load but not by pH (Walker and Marsh 2007; Martin and Maris, 2012). From the safety point of view, H_2O_2 is known to be a safe solution which does not cause allergic reactions, even at concentrations between 0.08 and 0.2% (Shikongo-Nambabi et al., 2010). Abadias et al. (2011) and Alexandre et al. (2012) reported that the highest total mesophile reductions (2.26 ± 0.38 and 1.59 ± 0.41 log units) were reached after washing strawberries with, respectively, 5 and 1% chemical solutions of H_2O_2.

C Ozone

Ozone, formed when oxygen atoms are exposed to a high-voltage electrical discharge, is a bluish gas with a strong odor and oxidizing potential. It is a potent antimicrobial agent that can be used against bacteria, fungi, viruses, protozoa and bacterial and fungal spores (Srey et al., 2013). Ozone is a highly effective agent that readily oxidizes organic matter, various microbes such as bacteria, fungi, viruses and protozoa, bacterial and fungal spores, and also pesticides and chemical residuals disinfection by-products (DBP). However, ozone may become ineffective with low amounts of organic materials and dirt around produce (Hassenberg et al., 2008). It is effective at lower concentrations (1−5 ppm) and shorter contact times (1−5 min) than chlorine (Selma et al., 2007; Olmez and Kretzschmar, 2009; Srey et al., 2013), it can react with organic matter up to 3000 times faster than chlorine and it can disrupt microbial cell membranes and bacterial spore coats (Rosenblum et al., 2012). Although ozone is a popular alternative to chlorine because of its inability to form trihalomethanes (THMs), it can generate DBPs such as bromate when high levels of bromide are present in the water (Wert et al., 2007). This has led the United States Environmental Protection Agency (USEPA) to establish a maximum contaminant level of 10 μg/l for bromate in drinking water (Rosenblum et al., 2012). Ozone can cause lethal surface damage to bacteria, which lead to protein release, lipid peroxidation, and changed cell permeability. Similarly, ozone can result in severe damage to the spore coat, which enables the ozone to diffuse deeper and to cause further injury (Perry and Yousef, 2011). Moreover, the microorganisms are eradicated by the disruption or breakdown of the cell envelope which, in turn, leads to the leakage of the cell contents. Cell lysis is a faster inactivation mechanism than that elicited by other antimicrobial agents, for which permeation through the cell membrane is necessary for effective inactivation of the microbe (Pascual et al., 2007). Selma et al. (2006) applied ozonated water to potatoes at 5 mg/l for 1 min and obtained reductions of log 1.6 and 0.8 colony-forming units (CFU)/g of *Yersinia enterocolitica* and *Listeria monocytogenes*, respectively. They used the same procedure at ozone levels of 2 and 5 mg/l to reduce *Shigella sonnei* in shredded lettuce by 0.5 and 1.8 log CFU/g, respectively, after 5 min (Selma et al., 2007); and Rosenblum et al. (2012) used ozonation at <2 mg/l to achieve an average log reduction of 1.56 of

Bacillus subtilis spores on fresh lettuce. Reductions between 1.5 and 2.5 log were achieved against natural microbial flora by applying ozonated water at 1.5 and 3 mg/l, at 2°C for 3 min to inoculated lettuce (Olmez and Kretzschmar, 2009). Exposure of fresh-cut red peppers to gaseous O_3 at 0.7 μg l^{-1} for 3 min reduced the populations of mesophiles, psychrotrophes and fungi on fresh-cut peppers by 2.5, 3.3 and 1.8 log units, respectively (Horvitz and Cantalejo, 2012).

D Organic acids

Organic acids are generally recognized as safe (GRAS) and can be used as sanitizers of fresh produce because of their bactericidal activity. Akbas and Olmez (2007) studied the antimicrobial activity of lactic acid, citric acid, acetic acid and ascorbic acid, all at 1%, against *E. coli* ATCC 25922 and *L. monocytogenes* on iceberg lettuce. Massilia et al. (2009) reported the inactivation of *E. coli* O157:H7, *Salmonella typhimurium*, and *L. monocytogenes* in apple, pear and melon juices, following treatment with malic acid. Choi et al. (2012) investigated the efficacy of aerosolized malic acid in inhibiting foodborne pathogens (*L. monocytogenes*, *S. typhimurium*, and *E. coli* O157:H7) on spinach and lettuce, and reported that aerosolized malic acid was effective at killing foodborne pathogens on spinach and lettuce without impairing produce quality. Therefore, aerosolized malic acid might be used as an alternative sanitizer to increase the microbial safety of fresh produce during transportation and storage.

Peracetic acid is formed by the reaction between hydrogen peroxide and acetic acid or by oxidation of acethaldehyde. The mixture has a strong odor and a low pH (2.8) and usually is produced in concentrations between 5 and 15%; it is known as an ideal antimicrobial agent because of its extremely strong oxidizing capacity. This agent also decomposes into safe and environmentally friendly residues in food, therefore it can be applied without rinsing, and its efficacy is not affected by protein residues. Cabeca et al. (2012) showed that peracetic acid at a concentration of 0.50% (w/v) could reduce *L. monocytogenes* biofilm that had adhered for 24 h by 5 log. According to Toté et al. (2010), peracetic acid eliminated approximately 98 and 99% of viable *Staphylococcus aureus* and *Pseudomonas aeruginosa*, respectively, with only 1 min of contact time, but did not eliminate the biofilm matrix. Martínez-Téllez et al., (2009) investigated the efficacy of sanitizers such as chlorine, hydrogen peroxide, and lactic acid against *S. typhimurium* inoculated into fresh green asparagus and green onions, and found that the most effective sanitizer — which reduced growth by close to 3 $\log_{10}$ CFU/g during exposure times of 40, 60, and 90 s — was the 2% lactic acid solution.

E Chlorine dioxide (ClO_2)

Chlorine dioxide (ClO_2) is an oxidizing agent with strong antimicrobial properties, which is effective over a wide range of pH (3−8) and exhibits strong biocidal activity against a broad range of microorganisms, including bacteria, fungi, yeasts and molds; it is 3.5 times as powerful as chlorine or chlorinated water (Artes et al., 2009, Gómez-López et al., 2009). Either gaseous or aqueous ClO_2 can be used for disinfecting fresh fruits and vegetables (Park et al., 2008). Du et al. (2003) achieved more than 5 log reduction of *E. coli* O157:H7 on apple skin by treatment with ClO_2 at 3.3 mg/l for 20 min or at 7.2 mg/l for 10 min. In another study Mahmoud et al. (2007) achieved 4.3−4.7 log reductions of *E. coli* O157:H7, *L. monocytogenes*, and *S. enterica* in strawberries that were treated with ClO_2 gas at 5.5 mg/l for 10 min; moreover, its effectiveness was not lessened by the presence of soil and/or other organic matter, and it does not form carcinogenic compounds such as chloroamines and THMs because it cannot react with ammonia, which is a common byproduct of treatment with chlorine or chlorinated water (Mahmoud et al., 2007; Artes et al., 2009). Tomás-Callejas et al. (2012) reported that populations of *E. coli* O157:H7 and *Salmonella* inoculated onto Red Chard leaves were reduced by 0.7 and 0.8−1.5 log, respectively, after processing with ClO_2 at 3 mg/l. Washing iceberg lettuce for 2 min with TriNova (ionic ClO_2^{-1} at 20, 100 and 200 mg/l) resulted in log reductions of *E. coli* O157:H7 populations by 0.96, 1.05 and 1.13 CFU/g, respectively (Keskinen and Annous, 2009). Trinetta et al. (2010) achieved a reduction of *Salmonella* in tomato by approximately 4.9 log by applying ClO_2 at 10 mg/l for 180 s.

F Modified atmosphere packaging (MAP)

Studies have shown that modified atmosphere packaging (MAP) and controlled atmosphere storage have the ability to delay quality impairment and thus to extend the shelf life of fresh, minimally processed or fresh-cut produce, because of the relatively low oxygen and high carbon dioxide levels inside the package. Modified atmosphere packaging of fruits can reduce respiratory activity, delay softening and ripening and reduce the incidence of various physiological disorders and pathogenic infestations (Caleb et al., 2013). Carbon dioxide is a colorless gas, with a slightly pungent smell at a very high concentrations; it readily dissolves in water at 1.57 g/kg at 100 kPa and 20°C, to produce carbonic acid, which reduces the pH of the solution (Sandhya, 2010). Carbon dioxide is the only gas used in MAP that confers a significant level of antimicrobial activity and survival on the produce. Microbial growth in various products is retarded under high concentrations of carbon dioxide, because of increased lag phase and generation time during the log phase of microbial growth. Various theories have been advanced to explain the antimicrobial influence of carbon dioxide in MAP products. These theories include: direct inhibition of enzyme systems or decreased enzyme reaction rates; alteration of cell membrane functions, including uptake and absorption of nutrients; gas penetration through bacterial membranes, leading to decreased intracellular pH; and direct changes in the physical and chemical properties of proteins (Caleb et al., 2013). A critical factor in the success of MAP is the choice of packaging material, because the degree to which the atmosphere in packages is modified depends on variables such as: film permeability to O_2, CO_2 and water vapor; film thickness; package surface area; and the free volume inside the package (Mahajan et al., 2008). Koide and Shi (2007) investigated the microbial and physicochemical qualities of green peppers stored in polylactic-acid-based biodegradable and LDPE film packaging; their results showed that the total coliform bacteria populations increased by 2.3 log CFU/g in LDPE film, and by 0.9 and 0.2 log CFU/g, respectively, in the perforated LDPE and biodegradable film packaging. These findings indicated that biodegradable film with higher water vapor permeability would maintain the quality of green peppers better. Active MAP in a polyethylene bag with a gas mixture of 10/10/80% $O_2/CO_2/N_2$ had an antimicrobial effect on indigenous lettuce microflora, but not on *Salmonella*; it even favored the survival of the pathogen, possibly because of elimination of its natural antagonists (Horev et al., 2012).

G Coatings

Edible films, which consist of a thin layer of edible materials applied to food surfaces are another type of coating (Mangaraj et al., 2009; Campos et al., 2011).

Pushkala et al. (2012) evaluated the efficacy of an innovative powder coating technique based on 0.3% chitosan – a biopolymer – with and without citric acid pretreatment (designated CACH and CH, respectively) for quality maintenance of shredded carrots: after 10 days at 10°C the populations of bacteria and yeasts in both the CH and CACH samples fell significantly, indicating the pronounced bactericidal effect of chitosan. A study conducted by Durango et al., (2006) supported the findings of the Pushkala et al. (2012) study; it found that a chitosan coating on minimally processed carrots brought about a reduction of 1.3 log CFU/g in the mesophilic aerobic bacterial count, without affecting the overall quality of the processed product. Similar results have also been reported for chitosan-coated fresh-cut broccoli: reductions of 1.5–2.5 log CFU/g in mesophilic aerobic bacterial counts were obtained with chitosan coating, compared with those in untreated controls (Moreira et al., 2011). The positively charged amino group present in chitosan interacts with the negatively charged microbial cell membranes, leading to leakage of intracellular constituents of the microorganisms (Dutta et al., 2009), which could be one mechanism of its bactericidal and fungicidal action.

H Essential oils

Essential oils have long been applied as flavoring agents in foods and, thanks to their antimicrobial compound content, they have potential as natural food preservation agents.

Noroviruses have been listed among the five highest-ranking pathogens in terms of the total cost of foodborne illness in the United States (Scharff, 2012). The effects of three essential oils – clove, oregano and zataria – on the infectivity of the norovirus surrogates feline calicivirus (FCV) and murine norovirus

(MNV) were evaluated by Elizaquível et al. (2013), who found that application of 2% oregano essential oil at 37°C decreased FCV titers by 3.75 log TCID50 ml^{-1}, with decreasing effects at lower concentrations; they decreased MNV titers by 1.04−1.62 log TCID/50 ml, depending on the concentration used. Effects of FCV clove and zataria essential oils showed similar trends in titer reductions to those obtained with oregano essential oil; the maximum titer reduction was achieved when FCV was treated with 0.1% zataria essential oil at 37°C.

I Relative humidity

Water loss is a major cause of postharvest deterioration because it results not only in direct quantitative losses, but also in impaired appearance and textural quality. The maintenance of relative humidity (RH) after harvest is not always possible and can influence the quality of the raw material, especially when it is intended for minimal processing (Clarkson et al., 2005; Ayala-Zavala et al., 2008).

Medina et al. (2012) studied the influence of short-term postharvest exposure (36 h at 15°C) in various RH conditions such as high (99%), medium (85%) and low (72%) on the microbial quality − as well as general quality and shelf life − of minimally processed baby spinach. Counts of psychrophilic bacteria and *Pseudomonas* spp. on samples exposed to high RH were 1 log higher than those on samples exposed to low and medium RH. These differences could be due to the high RH − microbial populations are known to be affected by extrinsic conditions such as RH (Ayala-Zavala et al., 2008; Aguero et al., 2011). Medina et al. (2012) concluded that control of RH after harvest is critical because it can influence the microbiological population and the maintenance of acceptable visual quality.

J UV-C light

UV-C light is the part of the electromagnetic spectrum, with wavelengths between 200 and 280 nm. Its use involves a non-thermal technology that is potentially suitable for fruit juice stabilization because it has a positive consumer image and is attractive to the food industry, thanks to its low cost. Its antimicrobial action is based on the absorption of UV light by microbial DNA, which causes the formation of cyclobutane pyrimidine dimers that render cells unable to replicate (Koutchma, 2009). It has been shown that the effectiveness of UV-C for microbial inactivation depends on radiation dose and the structure and topography of the surface of the product (Escalona et al., 2010).

Application of double-sided UV-C exposure at a low dose of 2.4 kJ/m^2 for 14 days at 5°C was effective in reducing initial microbial counts of the tested bacteria types and of psychrotrophic bacteria and Enterobacteria, and in keeping *L. monocytogenes* at low levels during the storage period, without affecting the sensory quality of fresh-cut baby spinach leaves (Escalona et al., 2010). Another study investigated the effects of UV-C light applied to both sides of mushrooms on microbial loads and product quality during storage for 21 days at 4°C: the results showed that UV-C doses of 0.45−3.15 kJ/m^2 resulted in reduction of *E. coli* O157:H7 inoculated on mushroom cap surfaces by 0.67−1.13 log CFU/g; the UV-C radiation also reduced total aerobic plate counts on the surface of mushrooms by 0.63−0.89 log CFU/g (Guan et al., 2012).

K Hot water

Hot water treatments are mainly applied to fresh-cut products for 1−5 min, at temperatures ranging from 40 to 60°C (Siddiqui et al., 2011; Silveira et al., 2011a,b). Fan et al. (2006) reported that surface pasteurization of melon fruit with hot water at 76°C for 3 min reduced the microbial population on the surface of whole fruits by 3.3 log, resulting in a lower microbial load on the fresh-cut cubes than on cubes cut from fruits treated with cold water. Treating melon fruits destined for fresh-cutting with hot water rinsing and brushing (HWRB) technology at 75°C for 20 s significantly reduced pathogen populations by 4 log, on naturally infected fruits, compared to untreated or chlorine-treated fruits (Fallik et al., 2007). Most seed-sprout-related outbreaks have been associated with *E. coli* O157:H7 and *Salmonella*. After hot water treatment at 90°C for 90 s followed by dipping in chilled water for 30 s, no viable pathogens were found, and no survivors were found in the enrichment medium or during the sprouting process. The germination yield of the seeds was not affected significantly (Bari et al., 2008). Djioua et al. (2009) reported that hot water dipping at 50°C for 30 min was the optimal heat treatment for improving the quality of fresh-cut "Keitt" mangoes. However, higher temperatures were reported to improve the microbial reduction and to benefit the overall quality of some fresh-cut products. Treating pre-cut shredded carrot at 100°C for 45 s proved to be more efficient than chlorinated water treatment, as indicated by microbial counts after 10 days' storage at 5°C followed by 3 days under shelf life conditions (Alegria et al., 2010).

L Irradiation

It has been reported that ionizing radiation is highly effective for the elimination of foodborne pathogens in various vegetables and leafy greens (Mahmoud, 2010; Grasso et al., 2011). Currently, more than 50 countries have given approval for over 60 foodstuffs to be irradiated for local consumption and/or for export, and approximately 40 different countries are using the food irradiation technology (Stefanova et al., 2010). Depending on the type of food and the desired effect, the dose levels can be divided into the three groups: a low dose up to 1 kGy is used to delay fresh fruits' and vegetables' ripening or sprouting as well as to control insects and foodborne parasites in cereals and pulses, fresh and dried fruits, dried fish and meat, etc.; a medium dose, 1−10 kGy is used to reduce spoilage and pathogenic microorganisms on fresh fish, strawberries, mushrooms, fresh and frozen seafood, and raw or frozen poultry and meat to improve their technological properties such as reducing cooking times for dehydrated vegetables and to extend the shelf life of foods; High doses, greater than 10 kGy (10−50 kGy), are used for the sterilization of meat, poultry, seafood and other prepared foods (Stefanova et al., 2010). Food treated with the gamma rays (cobalt-60 is the preferred source of radiation for food) does not become radioactive as no neutrons are emitted by cobalt-60; therefore, no nuclear changes are produced in the nuclei of food molecules. There is no scientific evidence that irradiated food will contain levels of radioactivity higher than those in non-irradiated food (Stefanova et al., 2010). Irradiation of fresh produce at a maximum level of 1.0 kGy is generally effective for eliminating microbial contamination (Gomes et al., 2009). Shim et al. (2012) found that exposure of contaminated lettuce leaves to 1 kGy of gamma irradiation reduced numbers of *S. typhimurium* and *S. aureus* by 3 log CFU per leaf. Grasso et al. (2011) reported that electron-beam irradiation at 2.3 kGy reduced the *E. coli* population on fresh-cut cabbage by more than 4 log CFU/g. However, irradiation of fresh produce has the disadvantage that at >1 kGy the quality of fresh produce may deteriorate in terms of changes in appearance, flavor, color and texture (Fan et al., 2008). Furthermore, some viruses and fungi can resist irradiation treatment (Warriner et al., 2009). A different type of decontamination treatment is plasma technology, which uses ionized gases, which contain free charged particles like ions and electrons. Plasma cannot only be used for microbicidal effects, but also for abrasion of organic materials as well as tissue treatment. A commercially used plasma process for antimicrobial treatments is the low-temperature-hydrogen peroxide-gas-plasma-sterilization (Sterrad®, Advanced Sterilization Products, Irvine, USA) (Schnabel et al., 2012). After a treatment time of 15 min with plasma, reduction rates between 0.5 and 5.2 log of *Bacillus atrophaeus* endospores were achieved on artificially inoculated seeds of *Brassica napus*. The viability of the seeds was not affected (Schnabel et al., 2012).

M Combined treatments

The effects of combinations of several types of treatments and/or disinfectants can be synergistic (Ha and Ha, 2011). Martin and Maris (2012) found a synergistic effect to control *Salmonella* sp., when combinations of 1.56% H_2O_2 and 0.625% citric acid were used. However, *Salmonella* sp. also showed a high level of sensitivity to five other combinations, comprising H_2O_2 with fumaric, succinic, mandelic, nitric and sulfuric acids. On lemon fruits, green and blue molds, both of which require wounds for infections to occur, were controlled by a combination of 1.5% H_2O_2 followed by inorganic salts, even when the solution temperatures were 25°C. Control of sour rot was poor with salt solutions alone, but significantly improved in treatments comprising H_2O_2 followed by potassium sorbate or sodium bicarbonate at 50°C (Cerioni et al., 2013). Washing baby spinach leaves with 3% H_2O_2 followed by a two minute treatment with 2.5% lactic acid (LA) + 1% allyl isothiocyanate (AIT) or 2.5% LA + 2% AIT reduced *E. coli* O157:H7 populations by 4.7 and >5 log CFU/g, respectively, after 10 days at 4°C. In the scale-up system, up to 4 log reduction of bacterial population was achieved with the same treatments, without causing any noticeable impairment of the appearance of leaves (Huang et al., 2013). Significant reductions by 1.00−1.49 log CFU/g in internalized *Salmonella* were observed in green onion treated with UV-C at 150 or 900 mJ/cm^2 or with UV-C plus chlorine/PAA at 200/80 mg/l (Ge et al., 2013). Hadjok et al. (2008) reported that using UV-C at 25.2−56.7 mJ/cm^2 combined with 1.5% H_2O_2, either by continuous spraying at 50°C, or through 10−30 s of contact during the UV-C illumination, achieved a 2.84 log reduction in the internalized *Salmonella* Montevideo population in iceberg lettuce, either of which was more efficient than using the UV-C or H_2O_2 alone.

A reduction by more than 5.0 log CFU/g of *E. coli* O157:H7 was achieved when mung bean seeds were treated with hot water at 85°C for 10−40 s, followed by soaking in a 2000 ppm chlorine solution for 2 h; the hot water treatment at 85°C for 40 s followed by the chlorine treatment completely eliminated *E. coli* O157:H7 from the mung bean seeds. Furthermore, a reduction in *Salmonella* by more than 5.0 log CFU/g was obtained after the hot water treatment at 85°C followed by the chlorine treatment. These treatments did not significantly affect the viability and germination of the mung bean seeds, and a sufficient yield for commercial use was obtained (Nei et al., 2013).

Monique et al. (2013) demonstrated the effectiveness of various pretreatments in increasing bacterial sensitivity to irradiation, reducing water loss and extending the shelf life of the food following storage at 4°C for 8 days. The pretreatments comprised the application of edible coatings containing natural antimicrobial compounds (carvacrol at 312 ppm), modified atmosphere packaging (MAP), or mild heat treatment at 30°C for 10 min, and they were applied before irradiation at 3.6 kGy was used to inactivate growth of *L. monocytogenes*, *S. typhimurium*, *E. coli* and *B. cereus*, or germination of *B. cereus* spores.

A combination of ultrasound treatment with surfactants, as an alternative to use of conventional sanitizers containing chlorine for reducing numbers of *B. cereus* spores on fresh produce, was reported by Sagong et al. (2013): the most effective treatment was the combination of ultrasound and 0.1% Tween 20; it yielded reductions of 2.49 and 2.22 log CFU/g on lettuce and carrots, respectively, without impairing product quality. These reductions were 1 log greater than those obtained by immersion in chlorine solution at 200 ppm for 5 min.

Transmission of *E. coli* O157:H7 from the rind to edible melon flesh during cutting was investigated. Four different treatments were evaluated: hot water at 75°C for 1 min, gaseous ozone at 10,000 ppm for 30 min, gaseous ozone carried by carbon monoxide gas, and the combination of hot water and gaseous ozone. Hot water, gaseous ozone and the combination of hot water and gaseous ozone were effective in reducing total microbial populations: the combination of hot water and gaseous ozone was the most effective treatment for controlling microbial growth, achieving reductions of 3.8, 5.1, 2.2 and 2.3 log for mesophilic and psychrotrophic bacteria, molds, and coliforms, respectively (Selma. et al., 2008).

Bacteriophages have been found to be effective in controlling pathogens in the environment and on foods, including fresh produce (Teplitski et al., 2011).

Ye et al. (2010) reported that the combination of a bacteriophage cocktail with antagonistic bacteria reduced numbers of *Salmonella* by 6 log CFU/ml in broth culture.

A feasibility study was conducted to develop chlorine dioxide (ClO_2)-releasing packaging films for decontaminating fresh produce. Sodium chlorite and citric acid powder were incorporated into polylactic acid (PLA) polymer, and a solvent-casting method was used to prepare films containing: 100 and 300 mg of PLA; reactant contents ranging from 5 to 60%; and sodium chlorite to citric acid ratios of 1 : 2 or 2 : 1 (Ray et al., 2013). The results indicate that the films were activated by moisture from tomatoes in the package and the released ClO_2 reduced *Salmonella* spp. and *E. coli* O157:H7 inoculated on the tomatoes to undetectable levels of <5 CFU/tomato, i.e., a reduction of more than 3 log. The film-treated tomatoes did not show significant changes in color or texture compared to controls, during storage at 10°C for 21 days (Ray et al., 2013).

III Detection

Food safety is a global health goal, and foodborne diseases could cause a major health crisis. Therefore, detection of foodborne pathogenic microorganisms is an important issue with regard to ensuring food safety and public health. "Low-tech" methods such as good agricultural practices (Kay et al., 2008), good manufacturing practices, and hazard analysis and critical control point (HACCP) (Mucchetti et al., 2008), cannot be neglected, and are very important for lowering risk factors. In addition, sophisticated, very accurate, sensitive and rapid detection methods are required to improve food safety.

A Culture- and colony-based methods

Conventional culture methods remain the most reliable and accurate techniques for foodborne pathogen detection. Although culture-based methods are standard microbiological techniques to detect single bacteria, amplification of the signal is required through growth of a single cell into a colony (Brichta-Harhay et al., 2007). The major drawbacks of microbiological methods are that they are labor-intensive and time-consuming; it takes 2−3 days to obtain the initial results, and up to 7−10 days for confirmation. This is obviously inconvenient in many industrial applications, particularly in the food-processing sector. However, in spite of their disadvantages, conventional culture methods remain a field in which progress is possible (Sanders et al., 2007; Velusamy et al., 2010).

B Immunology-based methods

Immunological detection with antibodies is perhaps the only technology that has been successfully employed for the detection of bacterial cells, spores, viruses and toxins alike (Velusamy et al., 2010). Methods based on antigen−antibody bindings are widely used for determining foodborne pathogens: immunology-based methods have been used for detection of several pathogenic bacteria such as *E. coli*, *Salmonella*, *Listeria*, Staphylococcal enterotoxins and *Campylobacter* spp. A number of antibody types and formats are available for immunodetection (Magliulo et al., 2007; Hochel et al., 2007; Jechorek and Johnson, 2008); they include conventional and heavy-chain antibodies, as well as polyclonal, monoclonal or recombinant antibodies. Monoclonal antibodies are often more useful than polyclonal antibodies for detecting a specific molecule, because they provide an unlimited supply of a specific individual antibody. However, the problems with monoclonal antibodies are that a skilled technician and specialized growth apparatus for tissue culturing are needed, and these are expensive. Examples of immunological techniques include: enzyme immunoassay (EIA), enzyme-linked immunosorbent assay (ELISA), flow injection immunoassay, enzyme-linked fluorescent assay (ELFA), bioluminescent enzyme immunoassay (BEIA), enzyme-linked immunomagnetic chemiluminescence (ELIMCL), immunochromatography (ICG) strip test, immunomagnetic separation, immuno-precipitation assay, agglutination test, radioimmunoassays (RIA) and the western blot test; technically modified western blot tests include the line immunoassay (LIA) and the recombinant immunoblot assay (RIBA), the application of surface-modified polyacrylonitrile (PAN) fibers as a novel immunoassay matrix for detection of foodborne pathogens, and the enzymatic signal enhancement method for highly sensitive, fast detection of food bacterial contamination. The last of these is based on generating a mass-enhancing product at the sensing interface, which is quantified by surface plasmon resonance (SPR) spectroscopy (Linman et al., 2010; Chattopadhyay et al., 2013).

C Polymerase chain reaction (PCR)

Polymerase chain reaction (PCR)-based methods are used in the detection of a wide range of pathogens. This method can detect a single copy of a target DNA sequence; therefore it can be used to detect a single pathogenic bacterium in food. It is promising because it detects the organism by amplifying the target rather than the signal and is, therefore, less prone to producing false positives. A target DNA can be amplified one-million-fold in less than an hour, with theoretical sensitivities down to a single target pathogen (O'Grady et al., 2008; Riyaz-Ul-Hassan et al., 2008). The various PCR-based methods used to detect pathogens are: real-time PCR; multiplex PCR, which is very useful because it enables simultaneous detection of several pathogens by introduction of several different primers to amplify DNA regions coding for specific genes of each targeted bacterial strain; reverse transcriptase PCR (RT-PCR); and real-time RT-PCR (Desai et al., 2008; Malorny et al., 2008; O'Grady et al., 2008). Recently, Ye et al. (2013) have developed a molecular predictive model based on appropriate real-time PCR methods, to describe the growth of a cocktail of *L. monocytogenes* strains. They concluded that the application of a molecular predictive model not only can help to more accurately establish models of certain pathogens in the presence of other bacteria, but also can save time and labor. However, in spite of its advantages, from an industrial point of view, the routine detection of microbes with PCR can be expensive and complicated, because it requires skilled workers to carry out the tests.

D Biosensors

In recent years more sophisticated methods using, e.g., biosensors or immunosensors, have been developed. They have become an alternative means of performing simple, sensitive, fast, selective and reliable measurements of pathogenic bacteria because they are both cost-effective and applicable to real-time monitoring (Velusamy et al., 2010; Shen et al., 2011). Biosensors based on the highly specific interactions between antibodies and antigens are being adapted as the most sensitive and specific options (Sadik et al., 2009). A biosensor is an analytical device that converts a biological response into an electrical signal; it consists of two main components: a bioreceptor or biorecognition element, which recognize the target analyte, and a transducer for converting the recognition event into a measurable electrical signal. A bioreceptor can be a tissue, a microorganism, an organelle, a cell, an enzyme, an antibody, a nucleic acid or a biomimic, and the transduction may be optical, electrochemical, thermometric, piezoelectric, magnetic or micromechanical, or a combination of two or more of these. For example, a biosensor developed by Barreiros dos Santos et al. (2013) showed a very low detection threshold of 2 CFU/ml and a wide linear range of 30 to 3×10^4 CFU/ml. Thus, immunosensors using electrochemical (Setterington and Alocilja, 2012; Vidal et al., 2013), optical (Subramanian et al., 2006; Linman et al., 2010) and mass-based (Shen et al., 2011) transduction methods have been applied for the detection of bacterial food contamination. Mycotoxins affect a broad range of agricultural products, most importantly, cereals and cereal-based foods (Vidal et al., 2013). The acute toxicity of these mycotoxins poses serious human and animal health problems. Recently, Yamashoji et al. (2013) reported that a chemiluminescent assay of menadione-catalyzed H_2O_2 was useful for the rapid evaluation of food safety with respect to mycotoxins, which are highly toxic secondary metabolites produced by molds.

E Imaging systems

Interest in and use of hyperspectral imaging in agriculture have accelerated in recent years, and Zhang et al. (2012) have demonstrated that imaging in the visible (VIS) spectrum can be the basis for sensitive methods for addressing agricultural problems. Recently a hand-held visible hyperspectral imaging device was developed to monitor the cleaning and sanitation processes in food facilities (Wiederoder et al., 2013). The device is capable of acquiring both reflectance images under ambient lighting and fluorescent responses to supplemental violet (405 nm) excitation. To enhance detection of relatively low-intensity fluorescent responses in the presence of ambient lighting, the device includes the ability to identify wavebands at which the intensity of ambient lighting is relatively low.

IV Future perspectives

Increasing consumption of fresh vegetables and fruits as part of a healthy diet, and the transition toward convenience foods, both necessitate continuing efforts to conserve nutrient value and to extend product shelf life, without compromising food safety. Serious outbreaks of produce-associated illness highlight the need to ensure that the agro-food industry produces high quality and safe foods all year round. The food chain from farm to fork offers multiple opportunities for produce to become contaminated but, nevertheless, the vast majority of produce sold in the markets, especially in developed countries, is considered safe. Although no-one can guarantee that food safety will not be compromised at some point along the production/supply chain, producers and the food industry should make every effort to minimize such events.

With regard to control measures, the application of good agricultural practices (GAP) was identified as the most important control measure to assure the safety of fresh produce, followed by the application of good hygienic practices (GHP), and the certification of food safety management systems (FSMS) (Kirezieva et al., 2013). Overall, increasing international trade and globalization were expected to have a large impact on food safety in fresh produce. Other contextual factors perceived to be important were the food safety policies adopted by governments and the food safety knowledge (or lack of it) among consumers and other stakeholders in the fresh produce supply chain (Van Boxstael et al., 2013). Therefore, more countries need to implement new food safety laws and management systems to improve their national food safety control systems and to reduce public and international concerns – measures that recently have been taken in several countries (Jia and Jukes, 2013). Furthermore, data obtained from food safety studies have indicated the need for much more consumer education regarding safe food handling practices in the domestic environment. Food handling practices and food safety are of public concern, and action is required to prevent foodborne illnesses. It seems that television and radio programs are important media for sharing food safety knowledge with consumers (Ergonul, 2013).

Conventional methods of detecting pathogens in food samples are time consuming – 3–5 days or longer are needed to obtain a confirmed positive result – and the intrinsic traits of some leafy vegetables can prevent or delay detection with commercial rapid-detection kit formats (D'lima and Suslow, 2009). Therefore, the need for development and application of rapid pathogen monitoring systems is very urgent. Detection of pathogens in the end product before shipping to the markets is critical for preventing recall and the associated economic losses. Since the shelf life of fresh produce and, especially, that of minimally processed produce is very short – usually around 10 days – microbial analysis should be available within hours rather than days. Similarly, on-line monitoring of microbial contamination might enable rapid intervention procedures in case contamination is found. A technology that might be very useful for inactivating microorganisms is dense phase carbon dioxide (DPCD), which is a non-thermal process for liquid and solid foods that uses pressure (>50 MPa) in combination with carbon dioxide (CO_2) (Ramírez-Rodrigues et al., 2013).

In addition, the rapid detection of mycotoxins must be improved. Recently Yamashoji et al. (2013) reported that a chemiluminescent assay of menadione-catalyzed H_2O_2 was useful for rapid evaluation of food safety with respect to toxins such as *Fusarium* mycotoxin, the tomato toxin tomatine, the potato toxin solanine, and the marine toxins terodotoxin and brevetoxin.

Development of more efficacious decontamination treatments, alone or in combination with other treatments, should focus on current and newly introduced chemicals and techniques that will preserve nutritional values, as well as organoleptic and esthetic attributes.

The EU recently has recommended (McCarthy et al., 2013) that, in order to improve the safety and health aspects of food, food and health research in Europe and other parts of the world should change its focus from "healthy food", i.e., food as a product, to research on "healthy eating", which is concerned with appropriate intake and disease prevention. Coordination of research on this theme, at all global levels and between member states, could deliver major economic and social benefits. Moreover, strengthening the collaboration and interaction between the scientific communities of plant pathology and food safety is essential and could be achieved through creation of an interdisciplinary research coordination network (Fletcher et al., 2013). However, even though there is strong focus on eliminating pathogens from produce at a commercial level, consumers, too, can employ simple methods to achieve additional pathogen reductions in the domestic kitchen (de Jong et al., 2008). Findings of Perez et al. (2012) suggest that EtOH at 70% (v/v) and H_2O_2 at 3% (v/v) may be effective antimicrobials for in-home decontamination of fresh produce, and that use of detergent and warm water is effective for decontamination of utensils used to prepare meals.

Acknowledgment

This is a contribution from the Agricultural Research Organization, the Volcani Center, Bet Dagan, Israel No. 669/13.

Bibliography

Abadias, M., Usall, J., Anguera, M., Solson, C., Vinas, I., 2008. Microbiological quality of fresh, minimally-processed fruit and vegetables, and sprouts from retail establishments. Int. J. Food Microbiol. 123, 121–129.

Abadias, M., Alegre, I., Usall, J., Torres, J., Torres, R., Vinas, I., 2011. Evaluation of alternative sanitizers to chlorine disinfection for reduction foodborne pathogens in fresh-cut apple. Postharvest Biol. Technol. 59, 289–297.

Aguero, M.V., Ponce, A.G., Moreira, M.R., Roura, S.I., 2011. Lettuce quality loss under conditions that favor the wilting phenomenon. Postharvest Biol. Technol. 59, 124–131.

Akbas, M.Y., Olmez, H., 2007. Inactivation of *Escherichia coli* and *Listeria monocytogenes* on iceberg lettuce by dip wash treatments with organic acids. J. Appl. Microbiol. 44, 619–624.

Alegria, C., Pinheiro, J., Goncalves, E.M., Fernandes, I., Moldao, M., Abreu, M., 2010. Evaluation of a pre-cut heat treatment as an alternative to chlorine in minimally processed shredded carrot. Innov. Food Sci. Emerg. Technol. 11, 155–161.

Alexandre, E.M.C., Brandao, T.R.S., Silva, C.L.M., 2012. Efficacy of non-thermal technologies and sanitizer solutions on microbial load reduction and quality retention of strawberries. J. Food Eng. 108, 417–426.

Araújo, P., Lemos, M., Mergulhão, F., Melo, L., Simoes, M., 2011. Antimicrobial resistance to disinfectants in biofilms. Science against microbial pathogens. Communicating Current Research and Technological Advances, pp. 826–834.

Artes, F., Gomez, P., Aguayo, E., Escalona, V., Artes-Hernandez, F., 2009. Sustainable sanitation techniques for keeping quality and safety of fresh cut plant commodities. Postharvest Biol. Technol. 51, 287–296.

Ayala-Zavala, J.F., Del-Toro-Sanchez, L., Alvarez-Parrilla, E., Gonzalez-Aguilar, G.A., 2008. High relative humidity in-package of fresh-cut fruits and vegetables: advantage or disadvantage considering microbiological problems and antimicrobial delivering systems? J. Food Sci. 73, R41–R47.

Badrie, N., Gobin, A., Dookeran, S., Duncan, R., 2006. Consumer awareness and perception to food safety hazards in Trinidad, West Indies. Food Control 17, 370–377.

Bari, M.L., Inatsu, Y., Isobe, S., Kawamoto, S., 2008. Hot water treatments to inactivate *Escherichia coli* O157:H7 and *Salmonella* in mung bean seeds. J. Food Prot. 71, 830–834.

Barreiros dos Santos, M., Agusil, J.P., Prieto-Simon, B., Sporer, C., Teixeira, V., Samitier, J., 2013. Highly sensitive detection of pathogen *Escherichia coli* O157:H7 by electrochemical impedance spectroscopy. Biosens. Bioelectron. 45, 174–180.

Barrera, M.J., Blenkimsop, R., Warriner, K., 2012. The effect of different processing parameters on the efficacy of commercial post-harvest washing of minimally processed spinach and shredded lettuce. Food Control 45, 745–751.

Brichta-Harhay, M.D., Arthur, T.M., Bosilevac, J.M., Guerini, M.N., Kalchayanand, N., Koohmaraie, M., 2007. Enumeration of *Salmonella* and *Escherichia coli* O157:H7 in ground beef, cattle carcass, hide and faecal samples using direct planning methods. J. Appl. Microbiol. 103, 1657–1668.

Cabeca, T.K., Pizzolitto, A.C., Pizzolitto, E.L., 2012. Activity of disinfectants against foodborne pathogens in suspension and adhered to stainless steel surfaces. Braz. J. Microbiol. 43, 1112–1119.

Caleb, O.J., Mahajan, P.V., Al-Julanda Al-Said, F., Opara, U.L., 2013. Modified atmosphere packaging technology of fresh and fresh-cut produce and the microbial consequences – a review. Food Bioprocess. Technol. 6, 303–329.

Campos, C.A., Gerschenson, L.N., Flores, S.K., 2011. Development of edible films and coatings with antimicrobial activity. Food Bioprocess. Technol. 4, 849–875.

Cerioni, L., Sepulveda, M., Rubio-Ames, Z., Volentini, S.I., Rodriguez-Montelongo, L., Smilanick, J.L., et al., 2013. Control of lemon postharvest diseases by low-toxicity salts combined with hydrogen peroxide and heat. Postharvest Biol. Technol. 83, 17–21.

Chattopadhyay, S., Fensterl, V., Zhang, Y., Veleeparambil, M., Wetzel, J.L., Sen, G.C., 2013. Inhibition of viral pathogenesis and promotion of the septic shock response to bacterial infection by IRF-3 are regulated by the acetylation and phosphorylation of its coactivators. mBio 4. Available from: http://doi:10.1128/mBio.00636-12.

Chmielewski, R.A.N., Frank, J.F., 2007. Inactivation of *Listeria monocytogenes* biofilms using chemical sanitizers and heat. In: Blaschek, H.P., Wang, H.H., Agle, M.E. (Eds.), Biofilms in the Food Environment. Blackwell Publishing, Ames, pp. 73–104.

Choi, M.-R., Lee, S.-Y., Park, K.-H., Chung, M.-S., Ryu, S.-R., Kang, D.-H., 2012. Effect of aerosolized malic acid against *Listeria monocytogenes*, *Salmonella typhimurium*, and *Escherichia coli* O157:H7 on spinach and lettuce. Food Control 24, 171–176.

Clarkson, J.J., Rothwell, S.D., Taylor, G., 2005. End of day harvest extends shelf life. HortScience 40, 1431–1435.

de Jong, A., Verhoeff-Bakkenes, L., Nauta, M., de Jong, R., 2008. Cross-contamination in the kitchen: effect of hygiene measures. J. Appl. Microbiol. 105, 615–624.

Desai, P.T., Walsh, M.K., Weimer, B.C., 2008. Solid-phase capture of pathogenic bacteria by using gangliosides and detection with real-time PCR. Appl. Environ. Microbiol. 74, 2254–2258.

Djioua, T., Charles, F., Lopez-Lauri, F., Filgueiras, H., Coudret, A., Freire Jr., M., et al., 2009. Improving the storage of minimally processed mangoes (*Mangifera indica* L.) by hot water treatments. Postharvest Biol. Technol. 52, 221–226.

Domingo, J.L., Gine Bordonaba, J., 2011. A literature review on the safety assessment of genetically modified plants. Environ. Int. 37, 734–742.

Du, J., Han, Y., Linton, R.H., 2003. Efficacy of chlorine dioxide gas in reducing *Escherichia coli* O157:H7 on apple surfaces. Food Microbiol. 20, 583–591.

Durango, A.M., Soares, N.F., Andrade, N.J., 2006. Microbiological evaluation of an edible antimicrobial coating on minimally processed carrots. Food Control 17, 336–341.

Dutta, P.K., Tripathi, S., Mehrotra, G.K., Dutta, J., 2009. Perspectives for chitosan based antimicrobial films in food applications. Food Chem. 114, 1173–1182.

D'lima, C.V., Suslow, T.V., 2009. Comparative evaluation of practical functionality of rapid test format kits for detection of *Escherichia coli* O157:H7 on lettuce and leafy greens. J. Food Prot. 72, 2461–2470.

EFSA/ECDC (European Food Safety Authority/European Centre for Disease Control), 2012. The European Union summary report on trends and sources of zoonoses, zoonotic agents and foodborne outbreaks in 2010. EFSA J. 10, 2597–3039.

Elizaquível, P., Azizkhani, M., Aznar, R., Sánchez, G., 2013. The effect of essential oils on norovirus surrogates. Food Control 32, 275–278.

Ergonul, B., 2013. Consumer awareness and perception to food safety: a consumer analysis. Food Control 32, 461–471.

Escalona, V.H., Aguayo, E., Martínez-Hernández, G.B., Artés, F., 2010. UV-C doses to reduce pathogen and spoilage bacterial growth in vitro and in baby spinach. Postharvest Biol. Technol. 56, 223–231.

Fallik, E., Rodov, V., Horev, B., Sela, S., Alkalai-Tuvia, S., Vinokur, Y., 2007. Hot water rinsing and brushing technology for the fresh-cut industry. Acta. Hortic. 746, 229–235.

Fan, X., Annous, B.A., Sokorai, K.J.B., Burke, A., Mattheis, J.P., 2006. Combination of hot-water surface pasteurization of whole fruit and low-dose gamma irradiation of fresh-cut cantaloupe. J. Food Prot. 69, 912–919.

Fan, X., Niemira, B.A., Prakash, A., 2008. Irradiation of fresh fruits and vegetables. Food Technol. 62, 36–43.

Fletcher, J., Leach, J.E., Eversole, K., Tauxe, R., 2013. Human pathogens on plants: designing a multidisciplinary strategy for research. Phytopathology 103, 306–315.

Forslund, A., Ensink, J.H.J., Markussen, B., Battilani, A., Psarras, G., Gola, S., et al., 2012. *Escherichia coli* contamination and health aspects of soil and tomatoes (*Solanum lycopersicum* L.) subsurface drip irrigated with on-site treated domestic wastewater. Water Res. 46, 5917–5934.

Fukuyama, S., Watanabe, Y., Kondo, N., Nishinomiya, T., Kawamoto, S., Isshiki, K., et al., 2009. Efficiency of sodium hypochlorite and calcinated calcium in killing *Escherichia coli* O157:H7, *Salmonella* spp., and *Staphylococcus aureus* attached to freshly shredded cabbage. Biosci. Biotechnol. Biochem. 73, 9–14.

Ge, C., Bohrerova, Z., Lee, J., 2013. Inactivation of internalized *Salmonella typhimurium* in lettuce and green onion using ultraviolet C irradiation and chemical sanitizers. J. Appl. Microbiol. 114, 1415–1424.

Golan, E., Unnevehr, L., 2008. Food product composition, consumer health, and public policy: introduction and overview of special section. Food Policy 33, 465–469.

Gomes, C., Da Silva, P., Moreira, R.G., Castell-Perez, E., Ellis, E.A., Pendleton, M., 2009. Understanding *E. coli* internalization in lettuce leaves for optimization of irradiation treatment. Int. J. Food Microbiol. 135, 238–247.

Gómez-López, V.M., Rajkovic, A., Ragaert, P., Smigic, N., Devlieghere, F., 2009. Chlorine dioxide for minimally processed produce preservation: a review. Trends Food Sci. Technol. 20, 17–26.

Grasso, E.M., Uribe-Rendon, R.M., Lee, K., 2011. Inactivation of *Escherichia coli* inoculated onto fresh-cut chopped cabbage using electron-beam processing. J. Food Prot. 74, 115–118.

Guan, X.-Q., Fan, X.-T., Yan, R.-X., 2012. Effects of UV-C treatment on inactivation of *Escherichia coli* O157:H7, microbial loads, and quality of button mushrooms. Postharvest Biol. Technol. 64, 119–125.

Gutierrez-Rodrıguez, E., Gundersen, A., Sbodio, A.O., Suslow, T.V., 2012. Variable agronomic practices, cultivar, strain source and initial contamination dose differentially affect survival of *Escherichia coli* on spinach. J. Appl. Microbiol. 112, 109–118.

Ha, J.-H., Ha, S.-D., 2011. Synergistic effects of sodium hypochlorite and ultraviolet radiation in reducing the levels of selected foodborne pathogenic bacteria. Foodborne Pathog. Dis. 8, 587–591.

Hadjok, C., Mittal, G.S., Warriner, K., 2008. Inactivation of human pathogens and spoilage bacteria on the surface and internalized within fresh produce by using a combination of ultraviolet light and hydrogen peroxide. J. Appl. Microbiol. 104, 1014–1024.

Harris, L.J., Bender, J., Bihn, E.A., Blessington, T., Danyluk, M.D., DeLaquis, P., et al., 2012. A framework for developing research protocols for evaluation of microbial hazards and controls during production that pertain to the quality of agricultural water contacting fresh produce that may be consumed raw. J. Food Prot. 75, 2251–2273.

Hassenberg, K., Froehling, A., Geyer, M., Schlueter, O., Herppich, W.B., 2008. Ozonated wash water for inhibition of *Pectobacterium carotovorum* on carrots and the effect on physiological behaviour of produce. Eur. J. Hortic. Sci. 73, 37–42.

Havens, E.K., Martin, K.S., Yan, J., Dauser-Forrest, D., Ferris, A.M., 2012. Federal nutrition program changes and healthy food availability. Am. J. Prev. Med. 43, 419–422.

Hochel, I., Slavickova, D., Viochna, D., Skvor, J., Steinhauserova, I., 2007. Detection of Campylobacter species in foods by indirect competitive ELISA using hen and rabbit antibodies. Food Agri. Immunol. 18, 151–167.

Horev, B., Sela, S., Vinokur, Y., Gorbatsevich, E., Pinto, R., Rodov, V., 2012. The effects of active and passive modified atmosphere packaging on the survival of *Salmonella enterica* serotype Typhimurium on washed romaine lettuce leaves. Food Res. Int. 45, 1129–1132.

Horvitz, S., Cantalejo, M.J., 2012. Effects of ozone and chlorine postharvest treatments on quality of fresh-cut red bell peppers. Int. J. Food Sci. Technol. 47, 1935–1943.

Hrudey, S.E., 2009. Chlorination disinfection by-products, public health risk tradeoffs and me. Water Res. 43, 2057–2092.

Huang, Y., Ye, M., Chen, H., 2013. Efficacy of washing with hydrogen peroxide followed by aerosolized antimicrobials as a novel sanitizing process to inactivate *Escherichia coli* O157:H7 on baby spinach. Int. J. Food Microbiol. 153, 306–313.

Jechorek, R.P., Johnson, R.L., 2008. Evaluation of the VIDAS (R) staph enterotoxin II (SET 2) immunoassay method for the detection of Staphylococcal enterotoxins in selected foods: collaborative study. J. AOAC Int. 91, 164–173.

Jevsnik, M., Ovca, A., Bauer, M., Fink, R., Oder, M., Sevsek, F., 2013. Food safety knowledge and practices among elderly in Slovenia. Food Control 31, 184–190.

Jia, C., Jukes, D., 2013. The national food safety control system of China – a systematic review. Food Control 32, 236–245.

Kay, D., Crowther, J., Fewtrell, L., Francis, C., Hopkins, M., Kay, C., et al., 2008. Quantification and control of microbial pollution from agriculture: a new policy challenge? Environ. Sci. Policy 11, 171–184.

Kerr, H., 2009. Commercial household disinfectant inactivation of *Bacillus cereus* spores on fruit and vegetable surface. Master's Thesis, University of Tennessee at: <http://trace.Tennessee.edu/utk_gradthes/39> (accessed May, 2010).

Keskinen, L.A., Annous, B.A., 2011. Efficacy of adding detergents to sanitizer solutions for inactivation of *Escherichia coli* O157:H7 on Romaine lettuce. Int. J. Food Microbiol. 147, 157–161.

Keskinen, L.A.B.A., Annous, B.A., 2009. Efficacy of chlorine, acidic electrolyzed water and aqueous chlorine dioxide solutions to decontaminate *Escherichia coli* O157:H7 from lettuce leaves. Int. J. Food Microbiol. 132, 134–140.

Kirezieva, K., Jacxsens, L., Uyttendaele, M., Van Boekel, M.A.J.S., Luning, P.A., 2013. Assessment of food safety management systems in the global fresh produce chain. Food Res. Int. 52, 230–242.

Koide, S., Shi, J., 2007. Microbial and quality evaluation of green peppers stored in biodegradable film packaging. Food Control 18, 1121–1125.

Koutchma, T., 2009. Advances in ultraviolet light technology for non-thermal processing of liquid foods. Food Bioprocess. Technol. 2, 138–155.

Kuda, T., Yano, T., Kuda, M.T., 2008. Resistances to benzalkonium chloride of bacteria dried with food elements on stainless steel surface. LWT – Food Sci. Technol. 41, 988–993.

Linman, M.J., Sugerman, K., Cheng, Q., 2010. Detection of low levels of *Escherichia coli* in fresh spinach by surface plasmon resonance spectroscopy with a TMB-based enzymatic signal enhancement method. Sens. Actuators B. Chem. 145, 613–619.

Lynch, M., Tauxe, R.V., Hedberg, C., 2009. The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. Epidemiol. Infect. 137, 307–315.

Magliulo, M., Simoni, P., Guardigli, M., Michelini, E., Luciani, M., Lelli, R., et al., 2007. A rapid multiplexed chemiluminescent immunoassay for the detection of *Escherichia* *coli* O157: H7, *Yersinia enterocolitica, Salmonella typhimurium*, and *Listeria monocytogenes* pathogen bacteria. J. Agri. Food Chem. 55, 4933–4939.

Magnuson, B.A., Jonaitis, T.S., Card, J.W., 2011. A brief review of the occurrence, use, and safety of food-related nanomaterials. J. Food Sci. 76, R126–R133.

Mahajan, P.V., Oliveira, F.A.R., Montanez, J.C., Iqbal, T., 2008. Packaging design for fresh produce: an engineering approach. New Food 1, 35–36.

Mahmoud, B.S.M., 2010. Effects of X-ray radiation on *Escherichia coli* O157:H7, *Listeria monocytogenes, Salmonella enterica* and *Shigella flexneri* inoculated on shredded iceberg lettuce. Food Microbiol. 27, 109–114.

Mahmoud, B.S.M., Bhagat, A.R., Linton, R.H., 2007. Inactivation kinetics of inoculated *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Salmonella enterica* on strawberries by chlorine dioxide gas. Food Microbiol. 24, 736–744.

Malorny, B., Lofstrom, C., Wagner, M., Kramer, N., Hoorfar, J., 2008. Enumeration of *Salmonella* bacteria in food and feed samples by real-time PCR for quantitative microbial risk assessment. Appl. Environ. Microbiol. 74, 1299–1304.

Mangaraj, S., Goswami, T.K., Mahajan, P.V., 2009. Application of plastic films for modified atmosphere packaging of fruits and vegetables: a review. Food. Eng. Rev. 1, 133–158.

Martin, H., Maris, P., 2012. Synergism between hydrogen peroxide and seventeen acids against six bacterial strains. J. Appl. Microbiol. 113, 578–590.

Martínez-Téllez, M.A., Rodríguez-Leyva, F.J., Espinoza-Medina, I.E., Vargas-Arispuro, I., Gardea, A.A., González-Aguilar, G.A., et al., 2009. Sanitation of fresh green asparagus and green onions inoculated with *Salmonella*. Czech J. Food Sci. 27, 454–462.

Massilia, R.M., Melgar, M.J., Belloso, M.O., 2009. Antimicrobial activity of malic acid against L*isteria monocytogenes, Salmonella enteritidis* and *Escherichia coli* O157:H7 in apple, pear and melon juices. Food Control 20, 105–112.

McCarthy, M., Cluzel, E., Dressel, K., Newton, R., 2013. Food and health research in Europe: structures, gaps and futures. Food Policy 39, 64–71.

McGill, C.R., Keast, D.R., Painter, J.E., Romano, C.R., Wightman, J.D., 2013. Improved diet quality and increased nutrient intakes associated with grape product consumption by U.S. children and adults: national health and nutrition examination survey 2003 to 2008. J. Food Sci. 78S, A1–A4.

Medina, M.S., Tudela, J.A., Marín, A., Allende, A., Gil, M.I., 2012. Short postharvest storage under low relative humidity improves quality and shelf life of minimally processed baby spinach (*Spinacia oleracea* L.). Postharvest Biol. Technol. 67, 1–9.

Monique, L., Samia, A., Dominic, D., Melanie, T., Stephane, S., Takala, P., et al., 2013. Irradiation in combined treatments and food safety. J. Radioanal Nuclear Chem. 296, 1065–1069.

Moreira, M.R., Roura, S.I., Ponce, A., 2011. Effectiveness of chitosan edible coatings to improve microbiological and sensory quality of fresh cut broccoli. LWT– Food Sci. Technol. 30, 1–7.

Mucchetti, G., Bonvini, B., Francolino, S., Neviani, E., Carminati, D., 2008. Effect of washing with a high pressure water spray on removal of *Listeria innocua* from Gorgonzola cheese rind. Food Control 19, 521–525.

Nei, D., Latiful Bari, M., Enomoto, K., 2013. Validation of hot water and chlorine treatments to inactivate pathogens inoculated on mung bean seeds: influence of the seed production area. Food Control 32, 186–189.

Olaimat, A.N., Holley, R.A., 2012. Factors influencing the microbial safety of fresh produce: a review. Food Microbiol. 32, 1–19.

Olmez, H., Kretzschmar, U., 2009. Potential alternative disinfection methods for organic fresh-cut industry for minimizing water consumption and environmental impact. LWT — Food Sci. Technol. 42, 686—693.

Osaili, T.M., Abu Jamous, D.O., Obeidat, B.A., Bawadi, H.A., Tayyem, R.F., Subih, H.S., 2013. Food safety knowledge among food workers in restaurants in Jordan. Food Control 31, 145—150.

Ozdemir, H.O., Buzoglu, H.D., Calt, S., Stabholz, A., Steinberg, D., 2010. Effect of ethylenediaminetetraacetic acid and sodium hypochlorite irrigation on *Enterococcus faecalis* biofilm colonization in young and old human root canal dentin: in vitro study. J. Endod. 36, 842—846.

O'Grady, J., Sedano-Balbas, S., Maher, M., Smith, T., Barry, T., 2008. Rapid real-time PCR detection of *Listeria monocytogenes* in enriched food samples based on the SSR A gene, a novel diagnostic target. Food Microbiol. 25, 75—84.

Pangloli, P., Hung, Y.-C., Beuchat, L.R., King, C.H., Zhao, Z.H., 2009. Reduction of *Escherichia coli* O157:H7 on produce by use of electrolyzed water under simulated food service operation conditions. J. Food Prot. 72, 1854—1861.

Park, E.J., Gray, P.M., Oh, S.W., Kronenberg, J., Kang, D.H., 2008. Efficacy of FIT produce wash and chlorine dioxide on pathogen control in fresh potatoes. J. Food Sci. 73, 278—282.

Pascual, A., Llorca, I., Canut, A., 2007. Use of ozone in food industries for reducing the environmental impact of cleaning and disinfection activities. Trends Food Sci. Technol. 18, S29—S35.

Perez, K.L., Lucia, L.M., Cisneros-Zevallos, L., Castillo, A., Taylor, T.M., 2012. Efficacy of antimicrobials for the disinfection of pathogen contaminated green bell pepper and of consumer cleaning methods for the decontamination of knives. Int. J. Food Microbiol. 156, 76—82.

Perry, J.J., Yousef, A.E., 2011. Decontamination of raw foods using ozone-based sanitization techniques. Annu. Rev. Food Sci. Technol. 2, 281—298.

Pushkala, R., Parvathy, K.R., Srividya, N., 2012. Chitosan powder coating, a novel simple technique for enhancement of shelf life quality of carrot shreds stored in macro perforated LDPE packs. Innov. Food Sci. Emerg. Technol. 16, 11—20.

Ramírez-Rodrigues, M.M., Plaza, M.L., Ferrentino, G., Balaban, M.O., Reyes-De Corcuera, J.I., Marshall, M.R., 2013. Effect of dense phase carbon dioxide processing on microbial stability and physicochemical attributes of *Hibiscus sabdariffa* beverage. J. Food Process Eng. 36, 125—133.

Ray, S., Jin, T., Fan, X., Liu, L., Yam, K.L., 2013. Development of chlorine dioxide releasing film and its application in decontaminating fresh produce. J. Food Sci. 78, M276—M284.

Rico, D., Martin-Diana, A.B., Barat, J.M., Barry-Ryan, C., 2007. Extending and measuring the quality of fresh-cut fruit and vegetables: a review. Trends Food Sci. Technol. 18, 373—386.

Riyaz-Ul-Hassan, S., Verma, V., Qazi, G.N., 2008. Evaluation of three different molecular markers for the detection of *Staphylococcus aureus* by polymerase chain reaction. Food Microbiol. 25, 452—459.

Rosenblum, J., Ge, C., Bohrerova, Z., Yousef, A., Lee, J., 2012. Ozonation as a clean technology for fresh produce industry and environment: sanitizer efficiency and wastewater quality. J. Appl. Microbiol. 113, 837—845.

Sadik, O.A., Aluoch, A.O., Zhou, A., 2009. Status of biomolecular recognition using electrochemical techniques. Biosens. Bioelectron. 24, 2749–2765.

Sagong, H.-G., Cheon, H.-L., Kim, S.-O., Lee, S.-Y., Park, K.-H., Chung, M.-S., et al., 2013. Combined effects of ultrasound and surfactants to reduce *Bacillus cereus* spores on lettuce and carrots. Int. J. Food Microbiol. 160, 367–372.

Sanders, S.Q., Boothe, D.H., Frank, J.F., Arnold, J.W., 2007. Culture and detection of *Campylobacter jejuni* within mixed microbial populations of biofilms on stainless steel. J. Food Prot. 70, 1379–1385.

Sandhya, 2010. Modified atmosphere packaging of fresh produce: current status and future needs. LWT – Food Sci. Technol. 43, 381–392.

Scharff, R.L., 2012. Economic burden from health losses due to foodborne illness in the United States. J. Food Prot. 75, 123–131.

Scheutz, F., Nielsen, E.M., Frimodt-Møller, J., Boisen, N., Morabito, S., Tozzoli, R., et al., 2011. Characteristics of the entero aggregative Shiga toxin/verotoxin-producing *Escherichia coli* O104:H4 strain causing the outbreak of haemolytic uraemic syndrome in Germany, May to June 2011. Eurosurveillance 16, <http://www.eurosurveillance.org/images/dynamic/EE/V16N24/art19889.pdf> (accessed 16.11.11) pii:19889.

Schnabel, U., Nijana, R., Krohmann, U., Winter, J., Schluter, O., Weltmann, K.D., et al., 2012. Decontamination of microbiologically contaminated specimen by direct and indirect plasma treatment. Plasma Process. Polym. 9, 569–575.

Selma, M.V., Beltran, D., Chacon-Vera, E., Gil, M.I., 2006. Effect of ozone on the inactivation of *Yersinia enterocolitica* and the reduction of natural flora on potatoes. J. Food. Prot. 69, 2357–2363.

Selma, M.V., Beltran, D., Allende, A., Chacon-Vera, E., Gil, M.I., 2007. Elimination by ozone of *Shigella sonnei* in shredded lettuce and water. Food Microbiol. 24, 492–499.

Selma, M.V., Ibanes, A.M., Allende, A., Cantwell, M., Suslow, T., 2008. Effect of gaseous ozone and hot water on microbial and sensory quality of cantaloupe and potential transference of *Escherichia coli* O157:H7 during cutting. Food Microbiol. 25, 162–168.

Setterington, E.B., Alocilja, E.C., 2012. Electrochemical biosensor for rapid and sensitive detection of magnetically extracted bacterial pathogens. Biosensors 2, 15–31.

Shen, Z.-Q., Wang, J.-F., Qiu, Z.-G., Jin, M., Wang, X.-W., Chen, Z.-L., et al., 2011. QCM immunosensor detection of *Escherichia coli* O157:H7 based on beacon immunomagnetic nanoparticles and catalytic growth of colloidal gold. Biosens. Bioelectron. 26, 3376–3381.

Shikongo-Nambabi, M., Kachigunda, B., Venter, S.N., 2010. Evaluation of oxidising disinfectants to control Vibrio biofilms in treated seawater used for fish processing. Water SA 36, 215–220.

Shim, W.-B., Je, G.-S., Kim, K., Mtenga, A.B., Lee, W.-G., Song, J.-U., et al., 2012. Effect of irradiation on kinetic behavior of *Salmonella typhimurium* and *Staphylococcus aureus* in lettuce and damage of bacterial cell envelope. Radiat. Phys. Chem. 81, 566–571.

Siddiqui, M.W., Chakraborty, I., Ayala-Zavala, J.F., Dhua, R.S., 2011. Advances in minimal processing of fruits and vegetables: a review. J. Sci. Ind. Res. 70, 823–834.

Silveira, A.C., Aguayo, E., Chisan, M., Artes, F., 2011a. Calcium salts and heat treatment for quality retention of fresh-cut 'Galia' melon. Postharvest Biol. Technol. 62, 77–84.

Silveira, A.C., Aguayo, E., Escalona, V.H., Artes, F., 2011b. Hot water treatment and peracetic acid to maintain fresh-cut Galia melon quality. Innov. Food Sci. Emerg. Technol. 12, 569–576.

Simoes, M., Simoes, L.C., Vieira, M.J., 2010. A review of current and emergent biofilm control strategies. LWT – Food Sci. Technol. 43, 573–583.

Soon, J.M., Seaman, P., Baines, R.N., 2013. *Escherichia coli* O104:H4 outbreak from sprouted seeds. Int. J. Hyg. Environ. Health 216, 346–354.

Srey, S., Jahid, I.K., Ha, S.-D., 2013. Biofilm formation in food industries: a food safety concern. Food Control 31, 572–585.

Stefanova, R., Vasilev, N.V., Spassov, S.L., 2010. Irradiation of food, current legislation framework, and detection of irradiated foods. Food Anal. Methods 3, 225–252.

Strawn, L.K., Schneider, K.R., Danyluk, M.D., 2011. Microbial safety of tropical fruits. Crit. Rev. Food Sci. Nutr. 51, 132–145.

Subramanian, R., Khlystov, A.Y., Robinson, A.L., 2006. Effect of peak inert-mode temperature on elemental carbon measured using thermal–optical analysis. Aerosol Sci. Technol. 40, 763–780.

Teplitski, M., Warriner, K., Bartz, J., Schneider, K.R., 2011. Untangling metabolic and communication networks: interactions of enterics with phytobacteria and their implications in produce safety. Trends Microbiol. 19, 121–127.

Tomás-Callejas, A., López-Gálvez, F., Sbodio, A., Artés, F., Artés-Hernández, F., Suslow, T.V., 2012. Chlorine dioxide and chlorine effectiveness to prevent *Escherichia coli* O157:H7 and *Salmonella* cross-contamination on fresh-cut Red Chard. Food Control 23, 325–332.

Toté, K., Horemans, T., Vanden Berghe, D., Maes, L., Cos, P., 2010. Inhibitory effect of biocides on the viable masses and matrices of *Staphylococcus aureus* and *Pseudomonas aeruginosa* biofilms. Appl. Environ. Microbiol. 76, 3135–3142.

Trinetta, V., Morgan, M.T., Linton, R.H., 2010. Use of high-concentration-short-time chlorine dioxide gas treatments for the inactivation of *Salmonella enterica* spp. inoculated onto Roma tomatoes. Food Microbiol. 27, 1009–1015.

Van Boxstael, S., Habib, I., Jacxsens, L., De Vocht, M., Baert, L., Van De Perre, E., et al., 2013. Food safety issues in fresh produce: bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. Food Control 32, 190–197.

Van Haute, S., Sampers, I., Holvoet, K., Uyttendaele, M., 2013. Physicochemical quality and chemical safety of chlorine as a reconditioning agent and wash water disinfectant for fresh-cut lettuce washing. Appl. Environ. Microbiol. 79, 2850–2861.

Velusamy, V., Arshak, K., Korostynska, O., Oliwa, K., Adley, C., 2010. An overview of foodborne pathogen detection: in the perspective of biosensors. Biotechnol. Adv. 28, 232–254.

Vidal, J.C., Bonel, L., Ezquerra, A., Hemandez, S., Bertolin, J.R., Cubel, C., et al., 2013. Electrochemical affinity biosensors for detection of mycotoxins: a review. Biosens. Bioelectron. 49, 146–158.

Walker, J.T., Marsh, P.D., 2007. Microbial biofilm formation in DUWS and their control using disinfectants. J. Dent. 35, 721–730.

Warriner, K., Huber, A., Namvar, A., Fan, W., Dunfield, K., 2009. Recent advances in the microbial safety of fresh fruits and vegetables. Adv. Food Nutr. Res. 57, 155–208.

Wert, E.C., Rosario-Ortiz, F.L., Drury, D.D., Snyder, S.A., 2007. Formation of oxidation byproducts from ozonation of wastewater. Water Res. 41, 1481–1490.

WHO (World Health Organization), 2011a. Foodborne outbreaks: managing the risks. Bull. World Health Organ. 89, 554–555, <http://www.who.int/bulletin/volumes/89/8/11-040811/en/index.html>.

WHO (World Health Organization), 2011b. International health regulations. Outbreaks of *E. coli* O104:H4: update 30. <http://www.euro.who.int/en/whatwe-do/health-topics/emergencies/international-health-regulations/news/news/2011/07/outbreaks-of-e.-coli-o104h4-infection-update-30>.

Wiederoder, M.S., Liu, N., Lefcourt, A.M., Kim, M.S., Martin, L.Y., 2013. Use of a portable hyperspectral imaging system for monitoring the efficacy of sanitation procedures in produce processing plants. J. Food Eng. 117, 217−226.

Yamashoji, S., Yoshikawa, N., Kirihara, M., Tsuneyoshi, T., 2013. Screening test for rapid food safety evaluation by menadione-catalysed chemiluminescent assay. Food Chem. 138, 2146−2151.

Ye, J.X., Kostrzynska, M., Dunfield, K., Warriner, K., 2010. Control of *Salmonella* on sprouting mung bean and alfalfa seeds by using a biocontrol preparation based on antagonistic bacteria and lytic bacteriophages. J. Food Prot. 73, 9−17.

Ye, K., Wang, H., Zhang, X., Jiang, Y., Xu, X., Zhou, G., 2013. Development and validation of a molecular predictive model to describe the growth of *Listeria monocytogenes* in vacuum-packaged chilled pork. Food Control 32, 246−254.

Zhang, R., Ying, Y., Raoa, X., Li, J., 2012. Quality and safety assessment of food and agricultural products by hyperspectral fluorescence imaging. J. Sci. Food Agri. 92, 2397−2408.

This page intentionally left blank

CHAPTER

Sorting for Defects

12

A. Frank Bollen[a] and Stanley E. Prussia[b]

[a]*Zespri International Ltd, Mt Maunganui, New Zealand* [b]*University of Georgia, College of Engineering, Athens, Georgia, USA*

I Introduction

A Reasons for sorting

Modern industrialized supply chains have many established criteria and for producers to be competitive, they must meet the specified requirements. Buyers will pay premium prices for fruit and vegetables of uniform size and color. In general, items should not be misshapen or bruised and should be free of blemishes, diseases and mechanical damage. For exporters, many international and national quarantine regulations must also be met for insects and diseases. Product that will be stored for any length of time prior to marketing must also meet criteria for maturity, firmness, and damage to ensure storability (see also Chapters 13 and 14). These quality specifications have been established primarily to protect members of supply chains and ensure a saleable product arrives at the consumer.

Consumer perception of quality is highly variable and changes for many reasons, for example, time of year, supply of product, supply of other products, and end use (see Chapters 3 and 10). Although initial product quality is determined by the producer, the dynamic parameters of price and quality requirements are established largely by the retailer and consumer.

To assist both the seller and the buyer, many public agencies and marketing organizations have developed standards for the grades of most horticultural crops (see Chapters 1, 6 and 8). The documents commonly are called “grade standards” and include one or more sets of specifications and tolerances. Compliance with a specific set of requirements in the grade standard enables the lot to be sold as a shipment labeled with the specified grade, for example, U.S. Extra Fancy, Fancy, No. 1, or Utility. When required, a third party inspector evaluates samples from each lot shipped by a seller before certifying that the lot complies with the grade standard specified.

The application of grade standards in supply chains is essential to codify the quality attributes of a product that are acceptable; (a) to meet some supply chain requirement, such as storage or transport performance, or (b) that are considered acceptable to the consumer or buyer. Many such attributes have not been tested

Postharvest Handling.

specifically with consumers, but more often change over time based on experience and the expert opinion of marketers and others involved in each supply chain. Kusabs et al. (2006) investigated the relationship between sorters of mushrooms and consumer's ratings of the same product. There was little relationship between the two. The sorters were applying a set of attributes to sort against which differed from the visual attributes applied by the consumers. Jahns et al. (2001) attempted to use mapping of fuzzy image analysis attributes to predict consumer assessments of quality and used this approach as a technique to grade product that directly met consumer expectations.

The sorting operation must be viewed in the context of overall postharvest supply chains. It is important to understand how cultural practices and uncontrolled inputs such as weather cause variation of quality of products that enter the packinghouse. Likewise, at the time of shipping, it is important to be able to predict the quality of shipments as they progress through the rest of a postharvest supply chain. A major function of a packinghouse is to transform the highly variable product received from the harvesting operation into uniform lots of product for shipments that comply with the requirements of the buyer. The importance of the sorting operation cannot be overstated, since variations in this operation will affect returns for most parts of other postharvest supply chains.

B Sorting terminology

The following terminology is applied in this chapter. *Separation* is the removal of non-usable material from usable product. An early operation in packinghouses is the separation of debris and inedible items from the flow of marketable product. Separations are generally made with mechanical devices such as sizers, blowers, and washers.

Sorting is the segregation of edible or marketable product into distinct quality categories. Sorting of the marketable items is accomplished by both mechanical equipment (sizers or color sorters) and by human means (visual or tactile). The equipment used for sorting is referred to as a *sorting line*. People who perform sorting operations are referred to as *sorters*. *Graders* are the third party inspectors who evaluate whether or not the packed lot complies with requirements of a grade standard for a predetermined grade classification. *Inspection* of samples for this quality control process is more precise than, and differs from, the dynamic inspection of product necessary for sorting.

II Design and operation of manual sorting equipment

The basic manual sorting operation has developed over a long period of time. Most design and operating conditions have been determined by trial and error for parameters such as table width, table speed, number of sorters and speed of product rotation. Different products place different requirements on the system. Most sorting operations are still performed by human visual inspection of the product and manual removal of items with defects. Humans have unique abilities for identifying defects and for determining whether they exceed prescribed threshold criteria.

A typical sorting operation consists of a continuous flow of product passing in front of one or more stationary sorters (Figure 12.1). Normally, the task of the sorter is to remove items that do not meet the specifications for the lot being shipped. Nonconforming items are placed into a discard flow and items meeting other specifications are placed on separate conveyers that may flow to packing areas for lower-quality markets. The design of sorting equipment has a considerable effect on the efficiency of the sorter in detecting and removing defective items.

The interrelationship between physical design parameters, the productivity and accuracy of the sorters and the quality of the product are only partially understood (Prussia and Meyers, 1989), yet the result of the sorting operation has significant effect on postharvest supply chains. The authors of a book chapter on machine vision (Eissa and Khalik, 2012, p. 229) recognize that manual sorting currently achieves the best performance even though human sorting is costly and often inconsistent.

A sorting table should be designed at a height that is comfortable for the sorter to reach product on both sides of the table, and it should be easy to deposit rejects on the appropriate belt or in the appropriate chute. The design philosophy is to minimize hand movements to enable rapid location and removal of defective items. Also, hand movements should occur within a comfortable envelope of space. Dreyfus (1967) provides information indicating that the sorters should be positioned so that an angle of 45° is measured between the center of the table and

FIGURE 12.1

Typical sorting operation — well lit, with narrow tables and number of tables and sorters used matched to fruit flow and defect levels.

the shoulder. Also see Openshaw and Taylor (2006), Tilley and Henry Dreyfuss Associates (2002), Chaffin et al. (1999) and Woodson et al. (1992).

The most efficient sorting operations require two sorters per table for a line carrying products with low levels of defects. A good design allows accommodation of additional sorters in the event of high defect rates in the product. Sorting productivity is reduced if the sorters stand directly opposite one another, since they tend to compete for the same product and do not use the full width of the table properly. Research with kiwifruit on a table 0.8 m wide showed that the proportion of the defective fruit removed was 96% when the sorters were staggered and fell to 68% when the sorters were standing directly opposite each other (Bollen, 1986).

Research with simulated fruit (Meyers et al., 1990a) showed a 23% improvement in defect detection for sorters positioned at the end of an inspection conveyor compared with sorters positioned at the sides. Approximately two-thirds of the improvement was shown to result from the ability to see more of the surface area when at the end than when at the side.

Translation speed is the velocity at which products pass the sorter. If the feed rate for incoming items is constant, then changes in translation speed will vary the amount of product on the table at a given time (Prussia, 1985). Changing the translation speed must be done with caution since it is unsettling for sorters if speed is adjusted frequently. However, human sorters have the ability to adapt to a wide range of steady speeds. The limiting factors appear to be overflowing the table with product when operating at a low speed, and rotating the fruit too fast at a high translation speed. Most researchers suggest speeds of 6.5−9.0 m/min.

The quantity of product is often described in terms of product density on the table (kg/m^2 or fruit/m^2) or in terms of number of fruit per row. Loading can be regulated by adjusting the translation speed or the product feed rate. Loading should be regulated to ensure the capability of the sorters to maintain a desired accuracy, and to ensure that sufficient product can be handled when incoming quality has a high reject level. Product loading is generally between three and five fruit per row, irrespective of table width.

To achieve effective sorting, the product must be rotated in front of the sorter. It is desirable to rotate the fruit completely at least twice within the immediate field of view. The maximum rotational speed at which sorters can operate effectively is determined partly by the size and types of defects being removed but, in general, rotational speeds above 50 rev/min are detrimental.

A Lighting

Correct lighting is critical for an efficient sorting operation (Guyer et al., 1994). It improves defect detectability and reduces eye strain. Low-intensity light makes perception of contrasts difficult. A study on lighting for fruit sorting by Nicholson (1985) recommended a uniform light level of at least 1000 lux at the table.

Fluorescent tubes are used most commonly. If they are mounted 1.5 m above the table, there is minimum glare and the whole area is well lit. When it is necessary to mount lights at or below eye level to avoid shadowing, the lights should be fitted with deflectors and diffusers to direct a diffuse light onto the table where it is required, and not into the eyes of sorters. Both Guyer et al. (1994) and Nicholson (1985) also suggest that the surroundings should be well lit. When sorters look up from the table, their eyes adjust to the light intensity of the background. Background light of a similar intensity helps reduce eye strain. Neutral-colored walls help reflect diffuse light back to the table. Sorting products on white belts can produce glare or high reflectivity of the incident light. Dark, dull belts can ease eye strain and improve the visibility of the product.

If determining product color is important, then it is necessary to use lights that produce a spectrum similar to that of daylight. In the extreme case, green light falling on a red surface will make the surface appear dark to the eye, since most of the light at these wavelengths will be absorbed by the surface. Making accurate decisions based on dark images is difficult. Unfortunately, "cool white" fluorescent tubes have a high intensity but a blue bias, which makes products appear excessively green.

B Defect type

The types of defects have significant effects on the optimum operating parameters. Some simulated products could be sorted at very high throughput rates of 5.3 fruits/s (Meyers et al., 1990b), and 7.0−11.6 fruits/s (Hunter and Yaeger, 1970). These simulated defects tended to be limited to one or two types, and usually were all of similar size. A real sorting operation encounters a large range of defect types; sorters must make decisions on the severity of each. This additional decision process results in a significant slowing in the potential product throughput. Typical throughput rates with real product are reported as 2.0 fruit/s (Pasternak et al., 1989), 1.0 fruit/s (Stevens and Gale, 1970), and 1.6 fruit/s (Bollen, 1986).

C Visual perception

The ability of humans to perceive a visual image depends on both physical and cognitive factors (Prussia, 1991). Changes in the color and intensity of light change the image received by the eye. The method of presenting the product to the sorters also has an important effect on perception. If product speed (either translation or rotation) is too fast, it is not possible to fixate properly on a defect; hence, it is not possible to reach a decision about whether or not the item should be rejected.

Any vision difficulties adversely influence the detection of defects. Both visual acuity and visual processing ability declines as people age (Ip, 2011). Visual acuity typically declines 26% by the age of 60. Significantly more light is required with increasing age. A 40-year-old needs twice the light of a 20-year-old and a 60-year-old needs five to six times as much light. Older workers need more time to achieve accuracy. Compared with a 20-year-old worker: a 40-year-old requires 120% as much time; a 50-year-old requires 160% as much time; and a 60-year-old requires 270% as much time.

Vision examinations for sorters are useful for determining problems with visual acuity, peripheral vision and color blindness. Also, the inability to concentrate for long periods of time results in a relaxing of vigilance, which is an important factor of visual perception. These human factors can lead to highly variable performance between sorters and also variable performance over time.

III Automated sorting

While most sorting operations world-wide are still manual, they are now being progressively supplemented with automated sorting based on computer vision. These systems are typically implemented to perform pre-sorting operations to reduce the number and range of defects that human (manual) sorters need to work with. A typical system is shown in Figure 12.2. Fruit is received after the bin dump and cleaning brushes and carried on a singulated conveyor under a hood where the fruit is rotated and a camera, or set of cameras, captures a number of images of the fruit. The images are then rapidly processed and defects or quality attributes identified. The fruit are dropped from the conveyor at an appropriate position based on the decision reached by the image analysis (Kondo, 2010). These systems are also often used to pre-sort fruit from the orchard prior to placing bins in cool storage.

While the accuracy and range of defects and products that can be sorted is limited, the technology offers significant advantages over human sorters as it is generally fast, often more consistent, not prone to fatigue, more objective and becoming progressively lower in cost (Brosnan and Sun, 2002, 2004; Wu and Sun, 2013).

Early work in this area (Miller and Delwiche, 1989; Shearer and Payne, 1990; Yang, 1992) focused on techniques for identifying the fruit and descriptions of shape and color. Shape is particularly important as a grading parameter in fruit that have variable shapes, but need to be marketed with a consistent shape (Cubero et al., 2011), and also for estimation of the volume of fresh products where, combined with weight, it can be used as an internal defect detection

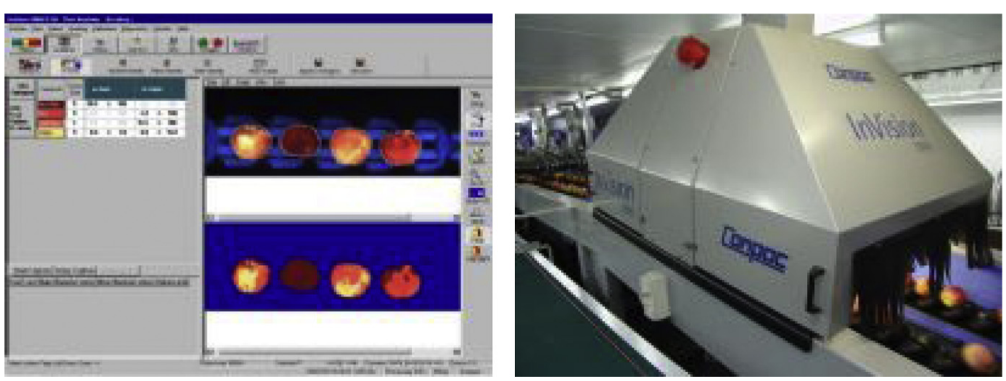

FIGURE 12.2

Automated sorting system.

method (Ruiz-Altisent et al., 2010). Achieving acceptable accuracy at high speeds is still difficult for many products (Moreda et al., 2009).

The early work on shape and color has lead to the development of very specific algorithms and analyses for much more complex quality traits and the identification of specific defects (Brosnan and Sun, 2002). The analysis techniques are beyond the scope of this chapter but a range of approaches that have been successfully implemented for fruit and vegetables are described by Graves and Batchelor (2003), Ngan et al. (2003), Du and Sun (2006), Zheng et al. (2006), Lopez-Garcia et al. (2010) and Ruiz-Altisent et al. (2010). The reader is referred to Amer Eissa and Abdel Khalik (2012) for a more detailed summary of the state of the technology.

The bulk of the reported research relates to apples, which have particularly difficult issues associated with the stem and calyx ends of the fruit (Leemans et al., 2000; Leemans and Destain, 2004; Zhu et al., 2007) which limits the accuracy of detection for russetting, scab and physical damage. More sophisticated lighting and filtering using multi-spectral imaging has also been used, in particular, to assist with the detection of bruising (Bennedsen et al., 2005; Xing and De Baerdemaeker, 2005; Kleynen et al., 2005).

Other applications that have been achieved include surface defects on citrus (Miller and Drouillard, 2001; Aleixos et al., 2002; Cubero et al., 2011; Lopez-Garcia et al., 2010) and shape and defects on cherries (Rosenberger et al., 2004).

In addition, several commercial systems are available for grading for color, shape and surface defects for a range of fruit and vegetables including apples, pears, kiwifruit, tomatoes, potatoes, onions, melons, several stonefruit, citrus, avocados and mangoes.

The accuracies of automated sorting algorithms, where reported, mostly range from 60% to 95%. Often misclassification is not measured, and yet for a commercial operation this can have significant effects as discussed above. The automated sorting process using other non-destructive technologies is further discussed in Chapter 13.

IV Analysis of sorting operations

To analyze a sorting operation, it is necessary to establish parameters such as efficiency or accuracy that may be useful for comparing performance under different conditions. Because of the complexity of sorting, no standard analysis has so far been established.

When analyzing an automated or manual sorting operation, the information directly available includes the throughput, the rate of removal of product, the proportion of defects removed and the proportion of good fruit removed with the rejects. Sometimes a breakdown by defect type is also possible. This information has been used by various investigators to predict the performance of operations, to provide sorting system design information and to provide operational information and management tools.

When using a systems approach to postharvest handling, it is useful to be able to predict how a particular operation might function under various conditions. It may be necessary, for example, to predict productivity and staffing levels for various throughput or quality conditions. Many attempts have been made to analyze and describe the sorting operation mathematically; some of these models can be useful in a systems analysis.

A Sorting performance

Sorting performance may be described primarily as a throughput variable, for example, (fruit/s)/sorter, or (kg/sorter)/h. Often throughput is correlated with the level of incoming defects, and decreases as some function of increasing defect level. The sorting throughput parameter does not describe the sorting accuracy, and assumes that a prescribed packout quality and an allowable level of good fruit in the reject flow are being maintained.

Peleg (1985) presents several quality criteria indices to describe the performance of the sorting operation. His following description of sorting includes both a sorting accuracy and a product throughput variable. The efficiency is defined as

$$E_i = \sum (P_{gi}, G_i/P_iQ) \qquad \text{(Eq. 12.1)}$$

for i separate quality grades, where E is efficiency, Q is throughput rate of incoming product, G_i is outflow rate sorted into the i^{th} grade, P_i is the proportion of i in the total incoming product flow Q, and P_{gi} is the proportion of i in the outflowing grade G_i. The most generalized definition includes weighting for the relative monetary value of the different grades of product. The weighted sorting efficiency for an entire operation is defined as

$$E_w = \sum (P_{gi}G_i/P_iQ)W_i \qquad \text{(Eq. 12.2)}$$

where the weighting function is

$$W_i = K_iP_i/\Sigma(K_iP_i) \qquad \text{(Eq. 12.3)}$$

and K_i is the cost fraction of grade i (must be ≤ 1.0). In a simple sorting operation, in which the product is either packed or discarded ($i = 1,2$; $K_i = 1$, $K_2 = 0$), Equation 12.2 is reduced to

$$E_w = P_{g1}G_1/P_1Q \qquad \text{(Eq. 12.4)}$$

The weighted efficiency E_w is equal to the probability of a correctly sorted product being placed in the correct grade of outflowing product.

B Empirical models

The advantage of developing a model of the sorting operation is the ability to fit a mathematical relationship to some observed or experimental data and then predict outcomes from other situations (Portiek and Saedt, 1974). In the systems approach it is useful to be able to simulate and evaluate how the impacts of different scenarios flow through whole supply chains.

By examining the momentary condition of a sorting process, it can be observed that a certain amount of work must be input to achieve a reduction in the quantity of defective product. From studies on the sorting of citrus fruit (Lidror et al., 1978), the following relationship was developed:

$$-kdP_p = P_q \mathrm{d}t \tag{Eq.12.5}$$

where t is the sorting work input in terms of inspection time (min/1000 fruit), k is a constant factor that is a function of product type, P_p is the proportion of defective fruit in the product outflow, and P_q is the proportion of defective fruit in the incoming product flow. The solution to the equation, which was correlated highly in over 300 experiments, was

$$t = \mathrm{k}(P_q - P_p)/P_q \tag{Eq.12.6}$$

with k = 18 for citrus. A similar expression is defined by Groocock (1986) as inspection effectiveness for industrial quality management.

In another study on the sorting performance of oranges, Pasternak et al. (1989) determined that the process was described effectively by

$$P_p = P_a \mathrm{A}\, e^{-\mathrm{B}t} \tag{Eq. 12.7}$$

where A and B are constants that are a function of defect type.

Significant differences were noted between sorting minor defects and sorting major ones. The model was developed using two sets of constants:

A = 0.86 and B = 0.027 for minor defects
A = 0.76 and B = 0.078 for major defects

These values were determined using a sorting system considered to be operating under optimum sorting conditions. Similar relationships could be established for other sorting operations. Different values of the constants A and B can be generated easily using curve fitting techniques with observed sorting data.

Equation 12.7 can be used in a systems analysis to predict the quantity of defective fruit that will pass on to the packing operation, for a given input defect level and sorting rate. However, this model does not take into account the quantity of good quality fruit rejected. Similar relationships could be established for other sorting operations.

C Signal detection theory

"Signal detection theory (SDT) represented a great leap forward in the thinking about sensory phenomena and how to measure them" (Lawless, 2013, p. 48). SDT was developed in the 1940s to quantify the effectiveness of systems used for detecting communication signals from background noise (reviewed by Egan, 1975). SDT continues to be adapted for applications such as wireless communication systems (Chavali, 2012) and detecting primary from secondary radio signals (Alipour and Ayat, 2012).

Outside of its original applications in the communications field, an early adaptation of SDT was in psychology experiments to determine human ability to distinguish a visual signal from background visual noise (Tanner and Swets, 1954). A recent human application is for the perception of acoustic signals (Mao et al., 2013). SDT has numerous applications to visual and other sensory perceptions for various industrial inspection tasks (Jaraiedi et al., 1986) and to vigilance, such as during airport baggage screening (Goh and Wiegmann, 2006). Even the process of retail customers searching for products has been analyzed using SDT (Liu et al., 2008). SDT is especially important during dynamic detection processes (Balakrishnan and MacDonald, 2011).

There is a direct analog with SDT applications and sorting applications based on manual and automated image processing. SDT gives the ability to analyze a signal described by two nondimensional parameters, d' and β. The first parameter gives a measure of the detectability of the signal and the second represents the criterion (bias) used to identify the signal.

Many psychology analysts (Mao et al., 2013), engineers (Alipour and Ayat, 2012), researchers on manual sorting of fruits and vegetables (Prussia, 1991; Yaptenco et al., 2013), food scientists (Lawless, 2013) and others have retained much of the original communications terminology of Green and Swets (1966). When attempting to detect a signal, there are two possibilities: a signal-plus-noise stimulus (SN) and a noise-with-no-signal stimulus (N). The two possible responses to a stimulus, “yes” and “no”, indicate the observer’s belief (or in the case of automated sorting, the algorithm estimate) that the signal is present or absent. That either response may be in error is always a possibility.

Adaptations of SDT for sorting fresh produce

For manual sorting operations, a flow of product passes in front of the sorter, who removes the defective product; the good product is conveyed to the packing area. In automated sorting, the product passes under a camera or set of cameras and defective product is directed to a reject drop. The incoming mixture of both good and defective product is considered SN. The incoming defective product can be considered the signal, S. The good product is considered N. The ability of the sorter (or algorithm) to make “yes” and “no” decisions correctly is influenced by the physical parameters of the operation; for example, speed, rotation, fruit density, number of defective fruit, types of defects and lighting. Decisions for manual sorting have further complications as they are also influenced by psychophysical factors such as sorter sensitivity to perceptual stimulus, sorter alertness and sorter motivation to give one response or the other. A major contribution of SDT is the ability to separate the physical conditions from the psychophysical influences.

The conditional probability of responding "yes" when a signal is present is termed the Hit rate, p(Hit) or p(H) and is calculated by dividing the number of Hits by the total number of defective items in the batch sorted. The conditional probability of responding "yes" when a signal is not present is termed the False Alarm rate, p(False Alarm) or p(FA) and is calculated by dividing the number of good items that were removed by the total number of good items sorted.

A third possibility is the conditional probability of responding "no" when a signal is present, which is called a p(Miss) or p(M) and is calculated by dividing the number of defective items incorrectly packed by the number of defective items in the batch sorted. The last conditional probability is that of responding "no" when a signal is not present, which is called p(Correct Rejection) or p(CR) and is calculated by dividing the number of good items packed by the total number of good items sorted. For this chapter, the traditional terminology for p(CR) is called p(Correct Acceptance) or p(CA) to better reflect the sorting response of correctly accepting good items for packing.

Since the probabilities are conditional, all four possibilities can be described using only two probabilities, since $p(M) = 1.0 - p(H)$ and $p(CA) = 1.0 - p(FA)$. All four responses to the SN and N stimuli are shown graphically in Figure 12.3

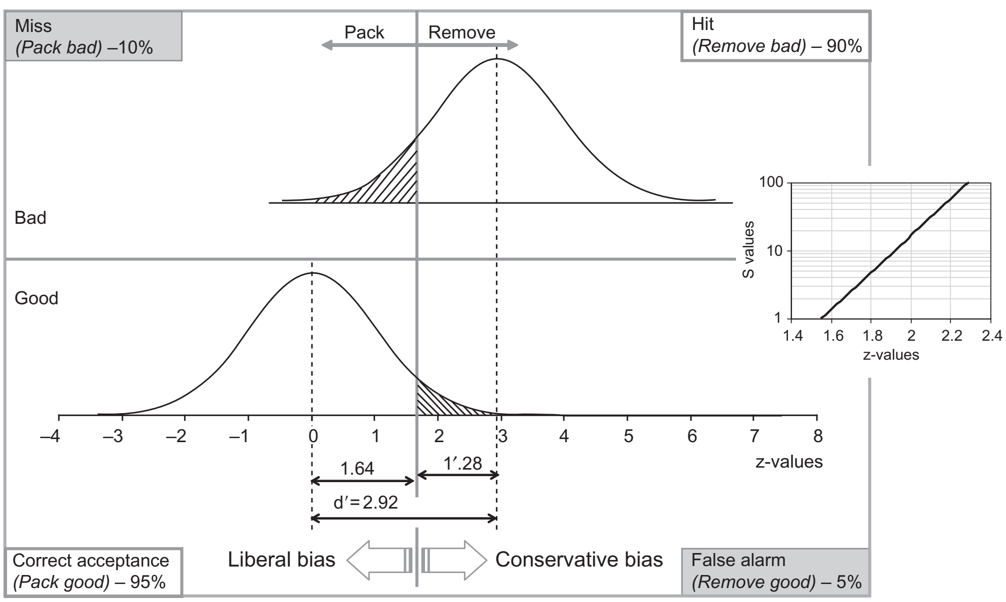

FIGURE 12.3

Probability distributions for signal intensity of "Noise-with-no-signal" (N or Good) and "Signal-plus-noise" (SN or Bad). The four possible outcomes (Hit, Miss, False Alarm, Correct Acceptance) are shown, as are representations for detectability, d′, and set point, S. As the sorter becomes more conservative S will move right in the figure, and if more liberal S will move to the left. The insert shows the logarithmic relation of set point values with z-values.

where the SN distribution is labeled "Bad" and the N distribution is labeled "Good". Conventional SDT techniques assume that the SN or Bad probabilities and the N or Good probabilities are distributed normally and are of equal variance as shown in Figure 12.3. Note that the curves are frequency distributions for the *intensity* of the signal, *not* for the *number* of Bad or Good items.

The quadrants in Figure 12.3 are defined by the distribution of signals from Bad items above the bold horizontal line and the distribution of signals from Good items below the line. The bold vertical line separates the items on the left that are packed and the ones on the right that are removed. Above the horizontal line, the Missed items are Bad items that get packed and Hits are Bad items that are removed. Below the line, the Correct Acceptance items are Good items that are packed and the False Alarms are Good items that are removed.

Detectability, d'

For a particular system in which the physical and operational parameters and the product characteristics do not change, the Bad and Good distributions do not change. The distance between the normal deviates of the means is described by the parameter d', the detectability (Freeman, 1973), where; z is the standard deviation value or z-value for a normal variate. The relative value of d' is also important. The easier the detection of defects, the further apart the two distributions will be, and d' becomes higher. A sorting table or sorting setup with a higher d′ indicates that the system has the potential to reduce both Misses and False Alarms better than those sorting operations with more overlap of the two distributions.

An equation for calculating d' can be determined from the example shown in Figure 12.3 by finding the z-value distances from the mean for the Good distribution to the mean for the Bad distribution. The vertical set point line in Figure 12.3 (described later) demarks the boundary between the areas representing Misses and Hits under the upper normal curve and simultaneously separates the areas representing Correct Acceptances and False Alarms in the lower normal curve.

The example distance of 1.64 from the mean for the Good distribution ($z = 0$) to the vertical set point line is the z-value for a Correct Acceptance rate of 95% which represents the unshaded area under the Good distribution to the left of the set point line. The remaining distance, shown in Figure 12.3 as 1.28, is the distance from the mean for the Bad distribution to the set point line and is the z-value for a miss rate of 10% for the example, which represents the shaded area under the Bad distribution to the left of the set point line.

The False Alarm rate receives more attention than Correct Acceptance during commercial sorting operations because it determines the number of rejected items that could have been sold at a higher price. An equation for calculating d' can use p(FA) because it is the complement of p(CA); making the z-value for p(FA) the negative value of the same number for the z-value of p(CA).

The equation for d' is the addition of the two distances from the set point line to the means of the two distributions, or the separation of the two distribution means. Sorting operations typically have probabilities of Misses and False Alarms much less than 50% making both of the resulting z-values negative. Therefore, the terms for both z-values in the equation for d' must have negative signs to make d' positive. The resulting equation is:

$$d' = -z[p(FA)] - z[p(M)] \qquad \text{(Eq. 12.8)}$$

The p(FA) and p(M) terms in Equation 12.8 replace the p(CA) and p(H) terms in some previously published equations for detectability because Equation 12.8 emphasizes the commerical importace of False Alarms and Misses. However, the numeric values for d' remain the same as shown in previous editions of this book because z-values on opposite sides of the mean are the same number with the opposite sign.

The detection performance at a sorting situation may be evaluated visually by using Receiver Operating Characteristic (ROC) plots (Figure 12.4), on which p(M) is plotted against p(FA). Changing from p(H) to p(M) changes the curves from convex towards the upper left corner to curves convex toward the lower left corner. In manual sorting, points for p(M) and p(FA) on a d'curve can be found by varying the instructions to the sorters or by adopting some incentive payment scheme. In automated sorting the points on a ROC curve can be found by varying algorithms or sensitivity parameters.

By selectively varying p(M) and p(FA), it is possible to generate any number of points on an ROC curve that all have the same value for d'. Since the physical parameters of the system (such as speed or rotation) have been unchanged, this curve is characteristic of that operation. Each sorting system has a curve for each value of p(M) and the corresponding p(FA); resulting in a unique detectability

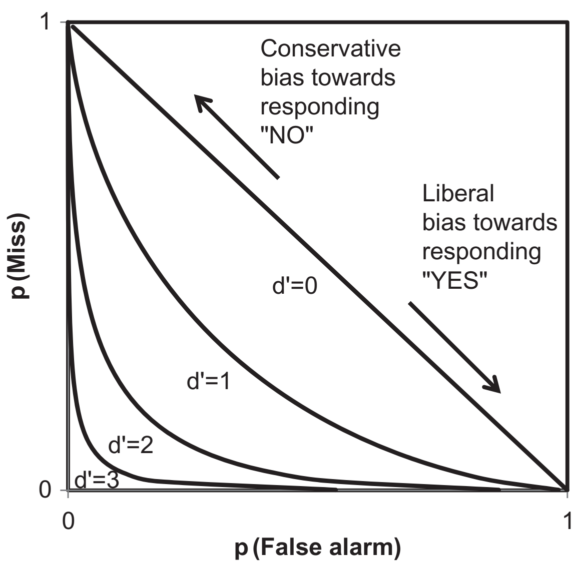

FIGURE 12.4

Typical receiver operating characteristic (ROC) plot showing relationships between p(MISS) and p(FALSE ALARM) as a family of detectability (d′) curves.

curve for that value of d'. The power of SDT is that, after one pair of p(M) and p(FA) values has been determined, it is possible to generate the complete curve.

Set point

The second useful descriptor for SDT theory is the criterion likelihood ratio or bias, β, which represents the probability that a decision was based on N stimuli relative to the probability that the decision was based on SN stimuli. For this chapter we use the term "Set point" S to emphasize the purposeful decisions of human sorters and the mechanical or electronic settings established on automated sorting equiment.

If the N and SN normal density functions are equal and have a standard deviation of 1.0, then their ratio simplifies to Equation 12.9 (from: Harvey, 2013; Meyers, 1988; Egan, 1975) after changing the p(CA) to p(FA) and the p(H) to p(M) as required to represent the physical reality in Figure 12.3. Both z-values are negative as in Equation 12.8 for d' because Equation 12.9 is also for p(FA) and p(M) less than 50%. The same numeric values result as for previously published equations because False Alarm and Correct Acceptance rates and Hit and Miss rates are complements of each other and also because squaring the negative z-values gives a positive term.

$$S = \frac{e^{0.5\{-z[p(FA)]\}^2}}{e^{0.5\{-z[p(M)]\}^2}} \qquad \text{(Eq. 12.9)}$$

The physical representation of the Set point, S, is a description of the cutoff position for an algorithm or that which a sorter sets in his or her mind. Changes in the set point can be visualized in Figure 12.3 by considering the changes resulting in the four conditional probabilities as the vertical line is moved to the right or left.

The value for S is 1.0 when the distance from the mean for the Good distibution to the set point is equal to the distance from the mean for the Bad disribution to the set point. At S = 1.0 the numerator and denominator in Equation 12.9 are equal and the shaded area representing the False Alarm rate is equal to the shaded area representing the Miss rate. When S = 1, the values for z(FA) and z(M) both equal half the value for d'.

As the set point moves to the right the values for S become greater than 1.0 because z(FA) increases making the numerator in Equation 12.9 larger. Note that the shaded area representing False Alarms decreases, making the negative z-values larger. Simultaneously, the denominator decreases as the set point moves toward the mean for the Bad distribution. The shaded area in the Good distribution representing Misses increases, making the negative z-values smaller. Likewise, the value for S is less than 1.0 as the set point moves to the left of the point where the FA rate is equal to the Miss rate.

Any stimulus above this set point is called a signal, regardless of whether it is SN or only N. The set point, S, may be varied by the sorter, and a deliberate change in S results in differing Miss and False Alarm rates for an otherwise constant sorting system (no change in d'). A low value for S moves the vertical line to the left and indicates that a considerable amount of N is being accepted as SN, so p(FA) is high and p(M) is low. Such a tendency is termed a liberal criterion. A high S moves the vertical line to the right, giving a low p(FA) and a high p(M) and is called a conservative criterion. The insert in Figure 12.3 shows the relationship between S and z-values, but is valid only for $d' = 2.92$ as shown.

Each pair of p(M) and p(FA) has a corresponding d' and S. For a particular system, d' is constant and all the values of p(M) and p(FA) will be on a curve for that value of d′ (see relevant curves in Figure 12.5). The position of points on a d' curve for a pair of p(M) and p(FA) values depends on the value of S. The system parameters d' and S thus are separated conveniently. The physical description is encapsulated by the value of d' and the psychological factors are described by S. Simulation models (Krantz, 2013) and applets (Claremont Graduate University, 2013) are available on the internet to show interactions of SDT parameters.

Analyses using SDT highlight the importance of determining the False Alarm rates in the assessment of any sorting operation, which is rarely considered. The resulting detectability and set point values have several useful applications.

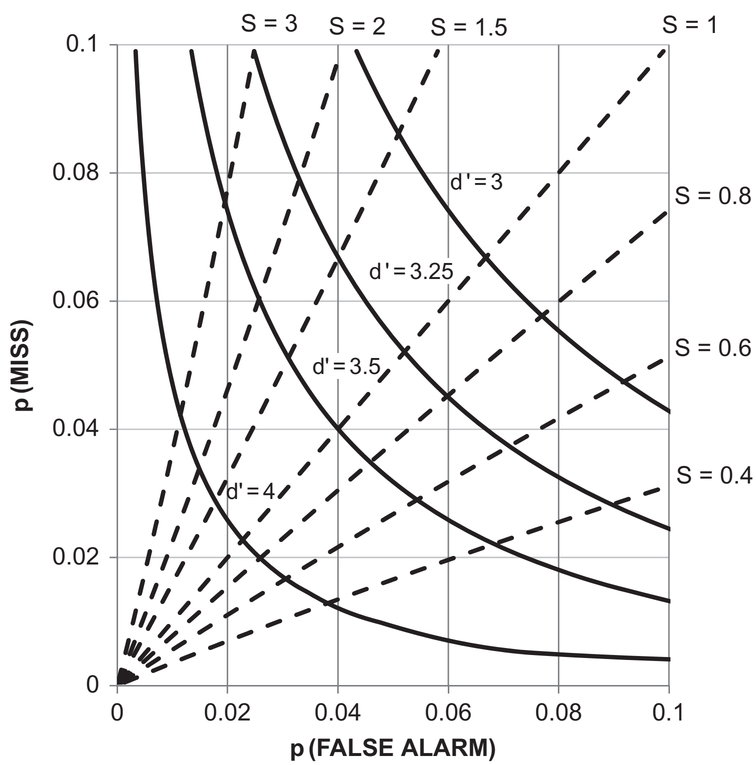

FIGURE 12.5

Section of receiver operating characteristic (ROC) plot with low values for p(FA) and p(H) that are common for sorting operations showing the contour lines for set points, S,(dotted curves) superimposed on a family of detectability curves, d′ (solid curves).

Physical design and operational parameters

The detectability, d', can be used to compare the design and operating characteristics of different sorting setups without consideration of sorter bias. For example, increasing d' is the only way to simultaneously avoid discarding good items and shipping bad items. Various alterations and modifications of operating conditions or designs for a particular system also can be optimized by using real product to find the highest possible d' values.

The advantage of SDT over the other techniques of evaluating sorting operations already discussed is that d' can be determined by different sorters with products of differing quality in various systems, and still allow comparisons. However, the SDT analysis has some limitations. For example, product quality does have some effect on the sorting behavior as some defects are easier to identify than others.

Sorter criterion

By calculating S for a sorter, it is possible to determine whether that sorter has a conservative or liberal approach, which could serve as a useful management tool. A conservative approach prevails when the sorter only removes the worst product.

In a commercial operation, the objective usually is to maintain a consistent quality of the packed product. If the incoming product quality is poor, it is necessary for the Miss rate to be low (high Hit rate), whereas if the quality is good, a higher Miss rate is adequate. The sorters thus are required to vary their own criterion, depending on the incoming quality. Analysis of individual criterion values help determine how effectively each sorter is able to adjust.

Performance of automated sorting

SDT is useful in the analysis of automated sorting systems. As with manual sorting, it is possible to separate out the different aspects of the system. Detectability, d', is generally a measure of the physical design including; how well lit the product is, product speed and rotation, camera design and resolution, and number of images captured. The set point, S, is predominantly a measure of the performance of the algorithm. There is some interaction between the two parameters.

Systems analysis

SDT mathematically describes the relationship between Miss and False Alarm rates. After a value of d' has been determined experimentally, it may be used in a model of the packinghouse to predict Miss and False Alarm rates. The analyst also has the ability to use S to vary the behavior of the sorters and predict the impacts of such changes on whole supply chains.

V Economics of sorting operations

In many cases, the ability to predict performance of a sorting operation using SDT is useful for management operations on a daily basis. In addition, the usefulness of the model can be extended if it is possible to predict the economic value of potential changes. Models provide a useful tool during planning and design phases, as well as for managing an operation. Economic models are also necessary to evaluate the impact of different sorting scenarios.

One method of optimizing a sorting operation is using the sorting efficiency defined by Peleg (1985) and described by Equation 12.10. Peleg's sorting efficiency requires the proportion of defective product to be known or estimated in both the incoming and the sorted product flows, and monetary values to be assigned to the various grades. The calculated efficiency is weighted according to product value, and allows a comparison of various scenarios. The total value of sorted product, V, is calculated:

$$V = E_w T\, v \qquad \text{(Eq. 12.10)}$$

where T is the throughput sold (e.g., kg/h, ton/season, and so forth), E_w is p(CA), and v is the unit value of the product (e.g., \$/kg, \$/ton). The returns, represented by total value can be used in addition to the costs to evaluate various alternatives or used as part of a wider system model.

For any marketed product, there will be a payout schedule that is a function of the product amount that is defective. Therefore, the higher the Hit rate, the better the returns (Figure 12.6). Every "False Alarm" represents a lost item, thus, the value of returns decreases with increasing p(FA).

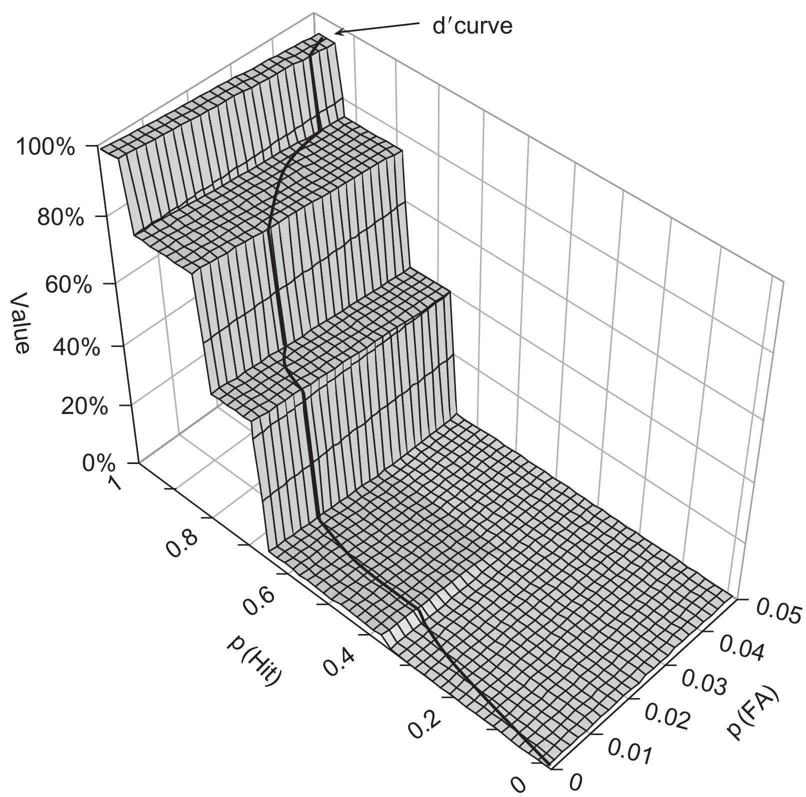

FIGURE 12.6

Example of a payoff matrix with receiver operating characteristic plot and d′ curve superimposed.

For a predetermined payment schedule, a payout matrix can be established, as represented in Figure 12.6. The payout must be established for a known incoming fruit quality to specify a Hit rate to produce the desired output quality. For example, for a required output quality of 95% good product, the sorter must maintain a Hit rate of 0.53 if 10% defects are incoming, but must have a Hit rate of 0.92 if 40% are defects.

If the relationship between p(FA) and p(H) for a particular system is known, or can be determined, this information can be used to determine the relationships between the sorting operation and the returns for product sold, thus combining economic and operational parameters into the same model. The $p(\text{H}) - p(\text{FA})$ relationship may be determined from historical data of sorter performance or it may be predicted using SDT.

For the example shown in Figure 12.6, managers might want to know the consequences of advising their sorters to "reduce the number of good fruit in the reject bin" (reduce False Alarms) or "reduce the number of defects in the outgoing product" (increase Hit rate). If the sorters concentrate on reducing good fruit entering the reject bin (p(FA)), the consequence will be an increase in the miss rate of defective product; similarly, the consequence of reducing rejects passing into the final pack (p(M)) will be an increase in good fruit entering the reject bin. This situation, as previously discussed, is represented by changing values for set point, s, when moving along the d' line shown in Figure 12.6.

If a buyer of quality product pays according to the following schedule:

Grade I < 2% defects
Grade II < 10% defects
Grade III < 15% defects
Grade IV < 25% defects
Will not buy >25% defects

and the packinghouse operator has incoming product with 35% defects, then sorters must achieve a Hit rate of 0.96 to ensure Grade I product, 0.79 for Grade II, 0.67 for Grade III, and 0.38 for Grade IV. Figure 12.6 shows these Hit rates.

If the operation is maintaining an average Hit rate of 0.8, then, referring to Figure 12.6, "a reduction in the number of good fruit in the reject bin" by lowering p(FA) to 0.015 would result in a reduction of p(H) to below 0.79. The payout schedule cutoff is represented by $p(\text{H}) = 0.79$; therefore, any reduction in the False Alarm rate will result in a considerably lower return to the packinghouse.

The second scenario is to "reduce the number of defects in the outgoing product." If the Hit rate was increased to 0.9, the objective would be achieved. However, the increase in p(H) will also result in an increase in False Alarms to above 0.02; thus, the return to the packinghouse will be reduced by the loss of salable fruit. Any changes in the instruction to the sorters will result in a reduction in overall packinghouse returns in the illustrated situation.

An operator contemplating an upgrade for the system can benefit from applying SDT techniques. The expected performance of some new equipment is an increase in Hit rate from 0.82 to 0.95 at a False Alarm rate of 0.018. A new d' curve is established for the upgraded system and represents $p(\mathrm{H}) = 0.92$ and $p(\mathrm{FA}) = 0.02$. Then, if the sorters are suitably instructed, it is possible for the operator to achieve a Hit rate of over 0.95 at a False Alarm rate of 0.02. The change increases the value of the product and determines whether it is a sufficient return on the capital invested in the upgrade.

Bibliography

Aleixos, N., Blasco, J., Navarron, F., Molto, E., 2002. Multispectral inspection of citrus in real-time using machine vision and digital signal processors. Comput. Electron. Agric. 33 (2), 121–137.

Alipour, H., Ayat, S., 2012. Identifying degree of separability in signal detection, for using in cognitive radio approach. International Journal of Computer and Engineering 4 (5). <http://www.ijcte.org/papers/577-A736.pdf> (accessed 19.09.13).

Amer Eissa, A.H., Abdel Khalik, A.A., 2012. In: Eissa, A.A. (Ed.), Understanding Color Image Processing by Machine Vision for Biological Materials, Structure and Function of Food Engineering. InTech, ISBN: 978-953-51-0695-1, <http://dx.doi.org/10.5772/50796>. Available from: <http://www.intechopen.com/books/structure-and-function-of-food-engineering/understanding-color-image-processing-by-machine-vision-for-biological-materials> (accessed 26.02.14).

Balakrishnan, J.D., MacDonald, J.A., 2011. Performance measures for dynamic signal detection. J. Math. Psychol. 55 (2011), 290–301.

Bennedsen, B.S., Peterson, D.L., Tabb, A., 2005. Identifying defects in images of rotating apples. Comput. Electron. Agric. 48 (2), 92–102.

Bollen, A.F., 1986. Sorting fruit: systems design and operation. Postharvest Manual. New Zealand Agricultural Engineering Institute/Ministry of Agriculture and Fisheries, Hamilton, New Zealand, Unpublished.

Brosnan, T., Sun, D.-W., 2002. Inspection and grading of agricultural and food products by computer vision systems: a review. Comput. Electron. Agric. 36 (2–3), 193–213.

Brosnan, T., Sun, D.-W., 2004. Improving quality inspection of food products by computer vision. Food Eng. 61 (1), 3–16.

Chaffin, D., Andersson, G.B.J., Martin, B., 1999. Occupational Biomechanics, third ed. John Wiley & Sons, Inc., New York.

Chavali, V.G., 2012. Signal detection and modulaton classification in non-gaussian noise evnironments. Ph.D. Dissertation. Virginia Polytechnic Institute and State University, Blacksburg Virginia. <http://scholar.lib.vt.edu/theses/available/etd-07242012-110332/unrestricted/Chavali_VG_D_2012.pdf> (accessed 16.09.13).

Claremont Graduate University, 2013. Criterion. Signal Detection Theory Tutorial. <http://wise.cgu.edu/sdtmod/index.asp> (accessed 17.09.13).

Cubero, S., Aleixos, N., Molto, E., Gomez-Sanchez, J., Blasco, J., 2011. Advances in machine vision applications for automatic inspection and quality evaluation of fruits and vegetables. Food Bioprocess. Technol. 4, 487–504.

Dreyfus, H., 1967. Measurement of Man: Human Factors in Design. Whitney Publications, New York.

Du, C.J., Sun, D.W., 2006. Learning techniques used in computer vision for food quality evaluation: a review. J. Food Eng. 72, 39−55.

Egan, J.P., 1975. Signal Detection Theory and ROC Analysis. Academic Press, Orlando, Florida.

Eissa, A.A., Khalik, A.A., 2012. Understanding color image processing by machine vision for biological materials. In: Eissa, A.A. (Ed.), Structure and Function of Food Engineering. InTech, http://dx.doi.org/10.5772/50796. <http://www.intechopen.com/books/structure-and-function-of-food-engineering> (accessed 26.10.13) (Chapter 10).

Freeman, P.R., 1973. Tables of d′ and BETA. Cambridge University Press, Cambridge.

Goh, J.J., Wiegmann, D.A., 2006. Effects of Automation Failures During a Visual Inspection Task on Reliance and Visual Skill Acquisition: A Comparison Between Direct and Indirect Cueing. Technical Report HFD-06-06. Human Factors Division HFD, Institute of Aviation, University of Illinois, Urbana-Champaign. <http://www.aviation.illinois.edu/avimain/papers/research/pub_pdfs/techreports/06-06.pdf> (accessed 17.09.13.).

Graves, M., Batchelor, B.G., 2003. Machine Vision for the Inspection of Natural Products. Springer-Verlag Inc., New York.

Green, D.M., Swets, J.A., 1966. Signal Detection Theory and Psychophysics. John Wiley & Sons, New York.

Groocock, J.M., 1986. Inspection effectiveness. The Chain of Quality, Market Dominance Through Product Superiority. John Wiley & Sons, New York.

Guyer, D., Brown, G., Timm, E., Brook, R., Marshall, D., 1994. Lighting Systems for Fruit and Vegetable sorting. Michigan State University, Extension Bulletin E-2559.

Harvey, L.O., 2013. Detection theory: sensory and decision processes. Class Notes for Psychology of Perception, Psychology 4165-100, Spring 2013. University of Colorado, Boulder, CO, <http://psych.colorado.edu/~lharvey/P4165/P4165_2012_Spring/2012_Spring_pdf_Class_Handouts/DetectionTheory.pdf> (accessed 17.09.13).

Hunter, J.H., Yaeger, E.C., 1970. Use of a Float Roll Table in Potato Grading Operations. Maine Agricultural Experimental Station Bulletin, No. 690. Orono, Maine.

Ip, W., 2011. Designing for an aging population. Interface vol. 1, pp. 1 and pp. 28−320. A Technical Publication Of The American Society of Safety Engineer's Ergonomics Practice Specialty. <http://www.asse.org/cops/docs/Winnie%20Ip%20Article_Ergonomics.pdf> (accessed 26.10.13).

Jahns, G., Moller-Nielsen, H., Paul, W., 2001. Measuring image analysis attributes and modelling fuzzy consumer aspects for tomato quality grading. Comput. Electron. Agric. 31 (1), 17−29.

Jaraiedi, M., Toth, G.J., Aghazadeh, F., Herrin, G.D., 1986. Modeling of decision making behavior of inspectors. Trends Ergon. III, 351−357.

Kleynen, O., Leemans, V., Destain, M.F., 2005. Development of a multi-spectral vision system for the detection of defects on apples. Food Eng. 60 (1), 41−49.

Kondo, N., 2010. Automation on fruit and vegetable grading system and food tracebility. Trends Food Sci. Technol., 145−152.

Krantz, J.H., 2013. Signal Detection Theory Tutorial. Hanover College, Hanover, Indiana, <http://psych.hanover.edu/JavaTest/STD/outcomes.html> (accessed 17.09.13).

Kusabs, N.J., Trigg, L., Bollen, A.F., Holmes, G., 2006. Objective measurement of mushroom quality relative to industry inspectors. Int. J. Postharvest Technol. Innov. 1 (2), 2006.

Lawless, H.T., 2013. Basics of signal detection theory. Quantitative Sensory Analysis: Psychophysics, Models and Intelligent Design. Wiley—Blackwell, Hoboken, NJ, pp. 404 (Chapter 3).

Leemans, V., Destain, M.F., 2004. A real-time grading method of apples based on features extracted from defects. Food Eng. 61 (1), 83—89.

Leemans, V., Destain, M.F., Magein, H., 2000. Quality fruit grading by colour machine vision: defect recognition. Acta Hort 517, 405—412.

Lidror, A., Roll, Y., Siv, S., 1978. Citrus fruit sorting parameters influencing manual work rate. Proc. Int'l. Soc. Citriculture 20, 115—116.

Liu, S.S., Chen, J., Melara, R.D., Massara, F., 2008. Consumers' product-locating behavior: exploring the application of signal detection theory. Psychol. Market. 25 (6), 506—520.

Lopez-Garcia, F., Andreu-Garcia, G., Blasco, J., Aleixos, N., Valiente, J.M., 2010. Automatic detection of skin defects in citrus fruits using a multivariate image analysis approach. Comput. Electron. Agric. 71, 189—197.

Mao, J., Vosoughi, A., Carneya, L.H., 2013. Predictions of diotic tone-in-noise detection based on a nonlinear optimal combination of energy, envelope, and fine-structure cues. Acoust. Soc. Am. 396—406. Available from: http://dx.doi.org/10.1121/1.4807815> (accessed 17.09.13).

Meyers, J.B., 1988. Improving dynamic visual inspection performance. Masters Thesis. University of Georgia, Athens, Georgia.

Meyers Jr., J.B., Prussia, S.E., Thai, C.N., Sadosky, T.L., Campbell, D.J., 1990a. Visual inspection of agricultural products moving along sorting conveyors. Trans. ASAE 33 (2), 367—372.

Meyers Jr., J.B., Prussia, S.E., Karwoski, C.J., 1990b. Signal detection theory for optimizing dynamic visual inspection performance. Appl. Eng. Agric. 6 (4), 412—417.

Miller, M.K., Delwiche, M.J., 1989. A color vision system for peach grading. Trans. ASAE 32 (4), 1484—1490.

Miller, W.M., Drouillard, G.P., 2001. Multiple feature analysis for machine vision grading of Florida citrus. Appl. Eng. Agric. 17 (5), 627—633.

Moreda, G.P., Ortiz-Canavate, J., Garcia-Ramos, F.J., Ruiz-Altisent, M., 2009. Non-destructive technologies for fruit and vegetable size determination — a review. J. Food Eng. 92, 119—136.

Ngan, P., Penman, D., Bowman, C., 2003. On-line automated visual grading of fruit: practical challenges. In: Graves, M., Batchelor, B. (Eds.), Machine Vision for the Inspection of Natural Products. Springer-Verlag Inc., New York, pp. 215—239.

Nicholson, J.V., 1985. Colour and light for the inspection table. SIRTEC Publication No. 1. New Zealand Department of Scientific and Industrial Research, Wellington, New Zealand.

Openshaw, S., Taylor, E., 2006. Ergonomics and Design A Reference Guide. Allsteel Inc., <http://cms.allsteeloffice.com/SynergyDocuments/ErgonomicsAndDesignReferenceGuideWhitePaper.pdf> (accessed 26.10.13.), 57 pp.

Pasternak, H., Lidror, A., Engel, H., 1989. The effect of the incidence of defect on orange inspection time. Can. Agric. Eng. 31 (2), 131—134.

Peleg, K., 1985. Produce Handling, Packaging, and Distribution. AVI, Westport, Connecticut.

Portiek, J.H., Saedt, A.P.H., 1974. An analytic and a descriptive model for the potato sorting process. J. Agr. Eng. Res. 19, 189—198.

Prussia, S.E., 1985. Visually Sorting at Ergonomically Designed Workstations. ASAE Paper No. 85-1618. American Society of Agricultural Engineers, St. Joseph, Michigan, 13 pp.

Prussia, S.E., 1991. Dynamic visual inspection. In: Roberts, D.L., Becker, W.I. (Eds.), Module 9 of Human Factors. American Society of Agricultural Engineers, St. Joseph, Michigan, 14 pp.

Prussia, S.E., Meyers Jr., J.B., 1989. Ergonomics for improving visual inspection at fruit packinghouses. Acta Hort 258, 357–364.

Rosenberger, C., Emile, B., Laurent, H., 2004. Calibration and quality control of cherries by artificial vision. J. Electron. Imag. 13 (3), 539–546.

Ruiz-Altisent, M., Ruiz-Garcia, L., Moreda, G., Lu, R., Hernandez-Sanchez, N., Correa, E.C., et al., 2010. Sensors for product characterization and quality of specialty crops – a review. Comput. Electron. Agric. 74, 176–194.

Shearer, S.A., Payne, F.A., 1990. Color and defect sorting of bell pepper using machine vision. Trans. ASAE 33 (6), 2045–2050.

Stevens, G.N., Gale, G.E., 1970. Investigations into the feasibility of semi-automatic quality inspection of fruit and vegetables. J. Agr. Eng. Res. 15 (1), 52–64.

Tanner, W.P., Swets, J.A., 1954. A decision-making theory of visual detection. Psychol. Rev. 61, 283–288.

Tilley, A.R., 2002. Henry Dreyfuss Associates. The Measure of Man and Woman, Revised Edition. John Wiley & Sons, Inc., New York.

Woodson, W.E., Tillman, B., Tillman, P., 1992. Human Factors Design Handbook, second ed. McGraw–Hill, Inc., New York.

Wu, D., Sun, D.-W., 2013. Colour measurements by computer vision for food quality control – a review. Trends Food Sci. Tech. 29, 5–20.

Xing, J., De Baerdemaeker, J., 2005. Bruise detection on 'Jonagold' apples using hyperspectral imaging. Postharvest Biol. Technol. 37 (2), 152–162.

Yang, Q., 1992. The potential for applying machine vision to defect detection in fruit and vegetable grading. Agr. Eng. 47 (3), 74–79.

Yaptenco, K.F., Angels, M.P., Esguerra, E.B., Serrano, E.P., Cho, M.A., Choi, S.T., 2013. Nondestructive firmness measurement as a maturity index for 'Carabao' mango (*Mangifera indica* L.) fruit. Philipp. Agric. Sci. 96 (1), 55–65.

Zheng, C., Sun, D.-W., Zheng, L., 2006. Recent developments and applications of image features for food quality evaluation and inspection – a review. Trends Food Sci. Technol. 17 (12), 642–655.

Zhu, B., Jiang, L., Tao, Y., 2007. Three-dimensional shape enhanced transform for automatic apply stem-end/calyx identification. Opt. Eng. 46, 1.

CHAPTER

Non-Destructive Evaluation: Detection of External and Internal Attributes Frequently Associated with Quality and Damage

13

Bart M. Nicolaï, Inge Bulens, Josse De Baerdemaeker, Bart De Ketelaere, Jeroen Lammertyn, Wouter Saeys, Pieter Verboven and Maarten L.A.T.M. Hertog

Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, Katholieke Universiteit Leuven, Leuven, Belgium

I Introduction

While most commercial quality classification systems for fruit and vegetables are based on the external aspect (color, size, absence of blemishes, etc.), there is an increasing interest in incorporating internal quality attributes as well. Consumers now demand fruit and vegetables which not only look nice but also taste good, have an appropriate texture, are free of contaminants and contain sufficient nutritional and health promoting substances. Until recently, destructive techniques were used to measure these properties. An obvious disadvantage of such techniques is that the fruit is lost after the measurement, so that only quality inspection at the batch rather than at the individual fruit level is feasible. However, during the last decade several novel systems have been developed to measure quality attributes non-destructively. Several of them are now commercially available as desktop units or mounted on a grading line, so that quality control of individual fruit becomes feasible. Additional advantages are the fact that no sample pre-treatments are required for non-destructive techniques, the absence of waste after the measurement, and often the measurement speed.

The objective of this chapter is to give an overview of some recent developments in non-destructive quality measurements. We will focus on systems to measure external appearance, internal defects, firmness, taste and aroma.

Postharvest Handling.

II External appearance

The external appearance is the main quality aspect each consumer is confronted with when buying food products. Historically, human perception of the product's appearance has been the main "instrument" for qualifying aspects like color, blemishes, gloss, shape and size. The main developments seen in assessing visual quality are related to moving away from subjective qualitative consumer evaluation by developing objective quantitative instrumental techniques. The first step was the introduction of color charts and other reference charts to standardize the evaluation process. The next step was the development of instrumental techniques to replace human vision. An additional benefit of introducing such quantitative instrumental techniques is that the quality attributes can be interpreted as continuous variables which allow the use of increasingly sophisticated statistical and numerical modeling techniques to analyze and interpret the data (Hertog et al., 2007).

A Color

The color of any object depends heavily on the nature of its illuminating light source; in the absence of light, as an extreme, color is non-existent. The properties of color distinguishable by the human eye are hue, saturation and brightness. While spectral colors can be one-to-one correlated to wavelength, the perception of compound light, consisting of multiple wavelengths, is much more complicated. It is found that many different combinations of wavelengths can produce the same color perception.

The color of a food product is the combined result of both its structure, affecting the scattering and reflectance properties of the food, and its pigmentation, affecting the absorption properties of the food. Small structural changes affecting the scattering properties of the food may induce larger changes in color than can be attributed to simple changes in the pigment concentrations (Macdougall, 1982).

Trichromatic colorimeters and spectrophotometers are commercially available to take single spot color measurements under standardized lighting conditions, and express color in units of one of the standardized color spaces (ASTM, 2000). The L*a*b* or the HCS (hue, chroma, saturation) color spaces are widely used in fruit or vegetable applications. Computer imaging systems have been developed that measure the color of the whole product's surface using digital cameras, incorporating possible spatial variation (Wu and Sun, 2013). In this configuration, images can be rapidly processed and used for on-line color sorting systems (Liao et al., 1992; Tao et al., 1995). However, careful calibration is required. Almost all manufacturers of sorting lines now provide on-line color inspection stations.

B Blemishes

With the ongoing developments in computer vision, imaging techniques have been developed as an inspection tool for the quality assessment of a variety of food products to recognize objects, to measure shape characteristics and to identify external defects. These techniques have been successfully applied to fruit (Abbott et al., 1997; Throop et al., 2005), meat (Swatland, 1995) and poultry (Park et al., 1998) and have also resulted in harvesting systems for fruit production (Kondo et al., 1996; Bulanon et al., 2002; Van Henten et al., 2002). The ongoing developments in hardware, going from grayscale cameras to color systems and multi/hyperspectral imaging techniques, have further contributed to the development of more sophisticated recognition systems to detect blemishes before they might even become visible to the human eye. Blemishes studied include rots, bruises, flyspecks, scabs and molds, fungal diseases and soil contaminations (Mehl et al., 2004). The base for any of these inspection techniques is to take multiple monochromatic images of the food objects at different wavelengths and to search for those wavelengths at which the blemish of interest shows a characteristic absorption behavior different from the unblemished tissue. By combining data for different wavelengths using multivariate techniques, the detection of blemishes can be further improved. Brosnan and Sun (2004) reviewed applications of machine vision to fruit and vegetables.

III Internal defects

Internal disorders in horticultural products are not revealed by external visual symptoms. Non-destructive and non-invasive monitoring techniques are beneficial to investigate the occurrence and development of internal disorders. Two non-destructive tomographic techniques have been applied for the direct structural and 3-D detection of internal defects in horticultural products: X-ray computed tomography (X-ray CT) and magnetic resonance imaging (MRI). While MRI has recently been shown to be applicable for on-line detection of internal defects, X-ray CT has the advantage of obtaining very high resolution images of the plant material's cellular and sub-cellular structure. These two techniques and the ways that they have been used in the scientific literature are discussed further. Other methods for internal quality evaluation are reviewed by Butz et al. (2005).

A Magnetic resonance imaging

^{1}H MRI employs static magnetic fields and radio frequencies in order to obtain images of proton mobility in biological systems. The proper radio frequency will rotate the magnetic moment of a proton by 90°. After removal of the radio frequency energy, relaxation results in a signal in the receiver. The energy loss depends on the environment surrounding the nucleus, leading to different but characteristic relaxation times. By applying magnetic field gradients in three directions, two- and three-dimensional images can be created (Butz et al., 2005). Basically, the signal comes from the aqueous fraction in the sample and is therefore mainly used to measure water content and profiles in products non-destructively (Nguyen et al., 2006).

MRI has been applied to the detection of core breakdown in "Bartlett" pears (Wang and Wang, 1989), the detection of void spaces, worm damage and bruises in fruit (Chen et al., 1989), quantitative NMR imaging of kiwifruit during growth and ripening (Clark et al., 1998a), the study of watercore in apples (Wang et al., 1988; Clark et al., 1998b; Clark and Richardson, 1999; Melado-Herreros et al., 2013) and woolly breakdown in nectarines (Sonego et al., 1995). Gonzalez et al. (2001) and Clark and Burmeister (1999) studied the progression of internal browning in "Fuji" and "Braeburn" apples, respectively, stored under disorder-inducing conditions. Lammertyn et al. (2003a,b) and Hernandez-Sanchez et al. (2007) used MRI to study browning and core breakdown in pears. Core breakdown in "Conference" pears is a storage disorder, which is characterized by brown discoloration of the tissue and development of cavities, and which cannot be detected by the consumer from the outside at the time of purchase. MRI was able to differentiate between unaffected tissue, brown tissue and cavities (Figure 13.1). The area percentage brown tissue per slice increased with the diameter of the pear, but was systematically underestimated by 6%, compared to the actual slices (Lammertyn et al., 2003b). The area percentage cavity corresponded very well to the actual case. At the macroscopic level, fast low angle shot MR images were acquired for pears on a sorting line and discriminated for internal breakdown according to histogram characteristics (Hernandez-Sanchez et al., 2007). Up to 96% of pears were correctly classified.

MRI shows large potential for on-line grading, sorting or quality evaluation of fresh produce (Ruiz-Altisent et al., 2010). Current research aims at developing cost-effective but fast equipment which can achieve commercial throughputs. In particular, the focus is on using cheaper, faster, low-field, wide-bore MRI scanners (Chayaprasert and Stroshine, 2005; Hernández-Sánchez et al., 2007; Milczarek and McCarthy, 2009; Van As and van Duynhoven, 2013), on smaller, mobile devices (Danieli et al., 2009, 2010), and on faster pulse sequences (e.g., gradient echo method, Abbott et al., 1997).

B X-ray computed radiography and tomography

X-ray tomography is based on X-ray radiography: an X-ray beam is radiated towards the sample and the transmitted beam is recorded by a detector. The level of transmission of these rays depends mainly on the mass density and mass absorption coefficient of the material (Maire et al., 2001; Salvo et al., 2003). The resulting image is a superimposed information (projection) of a volume in a 2-D plane. The classical way to get 3-D information is to perform a large number of radiographs while rotating the sample between 0° and 180°. The filtered back-projection algorithm can then be used to reconstruct the volume of the sample from these radiographs (Herman, 1980). X-ray CT allows the visualization and analysis of the architecture of cellular plant materials with a resolution down to a few micrometers, and without sample preparation or chemical fixation (van Dalen et al., 2003; Maire et al., 2003; Lim and Barigou, 2004; Mendoza et al., 2007; Verboven et al., 2008). X-rays are short wave radiation, which can penetrate

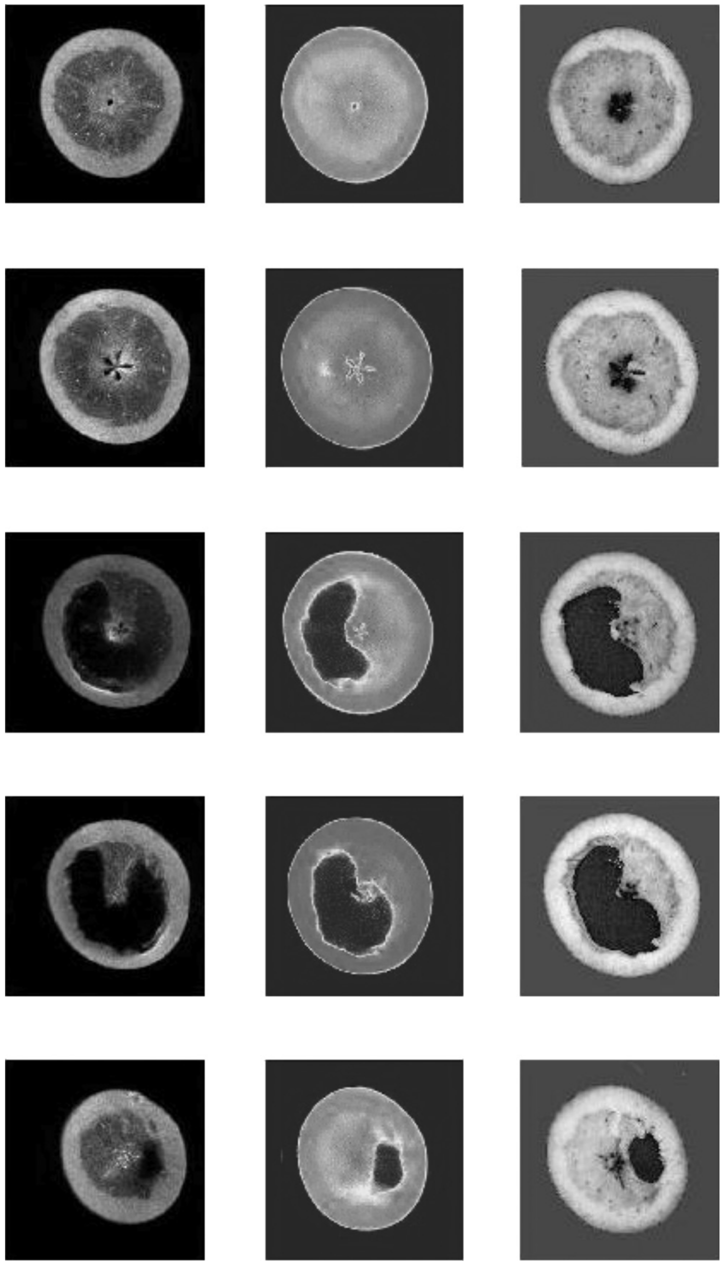

FIGURE 13.1

Comparative overview of the corresponding X-ray CT scans (left), MRI images (middle) and actual photographs (right) of core breakdown of pear tissue. Sound tissue, brown tissue and cavities are light gray, dark gray and black in the CT scans, and figure is in black and white in the MRI scans, respectively. There is a good correspondence between the different images.

From Lammertyn et al. (2003b); used with permission from Elsevier.

through plant tissue. Due to the high moisture content of fruit and vegetables, water dominates X-ray absorption. Defects that affect the density and the water content can, therefore, be visualized by X-ray imaging. Compared to two-dimensional radiography used in medicine and linescan radiography applied on grading machines, X-ray computer tomography (CT) is the most powerful technique from the horticultural research point of view, since two- and three-dimensional images can be reconstructed from the accumulated data to study internal physical and physiological processes. Generally, different sources are used to perform X-ray tomography. The first uses the divergent beam produced by a micro-focus X-ray tube and the second uses synchrotron radiation (Salvo et al., 2003).

Most internal disorders like woolliness in nectarines, hollow heart in potato, watercore and core breakdown in apples, and spongy tissue in mango affect the density and water content of the internal tissue and, hence, are detectable by means of X-ray measurements (Brecht et al., 1991; Tollner et al., 1992; Thomas et al., 1993; Sonego et al., 1995; Schatzki et al., 1997; Barcelon et al., 1999; Herremans et al., 2013). Lammertyn et al. (2003a,b) used X-ray CT to study the development of core breakdown disorder in "Conference" pears (*Pyrus communis* cv. Conference). After image processing of X-ray tomography slices of pears (Figure 13.1; left series of images), it was possible to measure non-destructively the breakdown development (in terms of area percentage of affected and unaffected tissue as well as the cavity and core area per slice) during storage measured on actual slices (Figure 13.1; right series of images) with an underestimation of 12%. MRI was proposed as a better method for following core breakdown during postharvest storage (Figure 13.1; middle series of images) (Lammertyn et al., 2003b). The advantage of X-ray CT is, however, its better resolution over MRI. Donis-Gonzalez et al. (2012a) used a medical CT system for evaluating the feasibility of inline sorting of chestnuts based on the presence of internal quality defects. Further progress will be required in hardware, image reconstruction and image processing algorithms to achieve sufficiently fast and affordable inline CT systems for product quality evaluation (Donis-Gonzalez et al., 2012b). Recently, as the resolution of the method is constantly improving, X-ray CT has been applied to study the fine structures of horticultural products at the submicron scale (Kuroki et al., 2004; Mendoza et al., 2007, 2010; Verboven et al., 2008; Ho et al., 2011; Musse et al., 2010).

IV Firmness

Firmness is traditionally measured by means of a Magness−Taylor (MT) penetrometer. The penetrometer test simulates the mastication of fruit tissue in the mouth, and the MT firmness incorporates several mechanical properties, including the elastic, shear and rupture properties, of the fruit tissue. The test is to some extent sensitive to the operator, and the MT firmness may be position dependent. The search for an alternative non-destructive firmness procedure for horticultural products has resulted in several techniques which allow using the same principles in laboratory and on-line conditions (De Ketelaere et al., 2003). Among the different technologies developed, sensors based on low mass impact and the acoustic impulse response are commercially available and most widely used. These are briefly discussed below.

A Impact analysis

Impact analysis is a simple and quick method for determining local fruit properties. De Baerdemaeker et al. (1982) and Rohrbach et al. (1982) made efforts to use either time domain or frequency domain characteristics of the impact force as a firmness indicator for a wide variety of fruits and vegetables. Nahir et al. (1986) reported that the characteristics of the impact response of dropping tomatoes on a rigid surface are highly correlated with both fruit weight and fruit firmness. Delwiche et al. (1987) found that impact characteristics derived from the time signal of peaches striking a rigid surface were highly correlated with the elastic modulus and penetrometer values of the fruit. A problem inherent in this technique is the fact that impact characteristics are highly dependent on the mass and radius of curvature of the fruit. A large variation in those parameters affects the accuracy of the technique. A different approach was suggested by Chen et al. (1985) who impacted the fruits with a small spherical impactor of known mass and radius of curvature. The deceleration of the impactor was related to fruit firmness (Chen et al., 1985; Chen and Ruiz-Altisent, 1996; Garcia-Ramos et al., 2003). The advantage of this technique is that the impact response is independent of the fruit mass and less sensitive to its radius of curvature. The technique was further investigated for a wide range of fruit by Jaren et al. (1992), Correa et al. (1992), Ruiz-Altisent et al. (1993), Molto et al. (1996) and Ragni et al. (2010). De Ketelaere et al. (2001, 2006a) used this technique to analyze apples and tomatoes and compared results to acoustic measurements which are discussed below.

B Acoustic impulse response measurements

The analysis of the acoustic fruit response to mechanical impulse in the frequency domain detects internal properties of the whole fruit, including firmness (Abbott et al., 1968; Finney and Norris, 1968; Cooke, 1972; Shmulevich et al., 1996; De Ketelaere et al., 2001, 2006b). Excitation of the fruit can be performed by a shaker (Peleg, 1993) or by impact excitation (Schotte et al., 1999). The fruit's response can be captured by an accelerometer (Peleg, 1993), a piezo-electric sensor (Galili et al., 1993) or a microphone (De Ketelaere et al., 2004). A computer which is hooked up to the transducer derives the frequency response spectrum from the time domain signal by means of a fast Fourier transform. A firmness index $F = f^2 m^{2/3}$ is typically calculated, where f is the first resonance frequency (Hz) and m is the mass of the fruit (kg) (Schotte et al., 1999).

The resonant frequencies and dynamic behavior of simply shaped objects (sphere, axisymmetric spheroid) are well understood and several studies have been carried out on various kinds of near-spherical agricultural objects such as apples (Chen and De Baerdemaeker, 1993), peaches (Verstreken and De Baerdemaeker, 1994), melons (Chen et al., 1996) and tomatoes (Langenakens et al., 1997). However, if the fruit shape is far from spherical, as in pears, Jancsók et al. (2001) have shown that an adapted firmness index which also includes a measure of shape S (e.g., the length/diameter ratio) is more appropriate:

$$F = \frac{1}{aS + b} f^2 m^{2/3}$$

where a and b are constants. As the authors only considered Conference pears, it is not clear whether the constants a and b depend on the species/cultivar.

As the firmness index is related to the elastic properties of the fruit only, it is fundamentally different from the MT firmness. This is illustrated in Figure 13.2, where the firmness index of tomato fruit is shown versus the compression force and the MT firmness (Hertog et al., 2004). The compression force (force required to compress the tomato fruit over a well-defined distance) essentially measures the elastic

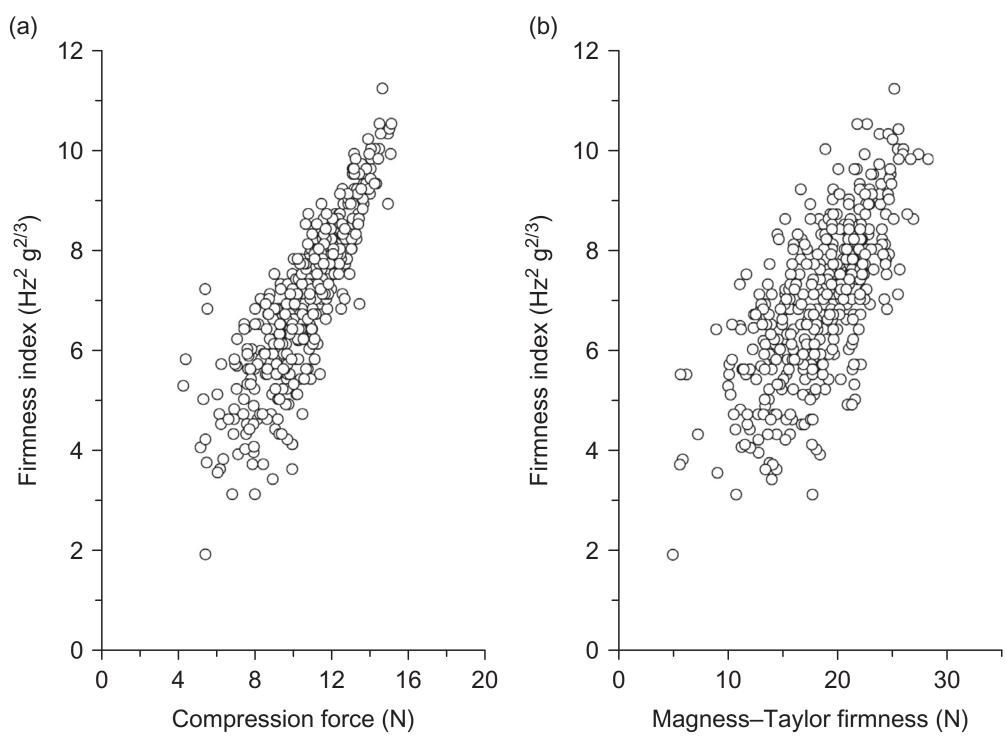

FIGURE 13.2

Firmness index versus compression force (a) and Magness–Taylor firmness (b) for tomato fruit.

Data from Hertog et al. (2004).

properties, and a relatively good relationship with the firmness index was obtained (Figure 13.2a). Conversely, a poor relationship was obtained between firmness index and MT firmness (Figure 13.2b). Shmulevich et al. (2003) compared an MT penetrometer, a commercially available low mass impact device and an acoustic device for apple firmness evaluation. They found that the correlation between low mass impact and acoustic firmness sensing was reasonably high ($r = 0.83-0.93$), while correlations with Magness–Taylor were low ($r = 0.43-0.60$). Golding et al. (2005) also reported moderate correlations between Magness–Taylor and non-destructive sensor technologies ($r = 0.62$ for an acoustic sensor and 0.82 for a low mass impact sensor). Similar conclusions were drawn by Valero and Crisosto (2004). De Ketelaere et al. (2006a) compared a commercial low mass impact sensor to a commercial acoustic sensor, and reported that the acoustic sensor is preferable for firm products, while for soft products the low mass impact sensor has its advantages. The lack of comparisons between techniques, together with the different physical backgrounds and related units, are the main reasons obstructing the rapid adoption of non-destructive firmness sensors in industry and among postharvest researchers.

Considering the commercial availability of these non-destructive sensors nowadays, and the proof of their ability to sense firmness and firmness changes of fruit with very different properties, the time might have come to consider these non-destructive techniques as new standards for fruit firmness evaluation, in place of the older destructive standard. However, in order to overcome the issues of comparison of technologies, there is a clear need for standardization of non-destructive firmness sensing of fruit and vegetables (De Ketelaere et al., 2006a).

V Taste components

Taste is defined as the sensation perceived through the tongue when exposed to certain classes of chemicals. Receptors have been identified for at least five taste attributes: sweet, acid, salt, bitter and umami. The latter attribute represents "savoriness" which is related to the presence of glutamates. While in fruit, sweetness and acidity are the most important taste attributes, in vegetables, other attributes may be important as well.

Taste attributes are typically measured by refractometry (sweetness), titration (acidity), high pressure liquid chromatography (HPLC; bitter and umami components) and atomic absorption (salts). These techniques all require destructive sampling. Non-destructive techniques for taste components are often based on the interaction of fruit or vegetable tissue with near infrared (NIR) radiation (wavelength range from 780 to 2500 nm).

A Near infrared spectroscopy

In NIR spectroscopy, the fruit or vegetable is irradiated with near infrared light, and the reflected or transmitted radiation is measured at a single or multiple spots

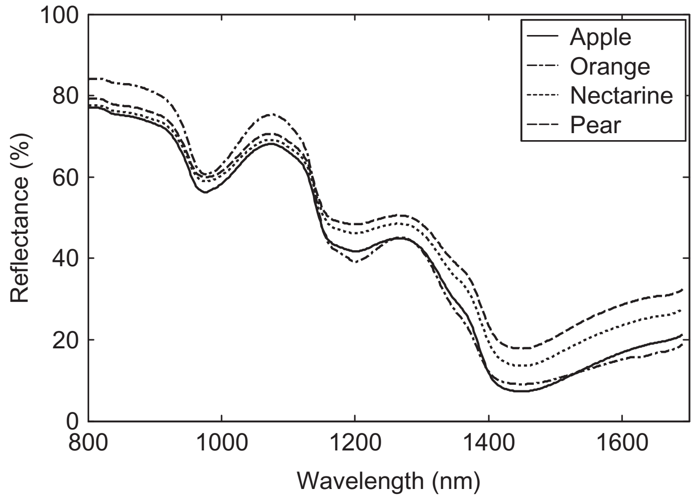

FIGURE 13.3

Typical NIR reflectance spectra of some fruit. The NIR reflectance spectra were recorded using a Corona 45 VIS/NIR diode array spectrophotometer (Carl Zeiss Jena Gmbh, Jena, Germany).

Reprinted from Nicolaï et al. (2007), with permission from Elsevier.

on the surface of the fruit. While the radiation penetrates the fruit, its spectral characteristics change through wavelength dependent reflection, scattering and absorption processes. This change depends on the chemical composition of the fruit including its sugar and acid content, as well on its light scattering properties which are related to its microstructure, and, hence, texture. Some typical near infrared reflectance spectra of different fruit species are shown in Figure 13.3. The near infrared spectrum of fruit and vegetables is dominated by the absorption bands of water and, therefore, advanced multivariate statistical techniques such as partial least squares regression are required to extract the required information from the usually convoluted spectra (Nicolaï et al., 2007).

The penetration depth of NIR radiation in fruit or vegetable tissue is limited. Lammertyn et al. (2000) found a penetration depth of up to 4 mm in the 700 to 900 nm range and between 2 and 3 mm in the 900 to 1900 nm range for apple. In a different optical configuration, Fraser et al. (2001) showed that the penetration depth in apple in the 700 to 900 nm range was at least 25 mm, while it became less than 1 mm in the 1400 to 1600 nm range. The limited penetration depth decreases the accuracy of NIR based measurements of internal quality attributes of thick-skinned fruit such as citrus. Transmission measurements, conversely, need very high light intensities which can easily burn the fruit surface and alter its spectral properties.

A drawback of NIR spectroscopy is that for each fruit species and cultivar a new calibration model is required, and the calibration models should be based on large datasets incorporating different orchards, seasons, cultivation systems, etc. (Peirs et al., 2003b). The prediction accuracy also depends on temperature

(Peirs et al., 2003a). Finally, the calibration models depend on the spectrophotometer, so that model transfer even between different spectrophotometers of the same brand and type is not straightforward.

NIR spectroscopy has been used to measure the soluble solids content (SSC) of various fruit including apple (Lammertyn et al., 1998), apricot (Carlini et al., 2000), cherry (Lu, 2001), kiwifruit (McGlone and Kawano, 1998), mandarin (Kawano et al., 1993), melon (Guthrie et al., 1998) and peach (Slaughter, 1995). The root mean squared error of prediction (RMSEP) is typically 0.5−1.0°Brix. Acidity in fruit is much more difficult to measure by means of NIR spectroscopy, although some reports have been published in which a reasonable accuracy was obtained (e.g., Peirs et al., 2002). Mehinagic et al. (2004) developed a calibration model to predict the sensory attributes of apple directly from NIR reflectance spectra. A full account of NIR applications in fruit and vegetables is given by Nicolaï et al. (2007).

Fruit grading lines equipped with NIR sensing devices are now commercially available from Aweta (IQA, www.aweta.nl), Greefa (iFA, www.greefa.nl), Mitsui-Kinzoku (www.mitsui-kinzoku.co.jp), Sacmi (F5, www.sacmi.it), TasteMark (www.taste-technologies.com) and others. Portable NIR spectrophotometers for field applications are available from Polychromix (now Thermo-Fisher Scientific, www.thermofisher.com—MicroPHAZIR).

B Multi- and hyperspectral imaging systems

Most applications of NIR spectroscopy which are described in the literature essentially rely on spot measurements. Peiris et al. (1999) however, observed a circumferential variation of up to 2% Brix for the SSC in a variety of fruit; the radial and proximal to distal variation was even larger. Several authors have, therefore, used multispectral (a few wavelengths) or hyperspectral (a continuous range of wavelengths) imaging systems to inspect the surface rather than only a single spot of the fruit. In such systems (e.g., Martinsen and Schaare, 1998), lines of spatial information with a full spectral range per spatial pixel are captured sequentially to complete a volume of spatial-spectral data. This is usually achieved by means of a spectrograph which disperses an incoming line of radiation into a spectral and spatial matrix which is captured by the camera. The horizontal and vertical pixels on the camera capture spatial and spectral information, respectively. Such a system, hence, provides full spectral information at every spatial position. The object must be moved stepwise under the camera by means of an actuator while at each step a line is scanned, but this is not necessarily a disadvantage when the system is mounted on a grading line on which the fruit is physically transported anyway. Novel developments include focal plane array cameras in combination with liquid crystal tuneable filters (LCTF), acousto-optical tunable filters (AOTF) or other monochromator principles which allow for much faster acquisition speeds (Bearman and Levenson, 2001).

Multi- and hyperspectral systems have been used to visualize the SSC distribution in kiwifruit (Martinsen and Schaare, 1998) and melons (Sugiyama, 1999; Long and Walsh, 2006).

C Spatially and time resolved spectroscopy

A typical reflectance or transmittance spectrum of fruit contains information about absorption as well as scattering properties. Absorption is related to the presence of chemical components, while scattering is related to the microstructure and, hence, the texture of the tissue. Several authors have attempted to develop techniques to measure absorption and scattering properties separately (Tu et al., 1995, 2000; McGlone et al., 1997). In *spatially resolved reflectance spectroscopy* (SRS) the fruit is irradiated with a light beam. Because of local scattering, the reflected spot is actually larger than the cross section of the light beam. In *time domain reflectance spectroscopy* (TRS), series of very short (pico or femto second) NIR light pulses are pumped into the fruit using a tunable laser or a solid state laser array (Cubeddu et al., 2001). The detector is positioned at some distance from the light entry point. Depending on the scattering properties of the tissue, the photons may follow a complicated path in the tissue and may take more or less time to reach the detector. As a result, the detector will measure a photon time-of-flight distribution from which, based on light diffusion theory, the absorption and scattering coefficient as a function of wavelength can be measured. These coefficient spectra can then be correlated with internal quality attributes such as taste or firmness.

TRS has been explored for the non-destructive quality evaluation of fruits such as apples, pears, nectarines, etc. (Cubeddu et al., 2001; Eccher Zerbini et al., 2002, 2006; Nicolaï et al., 2008; Rizzolo et al., 2009). For SRS, measurements based on a multispectral or hyperspectral camera have been used to acquire spatially resolved diffuse reflectance spectra for the prediction of fruit quality attributes (Lu, 2004; Qin and Lu, 2008; Qin et al., 2009).

VI Aroma

Aroma analysis is traditionally done by means of gas chromatography—mass spectrometry (GC-MS). In this technique, the headspace of the product is first sampled, either directly using a gas syringe, or via a concentration technique such as purge and trap or solid phase micro-extraction (SPME). The latter technique in particular has become very popular because it is simple, cheap and relatively straightforward to automate. After injection in the gas chromatograph, the headspace is separated into its different volatile components. For identification purposes, every eluting component is transferred to a mass spectrometer where it is fragmented into a mass spectrum. Although quadruple mass spectrometers are often used, more expensive time-of-flight mass analyzers are being used nowadays because of their higher sensitivity. The component can then be identified through a mass spectrum library search. While GC-MS remains the standard aroma analysis technique to date, it requires skilled personnel and the analysis time is too long for routine fruit aroma analyses.

A Fast mass spectrometric techniques

Unlike in normal GC-MS, in headspace fingerprint mass spectrometry (HFMS) the headspace of a sample is injected directly into the ionization chamber of a mass spectrometer without prior chromatographic separation (Shiers et al., 1999). This is typically implemented by means of a short capillary column which is operated at an elevated temperature so that a broad, featureless peak is obtained. The spectrum resulting from simultaneous ionization and fragmentation of the mixture of molecules introduced can be considered as a fingerprint of the actual aroma. Typically vials with juice are loaded into an autosampling system equipped with an SPME injector. While the technique is much faster than traditional GC-MS − samples can be analyzed every 2−5 min, depending on the headspace equilibration time required − headspace equilibration and extraction time and temperature must be controlled carefully to get reproducible results. A disadvantage of the technique is that it is unable to take variable odor thresholds into account. While for some products this may not be a problem, it certainly is when the headspace contains thiols or amines, which have a very low odor threshold. HFMS has been used successfully to measure ripeness of apple fruit (Saevels et al., 2004) and the aroma profile of tomato cultivars in a quality system (Berna et al., 2004). Recently, the evolution of aroma production in strawberries during superatmospheric oxygen storage was monitored using HFMS (Berna et al., 2007). Other techniques to speed up the gas chromatography analysis have been developed. In fast gas chromatography, a capillary column with a very small diameter is used in combination with a sensitive detector. The column temperature is often established using resistive heating, which allows very fast heating rates. Mondello et al. (2004) achieved an analysis time of 3.3 min for citrus essential oil, which represented an analysis speed gain factor of almost 14. Vandendriessche et al. (2013) used fast GC-MS for analyzing the headspace of strawberry.

Other novel mass spectrometry techniques for aroma analysis of fruit include soft ionization techniques such as atmospheric pressure chemical ionization (APCI; Boukobza et al., 2001; Garratt et al., 2005), selected ion flow tube mass spectrometry (SIFT-MS; Ascarate and Barringer, 2010), and multicapillary column chromatography coupled to ion mobility spectroscopy (IMS; Vandendriessche et al., 2012).

B Electronic noses

Electronic nose systems are sensor arrays which mimic the operation of a human nose. When an atmosphere loaded with volatile components flows over it, each sensor generates a signal. The combined signal of all sensors is then statistically related to, e.g., the response of a human taste panel. Sensors that rely on chemical properties of the target molecule, whether it can adsorb at a particular surface, or be oxidized or reduced, have been developed for a variety of analytes. Popular at present are sensors based on the conduction of semiconductors such as tin oxide or polymers such as polypyrrole (Gardner and Bartlett, 1994; Di Natale et al., 2000). More sensitive are sensors that "weigh" impinging molecules such as piezoelectric crystals and surface acoustic wave devices. Recently, immobilized olfactory neurons of rodents have been explored as a basis of a bio-electronic nose (Micholt et al., 2013). Signal drift remains an important problem in all sensor types.

In horticulture, electronic noses have been successful in monitoring the aroma of melons (Benady et al., 1995), pears (Oshita et al., 2000), peaches (Molto et al., 1999), nectarines (Di Natale et al., 2001) tomatoes (Maul et al., 1998; Berna et al., 2004), mango (Li et al., 2009) and citrus (Pallottino et al., 2012). Most research has focused on the classification of cultivars or the evaluation of changes in the aroma profile during maturation and ripening. Measuring the headspace of apples has been an interesting challenge for electronic noses, since the aroma is an important maturity indicator that correlates well with consumer acceptance (Brezmes et al., 2001). Hines et al. (1999) and Young et al. (1999) used an electronic nose to measure ripeness of apples. Aroma changes of apples during shelf life and the optimal picking date were successfully determined non-destructively using an electronic nose by Saevels et al. (2003) and Saevels et al. (2004). Berna et al. (2004) investigated the effect of shelf life and cultivar on the aroma of tomato using a quartz microbalance electronic nose system. These authors also correlated tomato aroma measured using an electronic nose successfully with sensory properties and consumer preference (Berna et al., 2005a,b).

An important step in miniaturization and cost reduction was made by Rakow and Suslick (2000), who developed a two-dimensional array of metalloporphyrins as sensor elements for the visual identification of a wide range of olfactants and even weakly ligating solvent vapors. The color of the sensors change depending on the absorbed volatile molecules, and the resulting 2-D fingerprint can be measured with a scanner. While this technology has, as far as we know, not been used in postharvest applications, it opens up the possibility of low cost, disposable electronic nose sensors. The New Zealand company ripeSense (www.ripesense.com) has taken up this idea and developed a disposable sensor which reacts to the aromas released by the fruit as it ripens. The sensor is initially red and graduates to orange and finally yellow. The sensor can be integrated into a package and gives the consumer an idea of the ripeness of the fruit. It can be expected that similar sensors will emerge within the next couple of years.

VII Conclusions

Many novel non-destructive systems have become available to measure internal quality attributes of fruit and vegetables. Some of them, in particular vibration and impact based techniques for measuring firmness as well as NIR spectroscopy for measuring soluble solids content, are now implemented on grading lines.

As a consequence, grading based on internal quality attributes rather than external appearance becomes possible, and this is expected to radically change the way fresh fruit are commercialized. Their market penetration is yet still relatively low, though, and depends as always on whether the value added by grading outweighs the investment cost. Also, a successful commercial implementation of these techniques will depend on the reliability of the measurements, their correlation with existing techniques and their speed.

Recent advances in portable NIR spectrophotometers open up the possibility to use non-destructive techniques in the orchard. Such information can be helpful to determine harvest maturity and optimal picking dates, and to construct quality maps in precision horticulture applications.

Acknowledgments

We would like to acknowledge the Fund for Scientific Research Flanders (project G.0298.06), the IWT-Vlaanderen (project 20670, 70585 and SBO/120033), and the University of Leuven through a bilateral scientific collaboration between Flanders and Russia (BIL/05/47).

Bibliography

Abbott, J.A., Bachman, G.S., Childers, R.F., Fitzgerald, J.V., Matusik, F.J., 1968. Sonic technique for measuring texture of fruit and vegetables. Food. Technol. 22, 101–112.

Abbott, J.A., Lu, R., Upchurch, B.L., Stroshine, R.L., 1997. Technologies for non-destructive quality evaluation of fruits and vegetables. Hortic. Rev. 20, 1–120.

ASTM, 2000. Standards on Color and Appearance Measurements, sixth ed. American Society for Testing and Materials, Philadelphia.

Azcarate, C., Barringer, S.A., 2010. Effect of enzyme activity and frozen storage on jalapeño pepper volatiles by selected ion flow tube-mass spectrometry. J. Food Sci. 75, C710–C721.

Barcelon, E.G., Tojo, S., Watanabe, K., 1999. X-ray CT imaging and quality detection of peach at different physiological maturity. Trans. ASAE 42, 435–441.

Bearman, G., Levenson, R., 2001. Biological imaging spectroscopy. <http://hdl.handle.net/2014/11729>.

Benady, M., Simon, J.E., Charles, D.J., Miles, G.E., 1995. Fruit ripeness determination by electronic sensing of aromatic volatiles. Trans. ASAE 38, 251–257.

Berna, A.Z., Lammertyn, J., Saevels, S., Di Natale, C., Nicolai, B.M., 2004. Electronic nose systems to study shelf life and cultivar effect on tomato aroma profile. Sens. Actuators B-Chem. 97, 324–333.

Berna, A.Z., Buysens, S., Di Natale, C., Grun, I.U., Lammertyn, J., Nicolaï, B.M., 2005a. Relating sensory analysis with electronic nose and headspace fingerprint MS for tomato aroma profiling. Postharvest. Biol. Technol. 36, 143–155.

Berna, A.Z., Lammertyn, J., Buysens, S., Di Natale, C., Nicolaï, B.M., 2005b. Mapping consumer liking of tomatoes with fast aroma profiling techniques. Postharvest. Biol. Technol. 38, 115−127.

Berna, A.Z., Geysen, S., Li, S., Verlinden, B., Lammertyn, J., Nicolai, B.M., 2007. Headspace fingerprint mass spectrometry to characterize strawberry aroma at super atmospheric oxygen conditions. Postharvest. Biol. Technol. 46, 230−236.

Boukobza, F., Dunphy, P.J., Taylor, A.J., 2001. Measurement of lipid oxidation-derived volatiles in fresh tomatoes. Postharvest. Biol. Technol. 23, 117−131.

Brecht, J.K., Shewfelt, R.L., Garner, J.C., Tollner, E.W., 1991. Using X-ray-computed tomography to nondestructively determine maturity of green tomatoes. HortScience 26, 45−47.

Brezmes, J., Llobet, E., Vilanova, X., Orts, J., Saiz, G., Correig, X., 2001. Correlation between electronic nose signals and fruit quality indicators on shelf-life measurements with pinklady apples. Sens. Actuators B-Chem. 80, 41−50.

Brosnan, T., Sun, D.W., 2004. Improving quality inspection of food products by computer vision − a review. J. Food Eng. 61, 3−16.

Bulanon, D.M., Kataoka, T., Ota, Y., Hiroma, T., 2002. Segmentation algorithm for the automatic recognition of Fuji apples at harvest. Biosyst. Eng. 83, 405−412.

Butz, P., Hofmann, C., Tauscher, B., 2005. Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. J. Food. Sci. 70, R131−R141.

Carlini, P., Massantini, R., Mencarelli, F., 2000. Vis-NIR measurement of soluble solids in cherry and apricot by PLS regression and wavelength selection. J. Agric. Food. Chem. 48, 5236−5242.

Chayaprasert, W., Stroshine, R., 2005. Rapid sensing of internal browning in whole apples using a low-cost, low-field proton magnetic resonance sensor. Postharvest. Biol. Technol. 36, 291−301.

Chen, H., De Baerdemaeker, J., 1993. Finite-element-based modal analysis of fruit firmness. Trans. ASAE 36, 1827−1833.

Chen, H., De Baerdemaeker, J., Bellon, V., 1996. Finite element study of the melon for nondestructive sensing of firmness. Trans. ASAE 39, 1057−1065.

Chen, P., Ruiz-Altisent, M., 1996. A Low-mass impact sensor for high-speed firmness sensing of fruits. In: Proceedings of the Agricultural Engineering International Conference 96, AGENG 96, Madrid, Spain, 23−26 September 1996, paper 96F-003.

Chen, P., Tang, S., Chen, S., 1985. Instrument for testing the response of fruits to impact. ASAE Paper 75−3537. ASAE, St. Joseph, MI.

Chen, P., McCarthy, M.J., Kauten, R., 1989. NMR for internal quality evaluation of fruits and vegetables. Trans. ASAE 32, 1747−1753.

Clark, C.J., Burmeister, D.M., 1999. Magnetic resonance imaging of browning development in ‘Braeburn’ apple during controlled-atmosphere storage under high CO2. HortScience 34, 915−919.

Clark, C.J., Richardson, C.A., 1999. Observation of watercore dissipation in ‘Braeburn’ apple by magnetic resonance imaging. New Zeal. J. Crop. Hortic. Sci. 27, 47−52.

Clark, C.J., Drummond, L.N., MacFall, J.S., 1998a. Quantitative NMR imaging of kiwifruit (*Actinidia deliciosa*) during growth and ripening. J. Sci. Food. Agric. 78, 349−358.

Clark, C.J., MacFall, J.S., Bieleski, R.L., 1998b. Loss of watercore from ‘Fuji’ apple observed by magnetic resonance imaging. Sci. Hortic. (Amsterdam). 73, 213−227.

Cooke, J.R., 1972. Interpretation of resonant behavior of intact fruits and vegetables. Trans. ASAE 15, 1075−1080.

Correa, P., Ruiz-Altisent, M., de la Plaza, J.L., 1992. Physical parameters in relation to physiological changes of avocado during ripening (20°C) and cold storage (6°C) in different conditions. In: Proceedings of the Agricultural Engineering International Conference 92, AGENG 92, Uppsala, Sweden, 1–4 June 1992, paper 9211–16.

Cubeddu, R., D'Andrea, C., Pifferi, A., Taroni, P., Torricelli, A., Valentini, G., et al., 2001. Nondestructive quantification of chemical and physical properties of fruits by time-resolved reflectance spectroscopy in the wavelength range 650–1000 nm. Appl. Opt. 40, 538–543.

Danieli, E., Mauler, J., Perlo, J., Blümich, B., Casanova, F. , 2009. Mobile sensor for high resolution NMR spectroscopy and imaging. J. Magn. Reson. 198, 80–87.

Danieli, E., Berdel, K., Perlo, J., Michaeli, W., Masberg, U., Blümich, B., et al., 2010. Determining object boundaries from MR images with sub-pixel resolution: towards in-line inspection with a mobile tomograph. J. Magn. Reson. 207, 53–58.

De Baerdemaeker, J., Lemaitre, L., Meire, R., 1982. Quality detection by frequency-spectrum analysis of the fruit impact force. Trans. ASAE 25, 175–178.

De Ketelaere, B., Ruiz-Altisent, M., Correa, E., De Baerdemaeker, J., Barreiro, P., 2001. Reliability of vibration measurements and impact response characteristics for the quality assessment of tomatoes. In: Proceedings of the Sixth International Symposium on Fruit, Nut and Vegetable Production Engineering, Potsdam, Germany, 11–14 September 2001, pp. 487–492.

De Ketelaere, B., Lammertyn, J., Molenberghs, G., Nicolai, B., De Baerdemaeker, J., 2003. Statistical models for analyzing repeated quality measurements of horticultural products. Model evaluations and practical example. Math. Biosci. 185, 169–189.

De Ketelaere, B., Lammertyn, J., Molenberghs, G., Desmet, M., Nicolaï, B., De Baerdemaeker, J., 2004. Tomato cultivar grouping based on firmness change, shelf life and variance during postharvest storage. Postharvest. Biol. Technol. 34, 187–201.

De Ketelaere, B., Howarth, M.S., Crezee, L., Lammertyn, J., Viaene, K., Bulens, I., et al., 2006a. Postharvest firmness changes as measured by acoustic and low-mass impact devices: a comparison of techniques. Postharvest. Biol. Technol. 41, 275–284.

De Ketelaere, B., Stulens, J., Lammertyn, J., Cuong, N.V., De Baerdemaeker, J., 2006b. A methodological approach for the identification and quantification of sources of biological variance in postharvest research. Postharvest. Biol. Technol. 39, 1–9.

Delwiche, M.J., Mcdonald, T., Bowers, S.V., 1987. Determination of peach firmness by analysis of impact forces. Trans. ASAE 30, 249–254.

Di Natale, C., Mantini, A., Macagnano, A., Paolesse, R., D'Amico, A., 2000. The application of an electronic nose to the analysis of post-harvested fruits. In: Proceedings of the Fourteenth European Conference on Solid-State Transducers, Eurosensors XIV, Copenhagen, Denmark, 27–30 August 2000, pp. 61–62.

Di Natale, C., Macagnano, A., Martinelli, E., Proietti, E., Paolesse, R., Castellari, L., et al., 2001. Electronic nose based investigation of the sensorial properties of peaches and nectarines. Sens. Actuators B–Chem. 77, 561–566.

Donis-Gonzalez, I.R., Guyer, D.E., Pease, A., Fulbright, D.W., 2012a. Relation of computerized tomography Hounsfield unit measurements and internal components of fresh chestnuts (*Castanea spp.*). Postharvest. Biol. Technol. 64, 74–82.

Donis-Gonzalez, I.R., Guyer, D.E., Pease, A., 2012b. Application of response surface methodology to systematically optimize image quality in computer tomography: a case study using fresh chestnuts (*Castanea spp.*). Comput. Electron Agric. 87, 94–107.

Eccher Zerbini, P., Grassi, M., Cubeddu, R., Pifferi, A., Torricelli, A., 2002. Nondestructive detection of brown heart in pears by time-resolved reflectance spectroscopy. Postharvest. Biol. Technol. 25, 87–97.

Eccher Zerbini, P., Vanoli, M., Grassi, M., Rizzolo, A., Fibiani, M., Cubeddu, R., et al., 2006. A model for the softening of nectarines based on sorting fruit at harvest by time-resolved reflectance spectroscopy. Postharvest. Biol. Technol. 39, 223–232.

Finney, D.D., Norris, K.H., 1968. Instrumentation for investigating dynamic mechanical properties of fruits and vegetables. Trans. ASAE 11, 94–97.

Fraser, D.G., Kunnemeyer, R., McGlone, V.A., Jordan, R.B., 2001. Near infra-red (NIR) light penetration into an apple. Postharvest. Biol. Technol. 22, 191–194.

Galili, N., Rosenhouse, G., Mizrach, A., 1993. Ultrasonic technique for fruit and vegetable quality evaluation. In: Proceedings of the Fourth International Symposium on Fruit, Nut and Vegetable Production Engineering, Valencia-Zaragoza, Spain, 22–26 March 1993, pp. 281–289.

Garcia-Ramos, F.J., Ortiz-Canavate, J., Ruiz-Altisent, M., Diez, J., Flores, L., Homer, I., et al., 2003. Development and implementation of an on-line impact sensor for firmness sensing of fruits. J. Food Eng. 58, 53–57.

Gardner, J.W., Bartlett, P.N., 1994. A brief history of electronic noses. Sens. Actuators B–Chem. 18, 211–220.

Garratt, L.C., Linforth, R., Taylor, A.J., Lowe, K.C., Power, J.B., Davey, M.R., 2005. Metabolite fingerprinting in transgenic lettuce. Plant. Biotechnol. J. 3, 165–174.

Golding, J.B., Spohr, L., Newman, S., Tanner, D.J., Orszulok, E., Smale, N., et al., 2005. Nondestructive assessment of peach and nectarine firmness. ISHS Acta Horticulturae 687: Int. Conf. Postharvest Unlimited Downunder 2004, 261–270.

Gonzalez, J.J., Valle, R.C., Bobroff, S., Viasi, W.V., Mitcham, E.J., McCarthy, M.J., 2001. Detection and monitoring of internal browning development in 'Fuji' apples using MRI. Postharvest. Biol. Technol. 22, 179–188.

Guthrie, J.A., Wedding, B., Walsh, K.B., 1998. Robustness of NIR calibrations for soluble solids in intact melon and pineapple. J. Near Infrared Spectrosc. 6, 259–265.

Herman, G.T., 1980. Image Reconstruction from Projections. Academic Press, New York.

Hernández-Sánchez, N., Hills, B.P., Barreiro, P., Marigheto, N., 2007. An NMR study on internal browning in pears. Postharvest. Biol. Technol. 44, 260–270.

Herremans, E., Verboven, P., Bongaers, E., Estrade, P., Verlinden, B., Wevers, M., et al., 2013. Characterization of 'Braeburn' browning disorder by means of X-ray micro-CT. Postharvest. Biol. Technol. 75, 114–124.

Hertog, M.L.A.T.M., Ben-Arie, R., Róth, E., Nicolaï, B.M., 2004. Humidity and temperature effects on invasive and non-invasive firmness measures. Postharvest. Biol. Technol. 33, 79–91.

Hertog, M.L.A.T.M., Lammertyn, J., De Ketelaere, B., Scheerlinck, N., Nicolai, B.A., 2007. Managing quality variance in the postharvest food chain. Trends Food Sci. Technol. 18, 320–332.

Hines, E.L., Llobet, E., Gardner, J.W., 1999. Neural network based electronic nose for apple ripeness determination. Electron. Lett. 35, 821–823.

Ho, Q., Verboven, P., Verlinden, B., Herremans, E., Wevers, M., Carmeliet, J., et al., 2011. A 3-D multiscale model for gas exchange in fruit. Plant. Physiol. 155, 1158–1168.

Jancsók, P., Clijmans, L., Nicolaï, B.M., De Baerdemaeker, J., 2001. Investigation of the effect of shape on the acoustic response of conference pears by finite element modelling. Postharvest Biol. Technol. 23, 1–12.

Jaren, C., Ruiz-Altisent, M., Perez de Rueda, R., 1992. Sensing physical stage of fruit by their response to nondestructive impacts. In: Proceedings of the Agricultural Engineering International Conference 92, AGENG 92, Uppsala, Sweden, 1–4 June 1992, paper 9211–113.

Kawano, S., Fujiwara, T., Iwamoto, M., 1993. Nondestructive determination of sugar content in satsuma mandarine using near-infrared (Nir) transmittance. J. Jpn. Soc. Hortic. Sci. 62, 465–470.

Kondo, N., Nishitsuji, Y., Ling, P.P., Ting, K.C., 1996. Visual feedback guided robotic cherry tomato harvesting. Trans. ASAE 39, 2331–2338.

Kuroki, S., Oshita, S., Sotome, I., Kawagoe, Y., Seo, Y., 2004. Visualization of 3-D network of gas-filled intercellular spaces in cucumber fruit after harvest. Postharvest. Biol. Technol. 33, 255–262.

Lammertyn, J., Nicolaï, B., Ooms, K., De Smedt, V., De Baerdemaeker, J., 1998. Nondestructive measurement of acidity, soluble solids, and firmness of jonagold apples using NIR-spectroscopy. Trans. ASAE 41, 1089–1094.

Lammertyn, J., Peirs, A., De Baerdemaeker, J., Nicolai, B., 2000. Light penetration properties of NIR radiation in fruit with respect to non-destructive quality assessment. Postharvest. Biol. Technol. 18, 121–132.

Lammertyn, J., Dresselaers, T., Van Hecke, P., Jancsok, P., Wevers, M., Nicolai, B.M., 2003a. Analysis of the time course of core breakdown in 'Conference' pears by means of MRI and X-ray CT. Postharvest. Biol. Technol. 29, 19–28.

Lammertyn, J., Dresselaers, T., Van Hecke, P., Jancsok, P., Wevers, M., Nicolaï, B.M., 2003b. MRI and X-ray CT study of spatial distribution of core breakdown in 'Conference' pears. Magn. Reson. Imag. 21, 805–815.

Langenakens, J., Vandewalle, X., De Baerdemaeker, J., 1997. Influence of global shape and internal structure of tomatoes on the resonant frequency. J. Agric. Eng. Res. 66, 41–49.

Li, Z.F., Wang, N., Raghavan, G.S.V., Vigneault, C., 2009. Ripeness and rot evaluation of 'Tommy Atkins' mango fruit through volatiles detection. J. Food Eng. 91, 319–324.

Liao, K., Reid, J.F., Paulsen, M.R., Ni, B., 1992. Knowledge based color discrimination of corn kernels. ASAE Paper 923579. ASAE, St. Joseph, MI.

Lim, K.S., Barigou, M., 2004. X-ray micro-computed tomography of cellular food products. Food Res. Int. 37, 1001–1012.

Long, R.L., Walsh, K.B., 2006. Limitations to the measurement of intact melon total soluble solids using near infrared spectroscopy. Aust. J. Agric. Res. 57, 403–410.

Lu, R., 2001. Predicting firmness and sugar content of sweet cherries using near-infrared diffuse reflectance spectroscopy. Trans. ASAE 44, 1265–1271.

Lu, R.F., 2004. Prediction of apple fruit firmness by near-infrared multispectral scattering. J. Texture Stud. 35, 263–276.

Macdougall, D.B., 1982. Changes in the color and opacity of meat. Food. Chem. 9, 75–88.

Maire, E., Buffière, J.Y., Salvo, L., Blandin, J.J., Ludwig, W., Létang, J.M., 2001. On the application of X-ray microtomography in the field of material science. Adv. Eng. Mater. 3, 546.

Maire, E., Fazekas, A., Salvo, L., Dendievel, R., Youssef, S., Cloetens, P., et al., 2003. X-ray tomography applied to the characterization of cellular materials. Related finite element modeling problems. Comp. Sci. Technol. 63, 2431–2443.

Martinsen, P., Schaare, P., 1998. Measuring soluble solids distribution in kiwifruit using near-infrared imaging spectroscopy. Postharvest. Biol. Technol. 14, 271–281.

Maul, F., Sargent, S.A., Balaban, M.O., Baldwin, E.A., Huber, D.J., Sims, C.A., 1998. Aroma volatile profiles from ripe tomatoes are influenced by physiological maturity at harvest: an application for electronic nose technology. J. Am. Soc. Hortic. Sci. 123, 1094–1101.

McGlone, V.A., Kawano, S., 1998. Firmness, dry-matter and soluble-solids assessment of postharvest kiwifruit by NIR spectroscopy. Postharvest. Biol. Technol. 13, 131–141.

McGlone, V.A., Abe, H., Kawano, S., 1997. Kiwifruit firmness by near infrared light scattering. J. Near Infrared Spectrosc. 5, 83–89.

Mehinagic, E., Royer, G., Symoneaux, R., Bertrand, D., Jourjon, F., 2004. Prediction of the sensory quality of apples by physical measurements. Postharvest. Biol. Technol. 34, 257–269.

Mehl, P.M., Chen, Y.R., Kim, M.S., Chan, D.E., 2004. Development of hyperspectral imaging technique for the detection of apple surface defects and contaminations. J. Food Eng. 61, 67–81.

Melado-Herreros, A., Muñoz-García, M.A., Blanco, A., Val, J., Fernández-Valle, M.E., Barreiro, P., 2013. Assessment of watercore development in apples with MRI: effect of fruit location in the canopy. Postharvest. Biol. Technol. 86, 125–133.

Mendoza, F., Verboven, P., Mebatsion, H.K., Kerckhofs, G., Wevers, M., Nicolaï, B., 2007. Three-dimensional pore space quantification of apple tissue using X-ray computed microtomography. Planta 226, 559–570.

Mendoza, F., Verboven, P., Ho, Q.T., Kerckhofs, G., Wevers, M., Nicolaï, B.M., 2010. Multifractal properties of pore-size distribution in apple tissue using X-ray imaging. J. Food Eng. 99, 206–215.

Micholt, E., Jans, E., Callewaert, E., Bartic, C., Lammertyn, J., Nicolaï, B.M., 2013. Extracellular recordings from rat olfactory epithelium slices using micro electrode arrays. Sen. Actuators B–Chem. 184, 40–47.

Milczarek, R.R., McCarthy, M.J., 2009. Low-field MR sensors for fruit inspection. In: Codd, S., Seymour, J. (Eds.), Magnetic Resonance Microscopy, Spatially Resolved NMR Techniques and Applications. Wiley–VCH, Weinheim Germany, pp. 289–299.

Molto, E., Selfa, E., Pons, R., Fornes, I., 1996. Non destructive measuring of firmness using impact sensors. In: Proceedings of the Agricultural Engineering International Conference 96, AGENG 96, Madrid, Spain, 23–26 September 1996, paper 96F–014.

Molto, E., Selfa, E., Ferriz, J., Conesa, E., Gutierrez, A., 1999. An aroma sensor for assessing peach quality. J. Agri. Eng. Res. 72, 311–316.

Mondello, L., Casilli, A., Tranchida, P.Q., Costa, R., Dugo, P., Dugo, G., 2004. Fast GC for the analysis of citrus oils. J. Chromatogr. Sci. 42, 410–416.

Musse, M., De Guio, F., Quellec, S., Cambert, M., Challois, S., Davenel, A., 2010. Quantification of microporosity in fruit by MRI at various magnetic fields: comparison with X-ray microtomography. Magn. Reson. Imag. 28, 1525–1534.

Nahir, D., Schmilovitch, Z., Ronen, B., 1986. Tomato grading by impact force response. ASAE Paper 86-3028. ASAE, St. Joseph, MI.

Nguyen, T.A., Dresselaers, T., Verboven, P., D'hallewin, G., Culeddu, N., Van Hecke, P., et al., 2006. Finite element modelling and MRI validation of 3D transient water profiles in pears during postharvest storage. J. Sci. Food. Agric. 86, 745–756.

Nicolaï, B.M., Beullens, K., Bobelyn, E., Peirs, A., Theron, K.I., Lammertyn, J., 2007. Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy. Postharvest. Biol. Technol. 46, 99–118.

Nicolaï, B.M., Verlinden, B.E., Desmet, M., Saevels, S., Theron, K., Cubeddu, R., et al., 2008. Time-resolved and continuous wave NIR reflectance spectroscopy to predict firmness and soluble solids content of conference pears. Postharvest Biol. Technol. 47, 68–74.

Oshita, S., Shima, K., Haruta, T., Seo, Y., Kawagoe, Y., Nakayama, S., et al., 2000. Discrimination of odors emanating from 'La France' pear by semi-conducting polymer sensors. Comp. Electron. Agri. 26, 209–216.

Pallottino, F., Costa, C., Antonucci, F., Strano, M.C., Calandra, M., Solaini, S., et al., 2012. Electronic nose application for determination of *Penicillium digitatum* in valencia oranges. J. Sci. Food. Agric. 92, 2008–2012.

Park, B., Chen, Y.R., Nguyen, M., 1998. Multi-spectral image analysis using neural network algorithm for inspection of poultry carcasses. J. Agric. Eng. Res. 69, 351–363.

Peiris, K.H.S., Dull, G.G., Leffler, R.G., Kays, S.J., 1999. Spatial variability of soluble solids or dry-matter content within individual fruits, bulbs, or tubers: implications for the development and use of NIR spectrometric techniques. HortScience 34, 114–118.

Peirs, A., Scheerlinck, N., Touchant, K., Nicolai, B.M., 2002. Comparison of Fourier transform and dispersive near-infrared reflectance spectroscopy for apple quality measurements. Biosyst. Eng. 81, 305–311.

Peirs, A., Scheerlinck, N., Nicolaï, B.M., 2003a. Temperature compensation for near infrared reflectance measurement of apple fruit soluble solids contents. Postharvest. Biol. Technol. 30, 233–248.

Peirs, A., Tirry, J., Verlinden, B., Darius, P., Nicolaï, B.M., 2003b. Effect of biological variability on the robustness of NIR models for soluble solids content of apples. Postharvest. Biol. Technol. 28, 269–280.

Peleg, K., 1993. Comparison of nondestructive and destructive measurement of apple firmness. J. Agric. Eng. Res. 55, 227–238.

Qin, J., Lu, R., Peng, Y., 2009. Prediction of apple internal quality using spectral absorption and scattering properties. Trans. ASABE 52, 499–507.

Qin, J.W., Lu, R.F., 2008. Measurement of the optical properties of fruits and vegetables using spatially resolved hyperspectral diffuse reflectance imaging technique. Postharvest. Biol. Technol. 49, 355–365.

Ragni, L., Berardinelli, A., Guarnieri, A., 2010. Impact device for measuring the flesh firmness of kiwifruits. J. Food Eng. 96, 591–597.

Rakow, N.A., Suslick, K.S., 2000. A colorimetric sensor array for odour visualization. Nature 406, 710–713.

Rizzolo, A., Vanoli, M., Zerbini, P.E., Jacob, S., Torricelli, A., Spinelli, L., et al., 2009. Prediction ability of firmness decay models of nectarines based on the biological shift factor measured by time-resolved reflectance spectroscopy. Postharvest. Biol. Technol. 54, 131–140.

Rohrbach, R.P., Franke, J.E., Willits, D.H., 1982. A firmness sorting criterion for blueberries. Trans. ASAE 25, 261–265.

Ruiz-Altisent, M., Ruiz-Garcia, L., Moreda, G., Hernandez-Sanchez, N., Correa, E., Diezma, B., et al., 2010. Sensors for product characterization and quality of specialty crops – a review. Comput. Electron. Agric. 74, 176–194.

Ruiz-Altisent, M., Jaren, C., Correa, P., 1993. Fruit quality sensing: post harvest ripeness. In: Proceedings of the Fourth International Symposium on Fruit Nut and Vegetable Production Engineering, Valencia–Zaragoza, Spain, 22–26 March 1993, pp. 211–222.

Saevels, S., Lammertyn, J., Berna, A.Z., Veraverbeke, E.A., Di Natale, C., Nicolai, B.M., 2003. Electronic nose as a non-destructive tool to evaluate the optimal harvest date of apples. Postharvest. Biol. Technol. 30, 3–14.

Saevels, S., Lammertyn, J., Berna, A.Z., Veraverbeke, E.A., Di Natale, C., Nicolaï, B.M., 2004. An electronic nose and a mass spectrometry-based electronic nose for assessing apple quality during shelf life. Postharvest. Biol. Technol. 31, 9–19.

Salvo, L., Cloetens, P., Maire, E., Zabler, S., Blandin, J.J., Buffiere, J.Y., et al., 2003. X-ray micro-tomography an attractive characterisation technique in materials science. Nucl. Instrum. Methods Phys. Res. Sect. B 200, 273–286.

Schatzki, T.F., Haff, R.P., Young, R., Can, I., Le, L.C., Toyofuku, N., 1997. Defect detection in apples by means of X-ray imaging. Trans. ASAE 40, 1407–1415.

Schotte, S., De Belie, N., De Baerdemaeker., J., 1999. Acoustic impulse–response technique for evaluation and modelling of firmness of tomato fruit. Postharvest. Biol. Technol. 17, 105–115.

Shiers, V., Adechy, M., Squibb, A., 1999. A new mass spectrometry-based electronic nose for headspace characterisation. In: Electronic Noses and Sensor Array Based Systems; Design and Application. Proceedings of the Fifth International Symposium on Olfaction and the Electronic Nose, Baltimore, Maryland, USA, 27–30 September 1998, pp. 289–295.

Shmulevich, I., Galili, N., Rosenfeld, D., 1996. Detection of fruit firmness by frequency analysis. Trans. ASAE 39, 1047–1055.

Shmulevich, I., Galili, N., Howarth, M.S., 2003. Nondestructive dynamic testing of apples for firmness evaluation. Postharvest. Biol. Technol. 29, 287–299.

Slaughter, D.C., 1995. Nondestructive determination of internal quality in peaches and nectarines. Trans. ASAE 38, 617–623.

Sonego, L., Benarie, R., Raynal, J., Pech, J.C., 1995. Biochemical and physical evaluation of textural characteristics of nectarines exhibiting woolly breakdown – NMR imaging, X-Ray computed-tomography and pectin composition. Postharvest. Biol. Technol. 5, 187–198.

Sugiyama, J., 1999. Visualization of sugar content in the flesh of a melon by near-infrared imaging. J. Agric. Food. Chem. 47, 2715–2718.

Swatland, H.J., 1995. On-Line Evaluation of Meat. Technomic Publishing Company, Inc., Lancaster, Pennsylvania.

Tao, Y., Heinemann, P.H., Varghese, Z., Morrow, C.T., Sommer, H.J., 1995. Machine vision for color inspection of potatoes and apples. Trans. ASAE 38, 1555–1561.

Thomas, P., Saxena, S.C., Chandra, R., Rao, R., Bhatia, C.R., 1993. X-Ray-imaging for detecting spongy tissue, an internal disorder in fruits of alphonso mango (*Mangifera-Indica L*). J. Hortic. Sci. 68, 803–806.

Throop, J.A., Aneshansley, D.J., Anger, W.C., Peterson, D.L., 2005. Quality evaluation of apples based on surface defects: development of an automated inspection system. Postharvest. Biol. Technol. 36, 281–290.

Tollner, E.W., Hung, Y.C., Upchurch, B.L., Prussia, S.E., 1992. Relating X-ray absorption to density and water-content in apples. Trans. ASAE 35, 1921–1928.

Tu, K., De Busscher, R., De Baerdemaeker, J., Schrevens, E., 1995. Using laser beam as light source to study tomato and apple quality non-destructively. In: Proceedings of the Food Processing Automation IV Conference, Chicago, Illinois, 3–5 November 1995, pp. 528–536.

Tu, K., Jancsok, P., Nicolaï, B., De Baerdemaeker, J., 2000. Use of laser-scattering imaging to study tomato-fruit quality in relation to acoustic and compression measurements. Int. J. Food Sci. Technol. 35, 503–510.

Valero, C., Crisosto, C.H., 2004. Relation between destructive and nondestructive bench top firmness measurements on peaches, nectarines and plums. Cent. Val. Postharvest News Lett. 13, 5–6.

Van As, H., Van Duynhoven, J., 2013. MRI of plants and foods. J. Magn. Reson. 229, 25–34.

van Dalen, G., Blonk, H., van Aalst, H., Hendriks, C.L., 2003. 3-D imaging of foods using X-ray microtomography. GIT Imag. Microsc. 3, 18–21.

Vandendriessche, T., Keulemans, J., Geeraerd, A., Nicolaï, B.M., Hertog, M.L.A.T.M., 2012. Evaluation of fast volatile analysis for detection of botrytis cinerea infections in strawberry. Food. Microbiol. 32, 406–414.

Vandendriessche, T., Nicolaï, B.M., Hertog, M.L.A.T.M., 2013. Optimization of HS SPME Fast GC-MS for high-throughput analysis of strawberry aroma. Food Anal. Methods 6, 512–520.

Van Henten, E.J., Hemming, J., Van Tuijl, B.A.J., Kornet, J.G., Meuleman, J., Bontsema, J., et al., 2002. An autonomous robot for harvesting cucumbers in greenhouses. Auton. Robots. 13, 241–258.

Verboven, P., Kerckhofs, G., Mebatsion, H., Ho, Q.T., Temst, K., Wevers, M., et al., 2008. Three-dimensional gas exchange pathways in pome fruit characterized by synchrotron X-ray computed tomography. Plant. Physiol. 147, 518–527.

Verstreken, E., De Baerdemaeker, J., 1994. Evolution of maturity of peaches: nondestructive firmness measurement from the acoustic impulse response. Int. Agrophys. 8, 469–473.

Wang, C.Y., Wang, P.C., 1989. Nondestructive detection of core breakdown in bartlett pears with nuclear magnetic-resonance imaging. HortScience 24, 106–109.

Wang, S.Y., Wang, P.C., Faust, M., 1988. Non-destructive detection of watercore in apple WITH nuclear magnetic-resonance imaging. Sci. Hortic. 35, 227–234.

Wu, D., Sun, D.W., 2013. Colour measurements by computer vision for food quality control – a review. Trends Food Sci. Tech. 29, 5–20.

Young, H., Rossiter, K., Wang, M., Miller, M., 1999. Characterization of royal gala apple aroma using electronic nose technology–potential maturity indicator. J. Agric. Food. Chem. 47, 5173–5177.

This page intentionally left blank

CHAPTER

Measuring Quality and Maturity

14

Robert L. Shewfelt

Food Science and Technology, University of Georgia, Athens, Georgia, USA

I Introduction

Consumer perception of quality and value is the driving force in a systems approach to postharvest handling. Quality attributes of importance vary from one fruit or vegetable to the next. Attributes of importance also tend to vary with the end use of the product (fresh or processed, raw or cooked, and so forth).

II Quality and acceptability

Quality is defined by the buyer (Kramer and Twigg, 1970; Shewfelt, 1999; Shewfelt and Tijskens, 2000), and their perception of the quality of a product changes as it travels through the handling system. The grower buys certified seeds or plants of a selected cultivar as well as a series of inputs (water, fertilizer or pest protection) that will help provide a good yield at a level of quality acceptable to the first buyer. Quality of a fresh product early in the postharvest system (at packinghouses or warehouses) is usually evaluated against grades and standards during sorting (Chapter 12). Such grades and standards tend to be based on attributes that can be readily determined visually – color, size, shape, and absence of defects. Visual sorting and grading operations use these attributes to determine the acceptability or rejection of shipments of a fresh product.

For any given lot of a fresh crop, a grade can be established at harvest, usually at the packing facility. Theoretically, the grade of that lot will not change, but the condition of the commodity will change during handling and storage as the product senesces. Perishability of a commodity is a function of how rapidly the condition of the product deteriorates under a given commercial storage regime.

The maturity of a crop is an assessment of physiological development. Physiological maturity is described as the stage of development when a plant or plant part will continue ontogeny even if detached; whereas commercial maturity is defined as the stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose (Watada et al., 1984). Maturity of a crop at harvest directly affects color and size of an item and, thus, its

Postharvest Handling.

grade. Other important quality characteristics such as texture, flavor and nutrient content as well as perishability and susceptibility to adverse handling and storage conditions are a function of harvest maturity. It is not enough for quality measurements to be internally valid (accurate, precise, sensitive), but they also must be externally valid (relevant to the marketplace) as described by Brueckner (2008).

Although grade and condition are the primary factors influencing buying decisions for fresh items from the farmer to the consumer, the consumer uses different criteria to judge quality. Quality attributes can be divided into purchase quality and consumption quality. Purchase quality is composed of those characteristics that are important to the consumer when deciding whether to buy a particular commodity and which item(s) to select. Purchase attributes may include color, size, shape, absence of defects, firmness to the touch and aroma. Consumption quality consists of those characteristics assessed by the consumer to determine how much that item is liked during eating. Consumption attributes include flavor (taste and aroma) and mouthfeel. In addition to purchase and consumption quality other attributes are hidden, such as wholesomeness, nutritional value and safety. These attributes are considered hidden because they cannot be detected readily either by visual inspection or by consumption, but require sophisticated analysis. Perception of these hidden attributes plays an important role in the consumer purchase decision.

Quality characteristics constitute part of a wider range of factors leading to food acceptability that is defined as "the level of continued purchase or consumption by a specified population" (Land, 1988). Extrinsic attributes or other factors that affect acceptability include packaging, price, marketing practices and merchandising techniques. More detailed descriptions of food acceptability (Thomson, 1988; Meiselman, 2006) and quality measurement (Shewfelt and Brueckner, 2000) are the subjects of other books. This chapter focuses on the intrinsic attributes of a fruit or vegetable that affect its acceptability, and places measurement of maturity and quality in a systems context.

III Commodity-specific quality attributes

A set of characteristics important to consumer acceptability is associated with each fresh fruit or vegetable. Broccoli should be green but green peaches are rejected. Celery should be crisp and crunchy, but strawberries are expected to be soft and succulent. Bland flavors are associated with lettuce and potatoes but are not desirable in tomatoes and blueberries.

Determining characteristics that are important in consumer acceptability is not as easy as it might seem. Few investigators determine consumer acceptability of specific fruits and vegetables in their research. More consumer acceptability studies have been performed on the tomato than on any other fresh commodity (Serrano-Megías and López-Nicolás, 2006; Brueckner et al. 2007; Garitta et al., 2008; Klein et al., 2010; Sinesio et al., 2010; Vogel et al., 2010; Barrett et al., 2012; Jaeger et al., 2012). Research establishes that external factors (particularly firm to the touch with uniform, but not fully ripe color) are of primary importance in tomato purchase. Unfortunately, a single test does not establish acceptability once and for all, since consumer tastes change with time and are influenced by cultural factors. Carefully planned studies identify specific target markets. For example, yellow kiwifruit appeal to a specific segment but not others (Jaeger et al., 2003). Apples are segmented by variety (Yue and Tong, 2011) and region (Hampson and Quamme, 2000). Tomatoes can be segmented by flavor and texture (Sinesio et al., 2010) and degree of ripeness (Garitta et al., 2008).

Despite good intentions to serve the consumer, the grower must satisfy the immediate buyer (packer or distributor) to stay in business. Most packers, wholesale distributors, and retail sales operators buy fruits and vegetables on the basis of grades and standards, as mentioned earlier. Many postharvest systems thus are biased toward purchase quality attributes that are closer to grades and standards. When designing specifications for quality management programs of a specific commodity, attributes must be selected that can be used to predict both purchase and consumption quality as perceived by the consumer, as well as being readily quantifiable throughout the handling system (Shewfelt, 1999). Techniques should be identified or developed for each attribute that would provide a single number on a linear scale to distinguish clearly between products of acceptable and unacceptable quality. Instrumental techniques usually are preferred over any other methods if they are rapid and provide reproducible results. Non-destructive instrumental methods are preferred to destructive ones since they decrease waste and permit repeated measures on the same items over time (Chapter 13). Chemical methods usually are preferred to sensory techniques, primarily for reproducibility. For some products, no instrumental or chemical analyses are available that adequately predict consumer response. In these cases, objective scales are developed for a commodity and items are evaluated by an expert judge. Pelletier et al. (2011) describe a scale for spoilage of strawberries and Hoque et al. (2010) use a quality scale for lettuce. At a minimum, the use of any technique must be validated by its relationship to the sensory perceptions of small, experienced or trained panels. When possible, these attributes should be tested to determine their ability to predict consumer acceptability in large, untrained panels (Chapter 4).

When evaluating a system, quantification of key attributes should be made at major points in the handling system. A technique that is dependent on a single expensive instrument bound to a particular location is not useful. Quick, reliable, reproducible methods that can be performed by available personnel at each critical step are ideal. Clearly written quality specifications coupled with defined actions for specific circumstances are beneficial. Monitoring quality attributes should start as close to the field as practicable. The earlier in the handling system a problem can be detected; the greater are the chances of taking corrective action to minimize economic losses. For example, if a quality check reveals that a harvested crop is deteriorating more rapidly than normal, a decision can be made to (1) expedite shipping and handling to market and distribute it directly to consumers while the quality is still acceptable, (2) grade and sort items to save those that will be able to withstand normal handling and discard those that will not, or (3) stop shipment immediately and discard the lot before any additional input costs are incurred.

Some postharvest operations collect additional product at each sampling step and partition the sample into subsamples that will be analyzed immediately and those that will be stored under anticipated handling conditions. This practice helps to increase the chances of detecting potential problems while they are still manageable and can provide insight into whether a problem is the result of inferior product or abusive handling conditions. Use of temperature recorders during transport or in storage rooms and of time-temperature indicators on the boxes of fresh product also can provide information about temperature abuse.

IV Sample collection and preparation

Part of any quality specification includes the number of samples and the frequency of collection. Requirements for individual commodities vary widely; specific recommendations are beyond the scope of this book. Factors that must be considered are normal fruit-to-fruit variation within a lot, seasonal and regional variability, degree of precision needed to predict acceptability and the capabilities of the analytical facilities. Integrating field experiments with postharvest studies is particularly challenging (Róth et al., 2007). A compromise must be reached between collecting so few samples that the resultant information is meaningless, and collecting more samples than can be analyzed accurately. Sampling plans should enhance the chances of detecting fruit-to-fruit variation in the lot at the expense of detecting variation in the methodology such as by increasing the number of fruit analyzed but not duplicating measures on the same fruit (Hertog et al., 2007).

The logistics of sensory and consumer testing generally preclude sampling and analysis by every replicate in a field trial. Usually samples from each replicate within a treatment (e.g., cultivar × nitrogen level × time of harvest) are pooled to provide the sample for sensory analysis. Replication then comes by repeating the sensory or consumer test at separate sessions. Two-tiered sampling plans are also useful, in which a certain result triggers more detailed sampling (e.g., subdivision of lots by color, texture or sweetness and tracing quality changes during storage). Typical sampling plans allow the measurement of a given number of samples at each period of storage. The power of a test can be improved while reducing the total number of samples by performing non-destructive tests during storage on the same fruit (Nicolaï et al., 2007).

All quality management programs must be well grounded in statistics, from the development of sampling schedules to the interpretation of results (Valero and Ruiz-Altisent, 2000). Statistical methods cannot merely be added on to a fully developed management program, but must be integrated thoroughly into the entire process. Pitfalls to be avoided include (1) undercollection of data so no valid conclusions can be drawn, (2) overcollection of data to answer questions that are not relevant to management problems, (3) subtle changes in collection techniques that invalidate the results and (4) failure to appreciate and account for the dynamic changes that occur in senescing plant tissue.

Once specifications, including sampling schedules, have been established, every effort must be made to provide the necessary equipment, supplies and personnel at each sampling location. A full commitment to the quality program is needed to reap any benefits. Any scaling back of monitoring efforts must be done only after a careful assessment of the implications of the changes.

V Maturity

Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during postharvest handling. Thus, it is critical that measures of maturity be obtained. An ideal maturity index can be measured non-destructively (Butz et al., 2005), is different at distinct levels of maturity and does not change with time of storage. Unfortunately, few such ideal measures exist. Maturity indices can be determined in many ways, including estimation of the duration of development; measurement of size, weight, or density; physical attributes such as color (Castrejón et al., 2008), firmness (Yaptenco et al., 2013) and moisture or solids content; other chemical attributes such as starch, sugar, or acid content (Hernández et al., 2007); or morphological evaluation (see review by Reid, 2002).

Development of such indices can help separate maturity effects from storage and handling effects, thus permitting more effective predictive modeling. An innovative modeling technique taking into consideration many measurements at harvest has been developed by Clément et al., (2008). Although the effects of maturity at harvest on quality and storage stability of numerous commodities are widely accepted, the use of maturity indices to separate maturity effects from handling effects has not been exploited sufficiently. Two techniques are available to quantify maturity effects:

- Separate maturity into discrete classes and plot the change in a particular quality attribute of each class as a function of storage time.
- Treat maturity as a continuous variable and plot change in a particular quality attribute at distinct steps in the handling process as a function of the maturity index.

An example of maturity classes, shown in Figure 14.1, is the measure of hue angle of a tomato. Maturity specifications must be evaluated carefully under commercial conditions and might require some adjustment, but the process puts maturity evaluation on a much more solid scientific basis than does the generally accepted earlier-is-better approach.

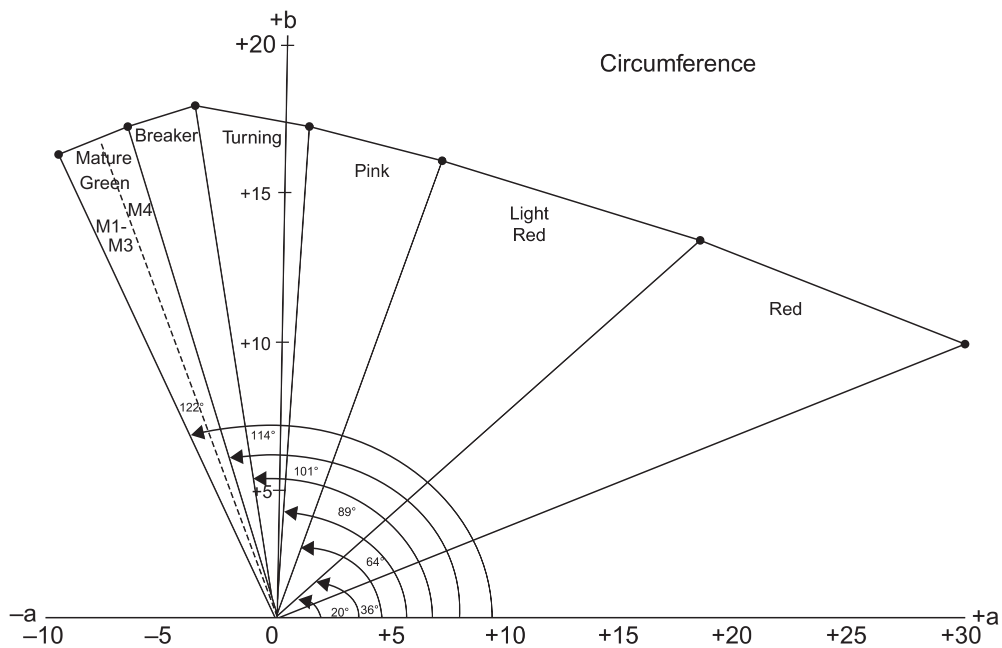

FIGURE 14.1

External color tomato (the mean of eight measurements around the circumference) as determined by hue angle [$\tan^{-1}$ (*b*/*a*)] as a maturity index for tomato.

Jordan et al. (2001) proposed BrimA (°Brix − k* total acid; where k represents a constant ranging from 2 to 10 based on human perception of specific acids) as a replacement for the Brix-to-acid-ratio (SSC/TA). An example of how BrimA can be used as a maturity index for oranges (Obenland et al., 2009) is shown in Figure 14.2. In this specific case, there is little difference between BrimA and Brix-to-acid-ratio in the first three classes (plot A), but the scatter increases and coefficient of determination (R^2) decreases as the maturity level advances from 1 to 4. Continuous data plots provide a clearer picture of the optimal maturity range than the maturity class plots, but they must be viewed with some caution. Use of a continuous index is preferable when the index is highly accurate and can be measured precisely, and the relationship of maturity and quality is correlated highly. Both techniques are dependent on how closely the defined test system mirrors actual handling conditions.

VI Measuring quality

A Visual evaluation

The visual evaluation of quality characteristics by an expert judge, despite its limitations, is still a widely used and accepted technique. Numerical scales for

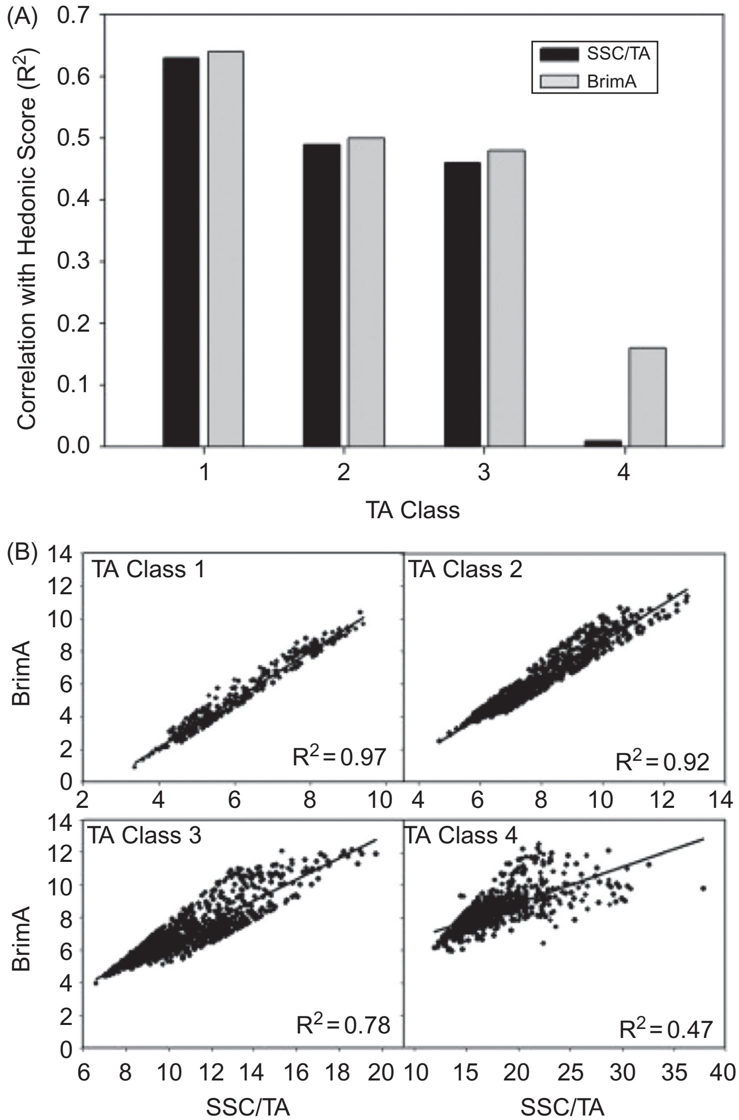

FIGURE 14.2

Use of BrimA (°Brix—*k** total acid; where *k* represents a constant ranging from 2 to 10 based on human perception of specific acids) as a maturity index for orange.

From Obenland et al. (2009) in Postharvest Biology and Technology ***52****,156–163.*
Reprinted with permission.

specific attributes are available for commodities when no chemical or physical measure is available that relates to a specific purchase characteristic (Nunes et al., 2009; Caponigro et al., 2010). Such scales are treated as objective measures, but they suffer from many of the problems of sensory analysis without having many of the safeguards of those techniques. Scoring is subject to variability by expert judge. It is almost impossible to "blind" the judge to treatments, particularly when the same samples are evaluated over time in a storage study. The full range of the scales rarely is used, since studies usually are stopped when the sample drifts into the lower (poor quality) end of the scale. Results tend to be analyzed assuming linearity of the scale, although in many cases no clear evidence exists that the points on the scale are at equal intervals.

Conversely, an experienced judge can detect subtle changes well before any differences can be detected by instruments or sensory panels. Sample variability within a treatment, the short length of most storage studies (which frequently span weekends) and large sample size requirements prevent the use of sensory panels in experimental studies or for routine quality control checks.

When faced with the need to use a visual evaluation technique or another sense (such as smell) to evaluate quality without consumption, some guidelines are recommended. A previously published scale should be used whenever possible so that results can be related to previous studies. Only those characteristics that relate directly to purchase quality attributes of the intended end use of the product should be evaluated. Expert judges selected should have little or no detailed knowledge of the design of the study and no stake in the results (e.g., not the graduate student who designed the study). The same judges must be used throughout each study or, in a quality control environment, the number of judges should be minimized. When possible, two or more judges should independently evaluate each item. Periodic discussions should be held to refresh the judge(s) on definitions of key terms. These discussions, however, should never be conducted in the middle of an ongoing experiment in which it is essential to maintain consistency of interpretation. The scale should be evaluated for its ability to predict likeability by an untrained consumer panel (30 or more panelists) for both the specific attribute(s) and overall acceptability.

B Color

Measurement of color is an important means of quality assessment of food products. Although the color of fruits and vegetables is an external manifestation of composition and form of plant pigments, a simple compositional analysis of extracted pigments does not necessarily predict visual impact. Fruit ripening and vegetable yellowing frequently involve the unmasking of carotenoids by the disappearance of chlorophyll (Barry and le Roux, 2010). A direct measure of chlorophyll concentration, however, is a poor predictor of the visual impact of broccoli color, but chlorophyll fluorescence is related to appearance (Toivonen and DeEll, 2001). Anthocyanins are the primary pigments in eggplant, present in the epidermis in metal-ion complexes. When extracted, however, the pigment is red with little resemblance to the coloration of whole fruit (Chatterjee et al., 2013). Coloration of anthocyanins is highly dependent on the intracellular environment, particularly pH (Hurtado et al., 2009). Traditional spectrophotometric methods for plant pigments have been replaced by HPLC methods that separate individual pigments. Published HPLC separation methods exist for the anthocyanins (Castrejón et al., 2008), betalains (Georgiev et al., 2010), carotenoids and chlorophylls (Lashbrooke et al., 2010). Hyperspectral imaging can also be used to measure changes in fruit and vegetable color during development (Qin and Lu, 2008).

In measuring changes in visual impact, it is more important to detect physical changes in the appearance (Barrett et al. 2010). Many color scales have been developed but the predominant scale used for fruits and vegetables is the Hunter "Lab" or its variant CIE L*a*b*. For most applications, either scale provides meaningful information. Since most investigators are switching to the CIE L*a*b* system, it is the scale of choice. For the sake of simplicity, the following discussion refers to *Lab*.

The most frequent error in color measurement is the use of *Lab* results directly without conversion to hue, value and chroma. The primary reason that food scientists use food colorimeters is that the readings are related to human color perception; this perception influences the consumer acceptability of the product. Humans and colorimeters "see" color differently. Humans see the color of a product in terms of its lightness, hue (color name such as red, blue or green), and chroma (brightness or saturation) by integrating some very complex signals into these three components. Colorimeters do not have the capacity to integrate directly and, thus, must break the signal down into a simpler construct. Instruments "see" color in terms of lightness (L), red−green character in the absence of yellow or blue components (a), and yellow−blue character in the absence of red or green components (b). L, a, and b measures are machine language, whereas hue, chroma, and lightness are terms that relate to human perception. Fortunately, we can convert the machine language, through some rather simple mathematical calculations, to numbers that have relevance to humans.

As soon as the specific terms of hue (for example, red or yellow) are used, different things are being said in machine and human terms. To the machine, an increase in yellowness is signaled by an increase in the magnitude of $+b$, whereas in human terms an increase in yellowness is signaled by the closeness of the hue angle ($\tan^{-1} b/a$) to 90°. Thus, in human terms, the yellowness of a sample can increase even if the $+b$ reading decreases if the $+a$ reading exhibits a greater decrease. Likewise, the yellowness of a sample can decrease even if the $+b$ reading increases if the $+a$ reading exhibits a greater increase.

In the example shown in Table 17.1 and Figure 14.3, apple S is more yellow than apple R, which is, in turn, more yellow than apple T to the instrument. In terms of human perception, however, the ranking of yellowness of the samples is just the opposite. Differences in chroma also may affect human perception in this case, but hue usually is more important in perception of fruit and vegetable quality.

Although color is related primarily to maturity or purchase quality, it also may contribute to consumption quality. Flesh color of many fruits and vegetables may not be observed until the time of consumption and may provide a different quality perception than external color. When measuring flesh color, the sample should be measured as soon after cutting the fruit as possible to avoid changes due to browning or desiccation. In addition, it is a good practice to clean any juice from

Table 14.1 Hypothetical Example to Demonstrate Difference in Yellowness of "Golden Delicious" Apples as Perceived by Humans and Instruments[1]

Apple	*L*	*a*	*B*	*b/a*	Hue angle
R	35	−5.0	+10.0	−2.00	120
S	35	−10.0	+12.5	−1.25	130
T	35	0	+7.5	4	90

[1]*See text for explanation of abbreviations used.*

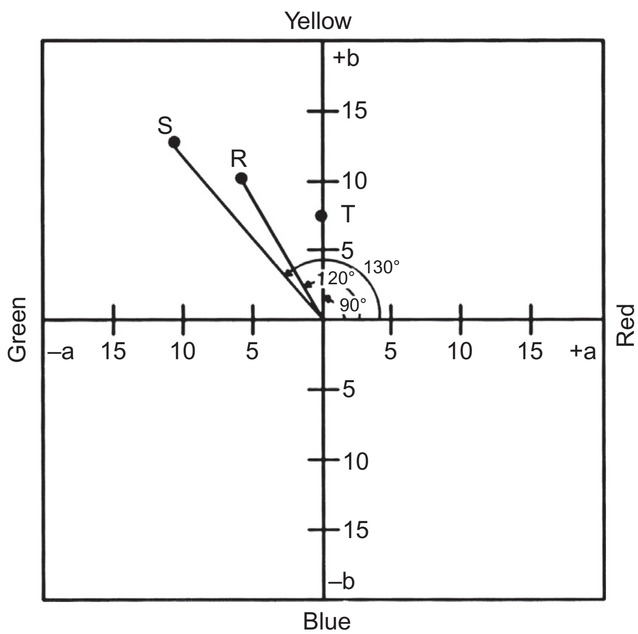

FIGURE 14.3

Illustration of the misleading conclusions drawn on the use of " + b" readings to determine yellowness of a sample.

the sample port between measurements. Other non-invasive techniques to measure fruit and vegetable appearance use radiant energy (Butz et al., 2005) or computer vision (Du and Sun, 2006).

C Texture

Firmness is the primary textural attribute measured in fruits and vegetables. Firmness usually is measured by puncture (Herrero-Langreo et al., 2012), deformation (Camps et al., 2012; Li et al., 2012) and mechanized Instron tests (Feng et al., 2011). These tests are being replaced by more non-destructive tests (Butz et al., 2005; Subedi and Walsh, 2008; Herrero-Langreo, 2012; Martínez et al., 2012). The validation of new non-destructive tests is determined by puncture as the standard (Subedi and Walsh, 2008; Herrero-Langreo, 2012). Non-destructive tests are particularly effective in sorting fruit by firmness, but may not be as effective a measurement in quality monitoring during handling and storage (Abbott, 2004). Sensory evaluation of apples was most likely to be predicted by puncture tests than other methods evaluated (Harker et al., 2002). Firmness of fresh-cut fruit products is determined by puncture (Saftner et al., 2007; Lana et al., 2007) and sensory (Giacalone and Chiabrando, 2013).

As in color measurement, sample presentation for textural analysis is important. The size of the surface area for puncture or deformation, the geometry of the sample, the means of support, and the interaction between the instrument and the sample all affect results. In puncture tests, a decision must be made about whether the peel should be retained or removed. In analyzing tomatoes, the peel usually is retained, but in analyzing peaches it usually is removed. The temperature of the samples can affect measurements and should be standardized. Penetration instruments yield data about firmness as a force. Thus, the SI unit of force, the Newton (N), should be used to report all results; probe diameter also must be reported. For more details on measurement of food texture, see Lan and Opara (2013).

D Flavor

Chemical analysis of fruit and vegetable composition is used primarily to estimate consumption quality and hidden attributes. Sweetness is a function of sugar concentration and sourness a function of acidity. Consumer perception of sweetness or sourness is related to the ratio of sugars and acids, but the relationship is complex (Crisosto et al., 2007). Sugar composition usually is estimated by measuring the percentage of soluble solids (°Brix) using a refractometer (Esti et al., 2002). Acidity is determined by titration with standard base. Attempts to predict titratable acidity non-destructively have not yet proved to be successful (Xie et al., 2010; Subedi et al., 2012). More detailed analysis and separation of individual sugars and acids can be determined using HPLC (Jakopic et al., 2012), but an identification of specific sugars and acids does little in predicting sweetness or consumption quality. Until we have better models of how sugars, acids, other taste components and mouthfeel attributes affect the acceptability of fruits and vegetables, we will need to use the sensory techniques described later in the chapter.

Volatile compounds are responsible for the distinctive aromas associated with fruits and vegetables. These compounds, in combination with taste sensations (sweet, sour and bitter), form characteristic flavors. The volatile constituents of numerous fruits have been isolated and characterized using chromatographic techniques. More than 200 volatile compounds are found in orange juice (Selli et al., 2003) and more than 300 in strawberries (Zorrilla-Fontanesi et al., 2012). Many fruits contain one or two volatile compounds, known as character impact compounds, which convey the flavor message. Examples of character impact compounds are nootkatone in grapefruit oil and 1-p-methyl-8-thiol in grapefruit juice, raspberry ketone, 4-(4′-hydroxyphenyl)-butan-2-one, and 3-mercapto-1-ethanol in passion fruit (Rowe and Tangel, 1999). The full aroma of any fruit, however, is a subtle combination of many compounds, which is why duplicating fruit flavors in artificial beverages is so difficult. Determining the volatile compounds responsible for aroma and flavor is a difficult task. The complexity of flavor and our inability to relate peaks of a few compounds to consumer perception of flavor adequately greatly limits our ability to incorporate flavor into quality evaluation programs. Sensory techniques are useful in narrowing down the list of volatile compounds to those that are critical to fruit flavor (Baldwin et al., 2010; Ng et al., 2012). Gas chromatography-olfactometry (GCO) is used to identify odor-active compounds (Zellner et al., 2008; Obenland et al., 2009; Sinuco et al., 2013). The presence of bitter compounds such as liminoids in citrus fruits (Sawalha et al., 2009) and the absence of a critical flavor components in chilled mango fruits (Singh, 2011) are examples of flavor problems identified using chromatographic techniques.

Molecular studies to improve fruit and vegetable quality seek to identify quantitative trait loci (QTL) for flavor components (Owino and Ezura, 2011). QTLs have been detected for flavor volatiles in apple (Dunemann et al., 2009), grape (Doligez et al., 2006), melon (Obando-Ulloa et al., 2010), raspberry (Paterson et al., 2013), strawberry (Zorrilla-Fontanesi et al., 2012), tomato (Mathieu et al., 2009) as well as for effects of chilling injury on volatiles in peach (Cantín et al., 2010). QTLs have also been identified for taste components in melon (Obando-Ulloa et al., 2009; Cohen et al., 2012), onion (McCallum et al., 2008), peach (ZhiJun et al., 2010), snap bean (van den Langenberg et al., 2012) and tomato (Prudent et al., 2011).

E Nutrients

Vitamins and minerals are hidden attributes that affect consumer perception. Nutrient composition varies widely in raw commodities because of genetics, preharvest factors (soil fertility, moisture content of the soil, growth temperature, growth regulators and cultural practices), maturity at harvest and postharvest handling conditions (mechanical damage, storage times, temperatures, relative humidity, gaseous atmosphere and use of additives). Despite the importance of these compounds, little is known about the rates of degradation of vitamins during postharvest handling although many of the factors affecting these losses have been identified (Barrett and Lloyd, 2012). Vitamin loss is not as much a problem in fresh-cut as in whole fruits as the spoilage proceeds more rapidly than nutrient degradation (Gil et al., 2006). Vitamin C is the nutrient most studied as an index of quality as it tends to degrade most rapidly during handling and storage (Lee and Kader, 2000; Nojavan et al., 2008).

Consumers buy certain items as good sources of specific nutrients, for example, leafy green vegetables for vitamin A, oranges for vitamin C and bananas for magnesium and potassium. Without sophisticated analytical equipment, however, the consumer cannot detect differences in individual products at the point of purchase

(Shewfelt, 1999). Thus, there is little incentive to measure nutrient content in a quality control program unless specific nutritional claims can be made. The two most commonly measured nutrients in fruits and vegetables are ascorbic acid (vitamin C) and β-carotene (pro-vitamin A). Ascorbic acid (Scherer et al., 2012) and carotenoids (Fish, 2012) are measured by HPLC. Mineral analysis usually is performed by ashing and atomic or molecular absorption (Dougnon et al., 2012). Mineral composition at harvest has been used as a predictor of postharvest storage diseases in citrus fruits (Nunes et al., 2010) and kiwifruit (Spadaro et al., 2010).

VII Sensory evaluation techniques

Known widely as "taste" testing, sensory evaluation incorporates a much wider range of senses than merely taste. Taste is the sense that detects chemical properties of foods in the mouth in the absence of aroma and is limited to sweet, sour, salty and bitter sensations in fruits and vegetables. The senses of smell to detect aroma combines with taste to form flavor. Sight, which detects color and other appearance characteristics, kinesthetics, which detect textural attributes by hands and mouth (mouthfeel) (Barrett et al., 2010), and even sound (Tunick et al., 2013), which is an indication of crispness and crunchiness, all play a role in an understanding of sensory perception of food quality.

A Types of sensory tests

Sensory tests are divided into affective and analytical tests (Meilgaard et al., 2006). Affective tests provide information on the preference (liking one sample better than other) or acceptability (how much is a sample liked or disliked) of products. Analytical tests seek to determine the level of specific attributes or the sensitivities of panelists. Most postharvest studies and quality control tests are designed to answer questions that require affective tests, whereas most tests conducted tend to be analytical. Examples of questions requiring affective tests include:

- Which treatment results in the preferred product?
- Is this product acceptable and will it remain acceptable long enough to satisfy consumer needs?

Unfortunately, analytical sensory tests are not designed to provide meaningful answers to such questions.

A minimum of 30 untrained panelists is essential to place any confidence in affective test results; usually 50−100 panelists are needed to provide adequate information. A demographic profile of the panelists is important to provide insight into the wider applicability of the results (e.g., 24 white Anglo-Saxon men would not provide an accurate projection of consumers in New York City). Score sheets typically ask panelists to rank the samples in order of preference or rate each product from 9 (like extremely) to 1 (dislike extremely), in a process known as hedonic scaling. Ranking tests give more direct information about which sample is preferred, but they give no information about how much a sample is preferred and why. Hedonic scales are treated statistically as linear equal-interval scales, although panelists tend to ignore both extremes. These scales are more readily adaptable to obtaining information about some specific attributes. A willingness-to-purchase scale from 5 (definitely would purchase) to 1 (definitely would not purchase) (Moskowitz et al., 2012) or an acceptability scale from 3 (tastes great) to 2 (acceptable) to 1 (unacceptable) (Dubost et al., 2003) are more useful measures of fruit and vegetable acceptability. Rather than being reported as a mean on the scale, willingness-to-purchase is expressed as a percentage of purchase acceptability and acceptability as a percentage of acceptability.

Analytical tests can be subdivided into descriptive and discriminative tests. Descriptive tests measure and quantify specific attributes of a product, for example, sweetness, juiciness or flesh color, whereas discriminative tests determine differences in samples and products. In descriptive tests, the panelist is asked to rate the intensity of a particular attribute on a scale. One such scaling technique is quantitative descriptive analysis (QDA) (Stone et al., 2012). An example of a QDA score sheet for peaches is provided in Figure 14.4. Note that the panelist is not asked to indicate which sample is preferred. For example, some panelists may prefer sweet apples whereas others prefer tart ones, but such opinions are not relevant to these tests. Descriptive tests provide important information about specific attributes and should be incorporated into any study in which appropriate chemical or physical tests cannot be developed for critical consumption attributes.

Normally, descriptive panels consist of 5−15 trained panelists, usually permanent support staff personnel. Selection of panelists is a critical step in any sensory test, but particularly for trained panels. Potential panelists should be prescreened to eliminate those who are not able to readily differentiate between aromatic, color, taste and textual characteristics. The duration of training depends on the number of fruits or vegetables to be evaluated and the complexity of the sensory components of these items. Some commercial food companies require panelists to undergo two hours of training each week for six months to a year before they become eligible to participate in ongoing projects. Selection of specific descriptors can be based on published studies with that item or by the panel itself. If the panel develops its own descriptors, an experienced panel leader is necessary to balance the opinions of group members with sensory dogma, prevent any member from dominating group-panel sessions and keep the panel on task. Training is usually accomplished with a wide range of test samples and descriptor standards. Finding a wide range of available fresh fruits in season may be difficult, particularly for crops such as blueberries that tend to have short seasons (Gianella, 2013).

Experienced panels contain panelists with a familiarity with the terminology and quality characteristics of the product but undergo much less training. Panelists have normal sensory acuity, in contrast with members of highly trained panels, who can detect subtle changes in a product. It is critical that, within a

SENSORY EVALUATION OF PEACHES

Name____________________ Date______________a.m./p.m. Set______

Please evaluate these samples of Peaches using the rating scales below. Place vertical marks on each of the scales to indicate your rating of each sample. Label each mark with the code number of the sample it represents.

THE SAMPLE CODE NOS. ARE: ___ ___ ___ ___ ___ ___

YOU SHOULD HAVE SIX MARKS ON EACH SCALE WHEN YOU COMPLETE THIS.

FLESH COLOR	green	yellow	red-orange
FLAVOR Sweetness	too bland	about right	too sweet
Sourness	too bland	about right	too sour
Peach flavor intensity	weak	moderate	strong
Overall flavor intensity	weak	moderate	strong
Off flavor (IF ANY)	slight	moderate	strong

DESCRIBE OFF-FLAVOR________________________

PLEASE TAKE YOUR SCORE CARD TO THE KITCHEN AREA TO EVALUATE SAMPLES FOR COLOR, FIRMNESS TO THE TOUCH AND OVERALL PREFERENCE.

FLESH COLOR	green	yellow	red-orange
OVERALL EXTERNAL COLOR	fair	good	excellent
FIRMNESS TO THE TOUCH	not firm	moderately firm	very firm

FIGURE 14.4

Sensory panel ballot for sensory descriptive analysis of peaches.

given study, changes in the composition of a panel are minimized. A panelist whose scores differ from the norm still can be useful if their judgments are consistent but can skew results greatly if present for only part of the study. Managers, who rarely can be tied down to a specific location at a specific time on a predictable schedule, and students, who tend to graduate, make poor panelists.

Discriminative tests can be subdivided further into difference and sensitivity tests. Difference tests such as paired-comparison, duo-trio, or triangle tests can be used to determine if two products differ from each other (Harker et al., 2005). Examples of the use of difference tests include use in juices (Lee et al., 2009; Koffi et al., 2010). A difference test has been used to determine potential differences in organic and conventional apple production (Peck et al., 2009), packaging treatments of blueberries (Almenar et al., 2010) and between sensory attributes of climacteric and non-climacteric melons (Fernández-Trujillo et al., 2012). However, finding no significant difference is not equivalent to finding no difference! Statistical tests are designed to minimize the risk of a Type I error (stating there is a difference when none exists) at the expense of making a Type II error (stating there is no difference when one exists) (Freund et al., 2010). Unfortunately, there are no simple tests to determine whether a modification of a system (for example, changing precooling temperature requirements) will result in a product of comparable quality. Standard tests can detect only significant differences in quality, if they exist.

B Sample preparation and presentation

Sensory evaluation tests are usually performed in special facilities housing a number of individual booths. These booths should provide an atmosphere conducive to making sound judgments; clean, adequately lighted and ventilated, free from audio and visual distractions, equipped with a sink for rinsing and expectoration, with ready access to the food preparation area. Samples should be presented to panelists in a form in which and at a temperature at which the item is consumed normally. Samples should be coded in a fashion that will not bias a panelist (three digit codes extracted from a random number table are sufficient) and they should be presented in a random fashion to avoid first or last sample biases. Consider the number of samples provided at a sitting to avoid panelist fatigue. Consuming an unsalted cracker between strong samples followed by a water rinse helps prevent carryover. Distilled water is preferable, particularly if a pronounced flavor is present in tap water. Tests should be conducted at the same time each day, preferably not to interfere with normal break times or close to a normal mealtime. More details on panel environment and sample preparation are provided by Meilgaard et al. (2006), Lawless and Heymann (2010) and Stone et al. (2012).

Design of a proper questionnaire for a sensory test is critical. Does the questionnaire adequately address the test objectives? Is the questionnaire readily understandable using unequivocal language? Is it too long, so it taxes the panelist? Does it present the samples to the panelist in the same order in which they are presented physically? As in any other analytical test, attention to detail is essential to generate valid, accurate data from sensory tests.

C Evaluating purchase and consumption attributes

Most sensory tests are associated with consumption attributes such as flavor and mouthfeel. As described earlier, sensory evaluation may be the only valid measure for consumption attributes for certain crops. Purchase attributes also can be evaluated by sensory techniques. Color, other appearance attributes, firmness to the touch and aroma are purchase attributes that can be assessed. Usually, purchase attributes are not evaluated in booths, but are measured on a well-lighted counter top. No communication is allowed between panelists. Unless individual items are small (peas or blueberries, for example), they should be evaluated individually and not in clusters of two or three. More samples can be evaluated for purchase attributes by a panelist, since fatigue is usually not as much of a factor as it is for consumption attributes. When measuring consumption and purchase attributes as part of the same test, it is usually preferable to perform consumption tests first, followed by purchase tests, since the latter are more likely to bias the former than vice versa. When filtered light is being used to screen out color differences, however, some time must be permitted between consumption and purchase evaluation to adapt to normal lighting, or the purchase attributes should be evaluated first. In any case, coding of samples for purchase and consumption samples should be different. It is always tempting to compare purchase and consumption attributes, although experience has consistently suggested that purchase attributes are not reliable predictors of consumption attributes. One goal of a systems approach is to improve consumption quality while maintaining acceptable purchase quality (Florkowski, 2006; Shewfelt, 2006; Opara et al., 2007; Albornoz et al., 2009; Golding et al., 2012).

D Correlating sensory and physicochemical results

Quality tests are only meaningful if they relate to consumer acceptability. In the absence of consumer acceptability data for many commodities, most chemical and physical tests are evaluated for their ability to correlate with sensory results. In many cases, simple correlation coefficients are used; a coefficient of 0.9 ($R^2 = 0.81$) is preferable and 0.8 ($R^2 = 0.64$) is considered acceptable. More sophisticated techniques have been developed using cluster analysis and factorial analysis, which help reduce the data required to discriminate between samples from multiple attributes to a few critical ones. Cluster analysis is particularly effective in identifying market segments (Brueckner et al., 2007; Onwezen and Bartels, 2011; Delgado et al., 2013). Too frequently, fruit quality studies assume that there is one quality ideal, but different consumer segments prefer a different bundle of characteristics (Shewfelt, 2006). In any decision making process, it is critical not to let the level of statistical significance obscure the practical implications of the results.

VIII Quality in a systems context

Quality is only one of the factors that influence consumer acceptability of a fruit or vegetable, but it is the only factor that is intrinsic to the item and the factor most directly affected by handling and storage conditions. Quality can be divided into purchase, consumption and hidden attributes. Each commodity has a unique set of quality attributes desired by the consumer. Maturity and quality indices have been developed for many commodities to permit quality evaluation of an item through the system and to separate "maturity effects" from "handling effects". Sensory evaluation represents an important means of assessing quality, but it is frequently misapplied in postharvest experiments. An understanding of the interaction of production systems and subsequent handling steps to affect quality represents the greatest potential application of a systems approach to postharvest handling.

Bibliography

Abbott, J.A., 2004. Textural quality assessment for fresh fruits and vegetables. In: Shahidi, F., Spanier, A.M., Ho, C.-T., Braggins, T. (Eds.), Quality of Fresh and Processed Foods. Kluwer Academic/Plenum Press, New York, pp. 265–280.

Albornoz, A., Ortega, L., Segovia, E., Bracho, Y., Cubillan, G., 2009. Purchase attributes of fresh fruits at domestic level. Bioagro 21, 57–62.

Almenar, E., Harte, J., Auras, R., Samsudin, H., 2010. Consumer acceptability of fresh blueberries in bio-based packages. J. Sci. Food Agric. 90, 1121–1128.

Baldwin, E., Plotto, A., Manthey, J., McCollum, G., Bai, J.H., Irey, M., et al., 2010. Effect of liberibacter infection (Huanglongbing disease) of citrus on orange fruit physiology and fruit/fruit juice quality: chemical and physical analyses. J. Agric. Food Chem. 58, 1247–1262.

Barrett, C.E., Zhao, X., Sims, C.A., Brecht, J.K., Dreyer, E.Q., Gao, Z., 2012. Fruit composition and sensory attributes of organic heirloom tomatoes as affected by grafting. HortTechnology 22, 804–809.

Barrett, D.M., Lloyd, B., 2012. Advanced preservation methods and nutrient retention in fruits and vegetables. J. Sci. Food Agric. 92, 7–22.

Barrett, D.M., Shewfelt, R.L., Beaulieu, J.C., 2010. Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. Crit. Rev. Food Sci. Nutr. 50, 369–389.

Barry, G.H., le Roux, S., 2010. Preharvest foliar sprays of prohexadione-calcium, a gibberellin-biosynthesis inhibitor, induce chlorophyll degradation and carotenoid synthesis in *Citrus* rinds. HortScience 45, 242–247.

Brueckner, B., 2008. Consumer acceptance of fruit and vegetables: the role of flavour and other quality attributes. In: Brueckner, B., Wyllie, S.G. (Eds.), Fruit and Vegetable Flavour. Woodhouse Publishing Ltd, Cambridge, England.

Brueckner, B., Schonhof, I., Schroedter, R., Kornelson, C., 2007. Improved flavour acceptability of cherry tomatoes. Target group: children. Food Qual. Pref. 18, 152–160.

Butz, P., Hofmann, C., Tauscher, B., 2005. Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. J. Food Sci. 70, R131–R141.

Camps, C., Simoné, C., Gilli, C., 2012. Assessment of tomato quality using portable NIR spectroscopy and PLSR with wavelengths selection. Acta Hort 936, 437–442.

Cantín, C.M., Crisosto, C.H., Ogundiwin, E.A., Gradziel, T., Torrents, J., Moreno, M.A., et al., 2010. Chilling injury susceptibility in an intra-specific peach [*Prunus persica* (L.) Batsch] progeny. Postharvest Biol. Technol. 58, 79–87.

Caponigro, V., Ventura, M., Chiancone, I., Amato, L., Parento, E., Piro, F., 2010. Variation of microbial load and visual quality of ready-to-eat salads by vegetable type, season, processor and retailer. Food Microbiol. 27, 1071–1077.

Castrejón, A.D.R., Eichholz, I., Rohn, S., Kroh, L.W., Huyskens-Keil, S., 2008. Phenolic profile and antioxidant activity of highbush blueberry (*Vaccinium corymbosum*, L.) during fruit ripening. Food Chem. 109, 564–572.

Chatterjee, D., Jadhav, N.T., Bhattacharjee, P., 2013. Solvent and supercritical carbon dioxide extraction of color from eggplants: characterization and food applications. LWT 51, 319–324.

Clément, A., Dorais, M., Vernon, M., 2008. Multivariate approach to the measurement of tomato maturity and gustatory attributes and their rapid assessment by vis-NIR spectroscopy. J. Agric. Food Chem. 56, 1538–1544.

Cohen, S., Tzuri, G., Harel-Beja, R., Itkin, M., Portnoy, V., Sa'ar, U., et al., 2012. Co-mapping studies of QTLs for fruit acidity and candidate genes of organic acid metabolism and proton transport in sweet melon (*Cucumis melo* L.). Theor. Appl. Genet. 125, 343–353.

Crisosto, C.H., Crisosto, G.M., Echeverria, G., Puy, J., 2007. Segregation of plum and pluot cultivars according to their organoleptic characteristics. Postharvest Biol. Technol. 44, 271–276.

Delgado, C., Crisosto, G.M., Heymann, H., Crisosto, C.H., 2013. Determining the primary drivers of liking to predict consumers' acceptability of fresh nectarines and peaches. J. Food Sci. 78, S605–S614.

Doligez, A., Audiot, E., Baumes, R., This, P., 2006. QTLs for muscat flavor and monoterpenic odorant content in grapevine (*Vitis vinifera* L.). Mol. Breed. 18, 109–125.

Dougnon, T.V., Bankolé, H.S., Johnson, R.C., Klotoé, J.R., Dougnon, G., Gbaguidi, F., et al., 2012. Phytochemical screening, nutritional and toxicological analyses of leaves and fruits of *Solanum macrocarpon* Linn (*Solanaceae*) in Cotonou (Benin). Food Nutr. Sci. 3, 1595–1603.

Du, C.-J., Sun, D.-W., 2006. Learning techniques used in computer vision for food quality evaluation: a review. J. Food Eng. 72, 39–55.

Dubost, N.J., Shewfelt, R.L., Eitenmiller, R.R., 2003. Consumer acceptability, sensory and instrumental analysis of peanut soy spreads. J. Food Qual. 26, 27–42.

Dunemann, F., Ulrich, D., Boudichevskaia, A., Grafe, C., Weber, W.E., 2009. QTL mapping of aroma compounds analysed by headspace solid-phase microextraction gas chromatography in the apple progeny 'Discovery' × 'Prima'. Mol. Breed. 23, 501–521.

Esti, M., Cinquanta, L., Sinesio, F., Moneta, E., Di Matteo, M., 2002. Physicochemical and sensory fruit characteristics of two sweet cherry cultivars after cool storage. Food Chem. 76, 399–405.

Feng, J., McGlone, A., Tanner, D., White, A., Olsson, S., Petley, M., et al., 2011. Effect of penetration speed on flesh firmness measured on stored kiwifruit. Postharvest Biol. Technol. 61, 29–34.

Fernández-Trujillo, J.P., Bueso, M.C., Hernández, M.S., 2012. Quality oriented breeding using sensory attributes in melon: the case of climacteric and non-climacteric near-isogenic lines obtained from non-climacteric parents. Acta Hort 934, 975–983.

Fish, W.W., 2012. Refinements of the attending equations for several spectral methods that provide improved quantification of β-carotene and/or lycopene in selected foods. Postharvest Biol. Technol. 66, 16–22.

Florkowski, W.J., 2006. Fruit and vegetable quality, the value of time and marketing. Acta Hort 712, 427–433.

Freund, R., Mohr, D., Wilson, W., 2010. Statistical Methods, third ed. Academic Press, San Diego.

Garitta, L., Hough, G., Hulshof, E., 2008. Determining optimum ripening time of fruits by applying survival analysis statistics to consumer data. Food Qual. Pref. 19, 747–752.

Georgiev, V., Weber, J., Kneschke, E.-M., Denev, P., Bley, T., Pavlov, A., 2010. Antioxidant activity and phenolic content of betalain extracts from intact plants and hairy root cultures of the red beetroot Beta vulgaris cv. Detroit Dark Red. Plant Foods Hum. Nutr. 65, 105–111.

Giacalone, G., Chiabrando, V., 2013. Effect of different treatments with calcium salts on sensory quality of fresh-cut apple. J. Food Nutr. Res. 52, 79–86.

Gianella, C.L., 2013. Sensory and Consumer Acceptability of Southern Highbush Blueberry Cultivars. M.S. Thesis. University of Georgia.

Gil, M.I., Aguayo, E., Kader, A.A., 2006. Quality changes and nutrient retention in fresh-cut versus whole fruits during storage. J. Agric. Food Chem. 54, 4284–4296.

Golding, J.B., Pristijono, P., Pearse, M., Spohr, L., McGlasson, B., 2012. Variability in peach and nectarine eating quality. Acta Hort. 962, 499–508.

Hampson, C.R., Quamme, H.A., 2000. Use of preference testing to identify tolerance limits for fruit visual attributes in apple breeding. HortScience 35, 827–832.

Harker, F.R., Maindonald, J., Murray, S.H., Gunson, F.A., Hallett, I.C., Walker, S.B., 2002. Sensory interpretation of instrumental measurements 1: texture of apple fruit. Postharvest Biol. Technol. 24, 225–239.

Harker, F.R., Norquay, C.R., Amos, R.R., Jackman, R.A., Gunson, A., Williams, M., 2005. The use and misuse of discrimination tests for assessing the sensory properties of fruit and vegetables. Postharvest Biol. Technol. 38, 195–201.

Hernández, M.S., Martínez, O., Fernández-Trujillo, J.P., 2007. Behavior of arazá (Eugenia stipitata Mc Vaugh) fruit quality traits during growth, development and ripening. Sci. Hort. 111, 220–227.

Herrero-Langreo, A., Fernandez-Ahumada, E., Roger, J.M., Palagos, B., Lleo, L., 2012. Combination of optical and non-destructive mechanical techniques for the measurement of maturity in peach. J. Food Eng. 108, 150–157.

Hertog, M.L.A.T.M., Lammertyn, J., De Ketelaere, B., Scheerlinck, N., Nicolaï, B.M., 2007. Managing quality variance in the postharvest food chain. Trends Food Sci. Technol. 18, 320–332.

Hoque, M.M., Ajwal, H., Smith, M.O.R., Cahn, M., 2010. Yield and postharvest quality of lettuce in response to nitrogen, phosphorous and potassium fertilizers. HortScience 45, 1539–1544.

Hurtado, N.H., Morales, A.L., González-Miret, M.L., Escudero-Gilete, M.L., Heredia, F.J., 2009. Colour, pH stability and antioxidant activity of anthocyanin rutinosides isolated from tamarillo fruit (*Solanum betaceum* Cav.). Food Chem. 117, 88–93.

Jaeger, S.R., Rossiter, K.L., Wismer, W.V., Harker, F.R., 2003. Consumer-driven product development in the kiwifruit industry. Food Qual. Pref. 14, 187–198.

Jaeger, S.R., Pineau, B., Bava, C.M., Atkinson, K.R., McRae, J.F., Axten, L.G., et al., 2012. Investigation of the impact of sensitivity to cis-3-hexen-1-ol (green/grassy) on food acceptability and selection. Food Qual. Pref. 24, 230–242.

Jakopic, J., Slatnar, A., Stampar, F., Veberic, R., Simoncic, A., 2012. Analysis of selected primary metabolites and phenolic profile of 'Golden Delicious' apples from four production systems. Fruits 67, 377–386.

Jordan, R.B., Seelye, R.J., McGlone, V.A., 2001. A sensory-based alternative to Brix/acid ratio. Food Technol. 55 (6), 36–38, 40–43, 44.

Klein, D., Gkisakis, V., Krumbein, A., Livieratos, I., Köpke, U., 2010. Old and endangered tomato cultivars under organic greenhouse production: effect of harvest time on flavour profile and consumer acceptability. Int. J. Food Sci. Technol. 45, 2250–2257.

Koffi, E.K., Ezoua, P., Sidibe, D., Agbo, N.G., 2010. Sensory analysis of the fruit juice of Palmyrah palm (*Borassus aethiopum*): a decision making tool. Afr. J. Food Agric. Nutr. Dev. 10, 2818–2833.

Kramer, A., Twigg, B.A., 1970. third ed. Quality Control for the Food Industry, vol. 3. AVI/van Nostrand, New York.

Lan, C., Opara, U.L., 2013. Texture measurement approaches in fresh and processed foods – a review. Food Res. Int. 51, 823–835.

Lana, M.M., Tijskens, L.M.M., De Theije, A., Dekker, M., Barrett, D.M., 2007. Measurement of firmness of fresh-cut sliced tomato using puncture tests – studies on sample size, probe size and direction of puncture. J. Text. Stud. 38, 601–618.

Land, D.G., 1988. Negative influences on acceptability and their control. In: Thomson, D. M.H. (Ed.), Food Acceptability. Elsevier, New York, pp. 475–483.

Lashbrooke, J.G., Young, P.R., Strever, A.E., Stander, C., Vivier, M.A., 2010. The development of a method for the extraction of carotenoids and chlorophylls from grapevine leaves and berries for HPLC profiling. Aust. J. Grape Wine Res. 16, 349–360.

Lawless, H.T., Heymann, H., 2010. Sensory Evaluation of Foods: Principles and Practices, second ed. Springer, New York.

Lee, S.K., Kader, A.A., 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol. 20, 207–220.

Lee, Y.-M., Chae, J.-E., Lee, H.-S., 2009. Effects of order of tasting in sensory difference tests using apple juice stimuli: development of a new model. J. Food Sci. 74, S268–S275.

Li, C.Y., Luo, J.W., MacLean, D., 2011. A novel instrument to delineate varietal and harvest effects on blueberry fruit texture during storage. J. Sci. Food Agric. 91, 1653–1658.

Martínez, M., Wulfsohn, D., Toldam-Andersen, T., 2012. Non-invasive estimation of firmness in apple fruit using VIS/NIR spectroscopy. Acta Hort. 934, 139–144.

Mathieu, S., Cin, V.D., Fei, Z., Li, H., Bliss, P., Taylor, M.G., et al., 2009. Flavour compounds in tomato fruits: identification of loci and potential pathways affecting volatile composition. J. Exp. Bot. 60, 325–337.

McCallum, J., Shigyo, M., Havey, M.J., McManus, M.T., 2008. Molecular approaches to characterizing and improving bulb composition in onion. Acta Hort. 770, 147–151.

Meilgaard, M., Civille, G.V., Carr, B.T., 2006. Sensory Evaluation Techniques, fourth ed. CRC Press, Boca Raton FL.

Meiselman, H.L., 2006. The role of context in food choice, food acceptability and food consumption. In: Shepard, R., Raats, M. (Eds.), The Psychology of Food Choice. CABI Publishing, Oxfordshire, UK.

Moskowitz, H.R., Beckley, J.H., Ressurreccion, A.V.A., 2012. Sensory and Consumer Research in Food Product Design and Development, second ed. Wiley-Blackwell, Hoboken NJ.

Ng, M., Lawlor, J.B., Chandra, S., Chaya, C., Hewson, L., Hort, J., 2012. Using quantitative descriptive analysis and temporal dominance of sensations analysis as complementary methods for profiling commercial blackcurrant squashes. Food Qual. Pref. 25, 121–134.

Nicolaï, B.M., Buellens, K., Bobelyn, E., Piers, A., Saeys, W., Theron, K.I., et al., 2007. Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: a review. Postharvest Biol. Technol. 46, 99–118.

Nojavan, S., Arabanian, A., Chalavi, S., Rahimi, A., Khalilian, F., Kiaie, F.M., 2008. Extraction and quantitative determination of ascorbic acid during different maturity stages of *Rosa canina* L. fruit. J. Food Comp. Anal. 21, 300–305.

Nunes, C., Duarte, A., Manso, T., Weiland, C., García, J.M., Cayuela, J.A., et al., 2010. Relationship between postharvest diseases resistance and mineral composition of citrus fruit. Acta Hort. 868, 417–422.

Nunes, M.C.M., Émond, J.-P., Rauch, M., Dea, S., Chau, K.V., 2009. Environmental conditions encountered during typical consumer retail display affect fruit and vegetable quality and waste. Postharvest Biol. Technol. 51, 232–241.

Obando-Ulloa, J.M., Fernández-Trujillo, J.P., Monforte, A.J., Eduardo, I., 2009. Identification of QTLs related to sugar and organic acid composition in melon using near-isogenic lines. Sci. Hort. 121, 425–433.

Obando-Ulloa, J.M., Ruiz, J., Monforte, A.J., Fernández-Trujillo, J.P., 2010. Aroma profile of a collection of near-isogenic lines of melon (*Cucumis melo* L.). Food Chem. 118, 815–822.

Obenland, D., Collin, S., Mackey, B., Sievert, J., Fjeld, K., Arpaia, M.L., 2009. Determinants of flavor acceptability during the maturation of navel oranges. Postharvest Biol. Technol. 52, 156–163.

Onwezen, M.C., Bartels, J., 2011. Which perceived characteristics make product innovations appealing to the consumer? A study on the acceptability of fruit innovations using cross-cultural consumer segmentation. Appetite 57, 50–58.

Opara, L.U., Al-Said, F., Al-Abri, A., 2007. Assessment of what the consumer values in fresh fruit quality: case study of Oman. New Zeal. J. Crop Hort. Sci. 35, 235–243.

Owino, W.O., Ezura, H., 2011. Biotechnology in postharvest research of fruits: prospects and achievements. Stewart Postharvest Rev. 7, 1–7.

Paterson, A., Kassim, A., McCallum, S., Woodhead, M., Smith, K., Zait, D., et al., 2013. Environmental and seasonal influences on red raspberry flavour volatiles and identification of quantitative trait loci (QTL) and candidate genes. TAG Theor. Appl. Genet. 126, 33–48.

Peck, G.M., Merwin, I.A., Watkins, C.B., Chapman, K.W., Padilla-Zakour, O.I., 2009. Maturity and quality of 'Liberty' apple fruit under integrated and organic fruit production systems are similar. HortScience 44, 1382–1389.

Pelletier, W., Brecht, J., Nunes, M.C.N., Émond, J.-P., 2011. Quality of strawberries shipped by truck from California to Florida as influenced by postharvest temperature management practices. HortTechnology 21, 482–493.

Prudent, M., Lecomte, A., Bouchet, J.-P., Bertin, N., Causse, M., Génard, M., 2011. Combining ecophysiological modelling and quantitative trait locus analysis to identify key elementary processes underlying tomato fruit sugar concentration. J. Exp. Bot. 62, 907–919.

Qin, J., Lu, R., 2008. Measurement of the optical properties of fruits and vegetables using spatially resolved hyperspectral diffuse reflectance imaging technique. Postharvest Biol. Technol. 49, 355–365.

Reid, M.S., 2002. Maturation and maturity indices. In: Kader, A.A. (Ed.), Postharvest Technology of Horticultural Crops, third ed. Univ. California Agric. Natur. Resources Publ. 3529, pp. 55–62.

Róth, E., Berna, A., Beullens, K., Yarramraju, S., Lammertyn, J., Schenk, A., et al., 2007. Postharvest quality of integrated and organically produced apple fruit. Postharvest Biol. Technol. 45, 11–19.

Rowe, D., Tangel, B., 1999. Aroma chemicals for the sweet field. Perfumer Flavorist 24 (6), 36–41.

Saftner, R.A., Abbott, J.A., Bhagwat, A.A., Vinyard, B.T., 2005. Quality measurement of intact and fresh-cut slices of Fuji, Granny Smith, Pink Lady, and GoldRush apples. J. Food Sci. 70, S317–S324.

Sawalha, S.M.S., Arráez-Román, D., Segura-Carretero, A., Fernández-Gutiérrez, A., 2009. Analytical methods: Quantification of main phenolic compounds in sweet and bitter orange peel using CE–MS/MS. Food Chem. 116, 567–574.

Scherer, R., Rybka, A.C.P., Ballus, C.A., Meinhart, A.D., Teixeira, J., Godoy, H.T., 2012. Validation of a HPLC method for simultaneous determination of main organic acids in fruits and juices. Food Chem. 135, 150–154.

Selli, S., Cabaroglu, T., Canbas, A., 2004. Volatile flavour components of orange juice obtained from the cv. Kozan of Turkey. J. Food Comp. Anal. 17, 789–796.

Serrano-Megías, M., López-Nicolás, J.M., 2006. Application of agglomerative hierarchical clustering to identify consumer tomato preferences: influence of physicochemical and sensory characteristics on consumer response. J. Sci. Food Agric. 86, 493–499.

Shewfelt, R.L., 1999. What is quality? Postharvest Biol. Technol. 15, 197–200.

Shewfelt, R.L., 2006. Defining and meeting consumer requirements. Acta Hort 712, 31–37.

Shewfelt, R.L., Brueckner, B., 2000. Fruit and Vegetable Quality: An Integrated View. Technomic Press, Lancaster PA, USA.

Shewfelt, R.L., Tijskens, L.M.M., 2000. A more integrated view. In: Shewfelt, R.L., Breuckner, B. (Eds.), Fruit and Vegetable Quality: An Integrated View. pp. 296–306.

Sinesio, F., Cammareri, M., Moneta, E., Navez, B., Peparaio, M., Causse, M., et al., 2010. Sensory quality of fresh French and Dutch market tomatoes: a preference mapping study with Italian consumers. J. Food Sci. 75, S55–S67.

Singh, S., 2011. Preservation technologies for fresh fruits and vegetables. Stewart Postharvest Rev. 7 (1), article 5.

Sinuco, D., Steinhaus, M., Osorio, C., Schieberle, P., 2013. Quantitation of the odour-active compounds in Andes berry (*Rubus glaucus* Benth) fruit using the molecular sensory approach. Eur. Food Res. Technol. 236, 373–378.

Spadaro, D., Galliano, A., Pellegrino, C., Gilardi, G., Garibaldi, A., Gullino, M.L., 2010. Dry matter, mineral composition, and commercial storage practices influence the development of skin pitting caused by *Cadophora luteo-olivacea* on kiwifruit 'hayward'. J. Plant Pathol. 92, 349–356.

Stone, H., Bleibaum, R., Thomas, H.A., 2012. Sensory Evaluation Practices, fourth ed. Academic Press, San Diego.

Subedi, P.P., Walsh, K.B., 2008. Non-invasive techniques for measurement of fresh fruit firmness. Postharvests Biol. Technol. 51, 297–304.

Subedi, P.P., Walsh, K.B., Hopkins, D.W., 2012. Assessment of titratable acidity in fruit using short wave near infrared spectroscopy. Part B: intact fruit studies. J. Near Infrared Spectr. 20, 459–463.

Thomson, D.M.H., 1988. Food Acceptability. Elsevier Applied Science, New York.

Toivonen, P.M.A., DeEll, J.R., 2001. Chlorophyll fluorescence, fermentation product accumulation, and quality of stored broccoli in modified atmosphere packages and subsequent air storage. Postharvest Biol. Technol. 23, 61–69.

Tunick, M.H., Onwulata, C.I., Thomas, A.E., Phillips, J.G., Mukhopadhyay, S., Sheen, S., et al., 2013. Critical evaluation of crispy and crunchy textures: a review. Int. J. Food Prop. 16, 949–963.

Valero, C., Ruiz-Altisent, M., 2000. Design guidelines for a quality assessment system of fresh fruits in fruit centers and hypermarkets. CIGR ejournal 2, 20, <http://www.ecommons.cornell.edu/bitstream/1813/10210/1/Fruits.PDF>.

van den Langenberg, K.M., Bethke, P.C., Nienhuis, J., 2012. Identification of quantitative trait loci associated with fructose, glucose, and sucrose concentration in snap bean pods. Crop Sci. 52, 1593–1599.

Vogel, J.T., Tieman, D.M., Sims, C.A., Odabasi, A.Z., Clark, D.G., Klee, H.J., 2010. Carotenoid content impacts flavor acceptability in tomato (Solanum lycopersicum). J. Sci. Food Agric. 90, 2233–2240.

Watada, A.E., Herner, R.C., Kader, A.A., Romani, R.I., Staby, G.L., 1984. Terminology for the description of developmental stages of horticultural crops. HortScience 19, 20–21.

Xie, L., Ye, X., Liu, D., Ying, Y., 2010. Prediction of titratable acidity, malic acid, and citric acid in bayberry fruit by near-infrared spectroscopy. Food Res. Int. 44, 2198–2204.

Yaptenco, K.F., Angeles, M.P., Esguerra, E.B., Serrano, E.P., Cho, M.-A., Choi, S.-T., 2013. Nondestructive firmness measurement as a maturity index for ‘carabao’ mango (*Mangifera indica* L.) fruit. Philippine Agric. Sci 96, 55–65.

Yue, C., Tong, C., 2011. Varieties: evidence from apple tasting choice experiments. HortTechnology 21, 376–383.

Zellner, B., Dugo, P., Dugo, G., Mondello, L., 2008. Review: gas chromatography–olfactometry in food flavour analysis. J. Chromat. A 1186, 123–143.

ZhiJun, S., RuiJuan, M., MingLiang, Y., ZhiXiang, C., JianLan, X., 2010. Mapping QTLs controlling flavor quality of peach using a cross population between nectarine and flat nectarine. Acta Hort. Sin. 37, 1735–1744.

Zorrilla-Fontanesi, Y., Rambla, J.-L., Cabeza, A., Medina, J.J., Sánchez-Sevilla, J.F., Valpuesta, V., et al., 2012. Genetic analysis of strawberry fruit aroma and identification of O-methyltransferase FaOMT as the locus controlling natural variation in mesifurane content. Plant Physiol. 159, 851–870.

CHAPTER

Modeling Quality Attributes and Quality Related Product Properties

15

L.M.M. Tijskens and R.E. Schouten

Group HPC: Horticultural Production Chains, Wageningen University and Research, Wageningen, The Netherlands

Introduction

Major changes, both in consumer behavior and in technical possibilities of production and understanding, have taken place in agriculture and horticulture in the last couple of decades. Consumers have become increasingly aware of the value of fruit and vegetable quality (Hewett, 2006; Fearne et al., 2006; Batt, 2006; Benner et al., 2003), and place more emphasis on the quality of their daily food. While retailers govern the fruit and vegetable supply chain in all developed countries, they have to comply with changing consumer demands and preferences to stay competitive. The increasing number of food quality issues covered in the media (milk scandal in China in 2008 and 2012, dioxine scandal Belgium in 1999 and in Germany in 2011, horse meat scandal in Europe in 2013) have added to the awareness and concern of the consumer, increasing the challenge to the grower and retailer.

Another change results from drastically increased technical and technological capabilities for measuring food quality together with the technology of modeling and data analysis. Combining this information at both the level of product usage and at the level of research and handling possibilities, it becomes increasingly clear that a systematic approach to fruit and vegetable quality, handling and modeling is vitally important. The traditional way of thinking about quality, and of developing empirical models and data analysis, has to be expanded to include all available knowledge and information. Consequently, models must include not only information contained in experimental data but also, and especially, information contained in chemical, physical and physiological expertise accumulated over decades of scholarship.

The ultimate goal of modeling is to predict the future behavior of any product, in any circumstance, from any region, and grown in any season. Modeling is the modern version of analyzing and understanding laboratory and practical experiments (Tijskens, 2004). It should allow the transfer of experimental results into practical applications. The world of food supply chains, however, and especially

Postharvest Handling.

globalized fruit and vegetable supply chains, has grown increasingly complicated. The quality of produce from different origins and growing conditions are sometimes different than expected, making the usually applied rules for quality control no longer generally applicable. Traditional models, mainly statistical or empirical models, are no longer sufficiently reliable for predicting quality. We have to include all (or as much as possible) available knowledge, both for the preharvest realm (i.e., fruit and vegetable production) and for the postharvest phase (i.e., harvesting, storage, distribution, processing, sales and service). The barrier between both phases desperately needs to be bridged so that ideas and information can be exchanged. Communication, however, between both realms is often problematic (Tijskens and van Kooten, 2006) due to differing viewpoints on the nature of quality and its importance in the supply chain. Process oriented modeling, based on the knowledge of the occurring processes, is a system of modeling that provides a feasible approach to integrate the preharvest and postharvest realm (Tijskens, 2004; Tijskens et al., 2001).

This chapter attempts to achieve just that by presenting an expanded view on quality, modeling and modeling of quality. Since the variation in properties of individual items in a batch of commodities accounts for a large part of the problems in understanding and dealing with product behavior, special attention is devoted to the omnipresent biological variation and ways to use it to gain competitive advantage.

II What is quality?

When applying a systems approach to modeling, built upon the processes active in commodities that change their behavior and quality over time, we also need a framework for quality within the same paradigm of a systems approach. As long as man is concerned with quality of food he will attempt to define that notion (see Chapters 3−5, 9−11, 13 and 14). It is sometimes assumed that it is easier to define quality in terms of levels of attributes or properties for large groups of consumers. The problem with this approach is that each individual perceives quality differently. As a consequence, every possible definition is of limited use in practice. To deal with the variation between individuals in developing quality models, Sloof et al. (1996) developed working concepts for quality that proved to be successful outside the modeling framework.

The framework (Figure 15.1) was adapted for evaluating the modeling requirements for globalization in fruit and vegetable supply chains (Tijskens et al., 2006a) and for quality assurance (Tijskens et al., 2005a). The main assumption behind the framework is that the processes by which humans evaluate the quality of any commodity are likely to be highly similar in every human being, regardless of culture, upbringing and social circumstances. The differences between individuals, regions, states, societies and cultures are induced by the difference in applied limits and "initial conditions" (Brückner, 2006). Although obtaining

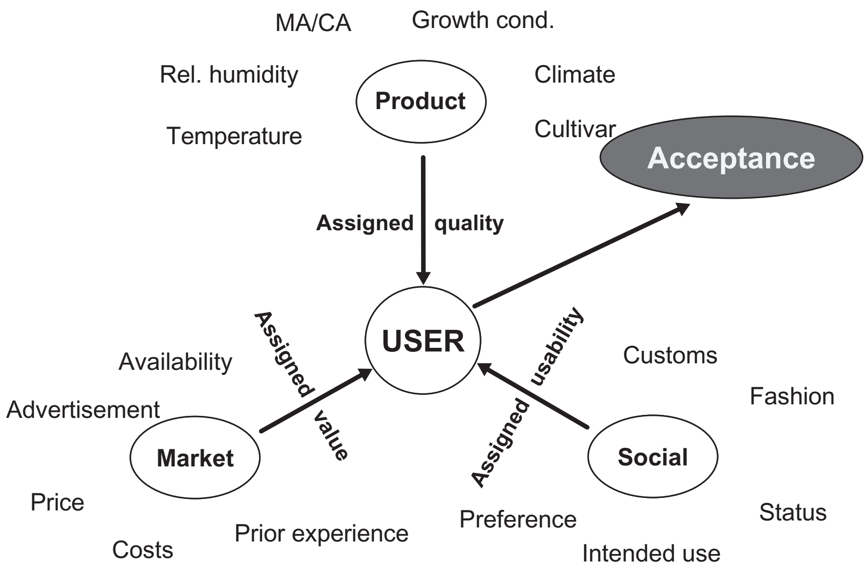

FIGURE 15.1

Schematic representation of quality and acceptance.

suitable data on human behavior in assessing quality and deciding on whether or not to purchase a particular commodity is still out of reach, psychologists are increasingly convinced of these premises (R. de Wijk, personal communication). Nevertheless, the fact that obtaining suitable data is virtually impossible should not prevent consideration of that framework. Lately, some efforts have been made to assess the effects of the combined variation in both product properties and consumer liking (Bavay et al., 2013, and references therein). A possible approach to deal with variation in both product properties and consumer liking is to estimate the cross-section between the distribution of the properties in a batch of products and the distribution in the consumer liking. This approach is discussed in more detail in the section *Acceptance with biological variance*.

Quality is assigned to a commodity by the user (buyer/consumer) in the center of the scheme (Figure 15.1) based on perceived properties of that particular specimen. By perception, those properties (e.g., sugar content) are converted into attributes (e.g., sweetness). The value of that particular specimen is assigned by the user based on the properties/attributes in respect of the market situation (assigned value). Based on the social circumstances of the evaluator (user, buyer) and the intended use for the commodity, a usability is assigned (assigned usability). All three assigned notions are then used to decide on the acceptance of a product.

On the first assigned item, quality (Figure 15.1), some information is available. With respect to modeling quality, that intrinsic or assigned quality depends almost exclusively on the quality attributes of the product and, hence, on properties of that product that are related to the attributes under consideration. On the last two assigned items (value and usability), however, not much is known

(Botonaki et al., 2006). Modeling acceptance is, therefore, much more difficult and cumbersome if the market situation and the social circumstance vary, because economical and psychological issues also come into play. Although there is increased interest in this area (Moskowitz, 2005; Morris and Young, 2000), as already mentioned, not much is known about the economical and psychological items in a systems approach framework.

Kramer and Twigg (1983) defined quality as: "The composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit by the buyer." Their definition clearly connects acceptability to product properties and attributes (here called characteristics). The keeping quality of products, that is the time over which a product remains acceptable during handling and storage, is closely related to acceptability (Rico et al., 2007; Tijskens et al., 1996; Tijskens and Polderdijk, 1996). At the same time, the definition of Kramer and Twigg stresses the importance of the difference between units of product, which is actually the biological variance present in a batch of individual items.

Consumer acceptance based on product attributes has been the subject of study and reports on its own merits (Crisosto et al., 2003, 2006; Berna et al., 2005; Tomlins et al., 2007). However, the research on consumer acceptance and its effects on postharvest technology applications will remain very cumbersome without an attempt to base this on fundamental models (Schouten et al., 2007a,b).

A Attributes versus properties

A consumer assigns attributes to a product based on the relevant properties present in a product (Figure 15.1). For practical application, the differences between product properties (physical, chemical) and quality attributes (psychological) are not that important. In fact, sometimes the differences between properties and attributes are not all that clear.

However, for the sake of developing theories and viewpoints and for research in the area of quality and human behavior, it is of the utmost importance to understand the difference. This is particularly true when a variable is measured using objective measuring techniques, when very often the variable is assumed to be a property. A good example is color. Does a tomato in pitch darkness have a color? We cannot judge that, since we need light to observe it. What a tomato always has, however, whether or not we observe them, are color compounds like chlorophyll or lycopene. Therefore, the properties related to the attribute color are light absorbing compounds.

It is important to note that frequently so-called objective measuring techniques are designed in such a way that the impact of the human sensitivity to the factor is already incorporated in the measuring technique. Again, color is a good example: the well-known L*a*b* color space does reflect the sensitivity of the human eye by the mere choice of used wavelengths.

Firmness can also be regarded as an attribute, based on properties of strength generating compounds. Many of the objective firmness measuring techniques do

Table 15.1 Relations Between Most Common Sensorial Attributes and Physical or Chemical Properties of Fruits and Vegetables

Attribute	Property
Color	Amount/concentration coloring compounds
	Wavelength light
Texture	Amount/concentration strength generating compounds
	Tissue structure
	Cell size
Sweetness	Amount/concentration sugars
	Amount/concentration acids
Flavor	Amount/concentration aroma compounds
	Texture (ripeness)
	Adsorbent properties tissue

reflect the way humans observe product strength while chewing, bending, breaking or touching the product. When dealing with this type of data, it is important to realize the nature of the variable measured, in order to deduce the proper framework of reasoning.

Most of the time, attributes are based on more than a single property, while properties may affect several attributes. The relations between properties and attributes are very complex and still not well understood. Table 15.1 shows some examples. A more elaborated example from texture research can be found in Table 15.2 as reported by Tijskens and Luyten (2004) based on the work of de Wijk et al. (2003).

B Assigned quality versus acceptance

From the definition by Kramer and Twigg (1983, see previous section) and the representation of quality relations (Figure 15.1), it is clear that assigned (or intrinsic) quality differs from product acceptance. The concepts are highly related to one another in a more or less unidirectional way: assigned quality can exist without acceptance, however acceptance never occurs without quality. In this first case, other issues like availability or costs (Figure 15.1 – Market) or personal preference (Figure 15.1 – Social) come into play in the context of acceptance. The principles of acceptance of potted plants based on assigned quality are described in Tijskens (2000) and Tijskens et al. (1996). Recently a similar approach has been applied to obtain information on consumer buying behavior for tomatoes (Schouten et al., 2007a,b), based on color and firmness as limiting attributes.

In most cases, laymen mean acceptance when referring to quality. Even in scientific publications, more often than not, quality is used in the meaning of acceptance. Yet, the concepts are not the same. For economic purposes, commercial

Table 15.2 An Illustration of the Complexity in the Attribute-Property Relations Using the Example of Mayonnaise and Custards

Physical Property	Affects	Sensorial property
Viscosity		Thickness, stickiness, compactness, melting, creaminess
Density		Compactness
Particle size		Compactness, creaminess
Adhesion		Thickness, stickiness
Concentration of flavoring compounds		Creaminess
Sensorial property	**Relates to**	**Physical Property**
Thickness		Viscosity, adhesion
Stickiness		Viscosity, adhesion
Compactness		Viscosity, density, particle size
Melting		Viscosity
Creaminess		Viscosity, particle size, concentration of flavoring compounds

Source: de Wijk et al. (2003).

companies are much more interested in product acceptance than in product quality. In that sense, acceptance is more important than assigned quality. Conversely, without quality the acceptance of the commodity is at risk.

In summary, both product acceptance and product quality are extremely important, sometimes hard to discern, and pose a challenge to model. A direct consequence of the applied quality philosophy, however, is that as long as one is primarily concerned with assigned or intrinsic quality and does not include economic or socio-psychological aspects, the modeling approach can be entirely based on the behavior of relevant product properties. If economic and social issues are also considered, modeling becomes very difficult, not so much due to practical or mathematical reasons, but because of the sheer differences in expertise and level of understanding in the three areas of product, market and consumer research.

C Acceptance and genetic effects

In the quality and acceptance scheme presented in Figure 15.1, it is implicitly assumed that the consumer makes all their evaluations and decisions in a conscious and reflective way. There is, however, evidence that preferences for food product are strongly determined by subconscious drives. The gene pattern of animals, including humans, urges the individuals to strive for high-density food (Ostan et al., 2009, 2010; Tijskens et al., 2010a). That would signify that besides the mechanism shown in Figure 15.1, another mechanism has to be included in the food acceptance system that is more related to the subconscious behavior of humans. How exactly this subconscious mechanism functions is currently unknown.

III Systems approach in modeling

Many scientists consider modeling to be very difficult, highly mathematical and far out of reach. But modeling is as old as science. Every conclusion based on scientific research is, in fact, a model. Not a mathematical one, not a statistical one, but a conceptual one, often applied inconsistently and variably, but nevertheless a model.

Mathematical modeling in agriculture started in the late sixties with, among others, the work of Thornley (1976) and the school of C.T. De Wit at what is now Wageningen University and Research Center (de Wit, 1968; Wierenga and De Wit, 1972; de Wit and van Keulen, 1972; van Keulen et al., 1976). For several decades, these traditional empirical/statistical models induced a tremendous impetus in agricultural research and optimization, especially in the area of production, both in open field and in greenhouses.

The technology of modeling however, has improved considerably over the last decades. Parameter estimation on measured data can now easily be based on nonlinear regression analysis (statistical package like SAS, Statistica, Genstat, R-Project), mechanisms can be automatically converted into differential equations and (possibly) solved for analytical solutions (e.g., Maple, MapleSoft, Waterloo Maple Inc, Waterloo, Canada or Mathematica, Wolfram Research, Inc., Champaign, IL, USA). Data can nowadays even be statistically analyzed through numerical integration of the differential equations when no analytical solution can be deduced, even including estimation of biological variation (Hertog et al., 2007c).

All these technical developments enable the use of conceptual models as directly derived from available expertise, and all laws of nature and scientific rules of disciplines in developing improved and more reliable, and more understandable models.

A Process oriented modeling versus statistical models

The main and usually the sole source of information for traditional mathematical models is the data gathered during experiments. The expertise and rules of statistics and data analysis are applied through the models and very often these type of models are developed, extended and refined over several years or even decades, and have often an amazing applicability (Sucros: Simane et al., 1994, still in use and maintained: http://models.pps.wur.nl/node/3 last visited July 2013).

However, those models mostly ignore the expertise and scientific knowledge that also exists. Concepts of processes occurring in nature, which are part of expert knowledge of a particular area of research, are much more valuable in general application power as well as in understanding power than the mere

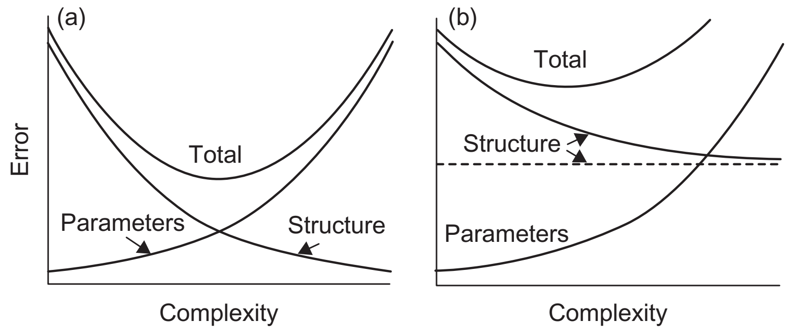

FIGURE 15.2

Notional components of prediction error in models of increasing complexity: (a) when the structure of the system is well understood; (b) when the model structure or the mechanism applied is wrong, with the irreducible structural error represented by the dotted asymptote. Complexity and error increase away from the intercept.

Source: Passioura (1996). Courtesy of Agronomy Journal*.*

mathematical/statistical models. For example, William of Ockham (14th century logician) was right with Ockham's razor (make models as simple as possible). Statisticians have, however, wrongly translated his wisdom into tests on the number of parameters of a model (e.g., goodness of fit). As Passioura reported (1996), a relationship exists between the estimation error (or goodness of fit measures), the structure of a model, the number of parameters in the model, and the complexity of the model. Only for very simple models does a minimum number of parameters provide a (statistically) better, more useful model (Figure 15.2). For more complex models, it seems futile to minimize the number of parameters. The structure of the model (which processes need to be included) becomes much more important. Ockham's razor can be applied perfectly in deciding which processes that occur in the product are important and which must be disregarded to arrive at models applicable in practice. In other words, the problem has to be decomposed into its constituent processes (Sloof, 2001). Simplification needs to be done at the level of processes to be included or not, and not at the level of mathematics and statistics.

Fundamental rules of disciplines (e.g., chemical kinetics) and the laws of nature (e.g., basic physics) are well established. Besides the use of statistical and mathematical skills, these rules and all the available expertise should be used in full in building models in complex and variable fields such as agriculture and food. Gathered data can and must then be used only for setting up the problem framework, and finally for calibration and validation of the developed models.

By including all available fundamental knowledge at our disposal, we achieve the ultimate goal of modeling: the prediction of future behavior in any circumstance, from any region, grown in any season, while generating more knowledge about the process under study. This approach yields the so-called fundamental, process oriented models. Research on the modeling effects for globalization (world-wide expansion of fruit and vegetable trade) is, as far we are aware, non-existent. Effects of different batches, seasons (both within one year and from year to year), harvest maturity and field management conditions are abundant. Proper interpretation in a global view, however, is mostly absent. By considering these differences, we basically deal with biological variation. Lately, reports have covered this subject (Hertog, 2002; Hertog et al., 2004; Schouten et al., 2004a; Tijskens et al., 2003, 2005c; Farneti et al., 2013; Jordan and Loeffen, 2013; Schouten et al., 2008, 2009, 2010; Tijskens et al., 2008, 2009, 2010b; Unuk et al., 2012). These reports indicate that it should be possible to interpret experimental data into a global view applying process oriented modeling.

The most basic rule of modern science is the repeatability of experiments. Under the same conditions, the same setup and ingredients should provide identical results. That means, for example, that the rate constant of chemical reactions should be the same regardless of the level of reactants present. Considering that many, presumably most, processes occurring in food products are of a chemical nature, the rate constant of a process has only to be determined once in the controlled circumstances of a laboratory, and henceforward, can be reused in different situations outside the lab. Moreover, a rate constant has to obey the fundamental rule of temperature dependence, according to Arrhenius' or Eyring's law (van Boekel and Tijskens, 2001). If, during model development and calibration, the rate constant of a process does not meet these requirements, either a wrong mechanism has been selected or more processes are active than have been considered in the model. In other words, the decomposition of the problem was improper (Sloof, 2001).

Applying fundamental rules and problem decomposition in a systems approach to build process oriented models are a few of the powerful tools capable of describing phenomena under any circumstances in a fruit and vegetable supply chain (Hertog et al., 2011). The next sections discuss examples of this approach applied to quality behavior in any link of supply chains.

B Area of dedication

Traditional empirical/statistical models are frequently specified for a very dedicated application, for one actor in a supply chain (growing, storage, transportation, etc.). When building models based on occurring processes however, it does not matter where the product is in a chain, or what conditions are forced upon it. For the occurring processes, for example of degreening, it is not important whether they occur in storage or during transport. The mechanism will be the same, as will be the derived model. Therefore, models developed based on the mechanism of occurring processes have a much wider applicability throughout an entire supply chain. Moreover, data gathered in different parts of a chain can be pooled and analyzed, increasing their applicability and reliability.

IV Examples of modeling

Firmness and color are the main attributes of the majority of agricultural commodities simply because they are important to consumers and trade. Moreover, firmness and color can be measured rather easily. Because both attributes have been measured for quite some time, a lot of knowledge has been accumulated about them. That does not mean that other quality attributes (e.g., sugar content, acid content, taste, flavor, juiciness) are less important for fruit and vegetables, but merely that there is less opportunity to analyze them because of the relatively more difficult measurement procedures. The majority of examples in the next sections are predominantly concerned with color and firmness of fruit and vegetables. In all examples, color and firmness must be defined to deal properly with the changes in these attributes.

Color is generated by coloring compounds like chlorophyll, pheophytine, lycopene and anthocyanins by reflection/absorption of incident light and by scattering of incident light by the structure of the tissue as observed by human senses. Changes in observed color can be caused by any of four major constituents: the senses, the light, the tissue structure and the levels of coloring compounds. For practical product research, incident light and senses are kept or considered constant, while the coloring compounds are items to be described and modeled. When the target area is changed, for example, to consumer research (what are possible differences between population segments?), the models developed for product research should not be translated/reused without considering the possible effect of changes in perception. However, in the product research, the main focus is on the chemistry of the coloring compounds involved in the product under study.

Most horticultural products are green (chlorophyll) at some stage of development, but develop towards maturity into a whole range of colors and coloring compounds. Chlorophyll content is or should be a good reference when considering maturity and ripening in any stage of development. The specific coloring compounds that are developed upon ripening (red tomatoes, yellow bananas, brown nuts) can also be used for that purpose, but only in the later (more critical) stages of maturity. The typical red coloration (for example, the blush in nectarines, apples) caused by anthocyanins is, most of the time, primarily related to the amount of sunlight received during growth (Steyn et al., 2009; Reay and Lancaster, 2001) and is barely related to that part of quality that is affected in postharvest handling.

Firmness can originate from different sources. Most common are pectines, cellulosic structuring material, cell turgor, granules inside cells and the shape and size of cells (Van Dijk and Tijskens, 2000; Tijskens and Luyten, 2004). Firmness is detected by applying a force to a structure. Again, the observer and the type and circumstances of the force applied may affect firmness behavior. In case of objective firmness measurement, it is a standardized procedure with a machine. Non-standardized human forces and senses are used in case of subjective assessment, again the major difference between product research and consumer/sensory research.

The different sources of firmness directly affect the development of models. Sometimes, but rarely, only one source of firmness is present in a commodity. In that case, modeling of firmness is rather straightforward, and focusses on that one factor. More frequently multiple sources of firmness are present. In these cases, each source of firmness can change at its own rate in actual conditions under study, including no change (zero rate). The latter case is the most common effect of multiple sources of firmness: firmness does not decay towards zero, but to a fixed end value. In any case, one has to be aware of multiple processes acting concurrently on multiple sources of firmness and take these into consideration when building a model of firmness.

A Models for storage

Color

Changes related to chlorophyll breakdown and pheophytine production are the most common color changes in fruits and vegetables during storage. The most frequent behavior of color, especially expressed in the L*a*b* system, shows a sigmoidal pattern that is modeled using a logistic function (see Table 15.3 for notation):

$$col = \frac{col_{\max} - col_{\min}}{1 + \left(\frac{col_{\max} - col_0}{col_0 - col_{\min}}\right) \cdot e^{k_{col} \cdot (col_{\max} - col_{\min}) \cdot t}} + col_{\min} \qquad \text{(Eq. 15.1)}$$

The logistic equation, of which Eq. 15.1 is just a specific case, has been used empirically to describe various kinds of sigmoidal behavior. The equation, however, can be deduced assuming an autocatalytic reaction:

$$\begin{aligned} col_{pre} + Enz &\xrightarrow{k_{col}} col + Enz \\ Enz_{pre} + Enz &\xrightarrow{k_{Enz}} 2 \cdot Enz \end{aligned} \qquad \text{(Eq. 15.2)}$$

This reaction can progress under the influence of an enzyme (*Enz*) or ethylene. The application of the fundamental rules of chemical kinetics, including the mass conservation laws, and the assumption that the two rate constants are the same, gives the analytical solution in Eq. 15.1. When the two rate constants are different, a more elaborate model describes an asymmetrical sigmoidal behavior often found in preharvest growth phenomena (Tijskens and van Kooten, 2006):

$$Col = \frac{Col_0}{(Enz_0 + Enz_{pre,0})^{-\frac{k_{col}}{k_{Enz}}}} \cdot (Enz_{pre,0} + e^{(k_{Enz} \cdot (Enz_0 + Enz_{pre,0}) \cdot t)} \cdot Enz_0)^{-\frac{k_{col}}{k_{Enz}}} \qquad \text{(Eq. 15.3)}$$

In Figure 15.3, an example is shown of both types of behavior. Although the models cannot be considered to be fully kinetic (the mechanisms are not proven, only assumed), the meaning of their parameters can be clearly described. Some model parameters are concentrations or are related to concentrations (Enz, Col), while others are reaction rate constants (k). From the rules of chemical kinetics,

Table 15.3 Description of Notation and Subscripts used

Name	Description
Col	Color (any type)
decay	Unnamed decay product
Ea	Activation energy
Enz	Enzyme activity
F	Firmness
k	Reaction rate constant
P	Density function
Pr	Probability function
Q	Quality
q_a, q_b	Lower and upper limit quality class
t	Time
T	Temperature
Δt	Time shift / biological shift factor
μ	Mean value
σ	Standard deviation or biological variation
Φ	Cumulative normal probability function
All Dimensions are Arbitrary Unless Indicated	
Subscripts	**Description**
col	Color
Enz, e	Enzyme
f	Firmness
fix	Invariable part/asymptotic end value
post	Postharvest conditions
max	Maximum value
min	Minimum value
pre	Precursor or preharvest conditions
ref	At some reference
0	Initial/at harvest
1	Source 1
2	Source 2
3	Source 3

one can deduce that reaction rate constants inherently depend on temperature according to the fundamental rule of Arrhenius (Eq. 15.4) or Eyring, which can be found in textbooks on chemical or enzymatic kinetics:

$$k = k_{ref} \cdot e^{\frac{Ea}{R} \cdot \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)} \quad \text{(Eq. 15.4)}$$

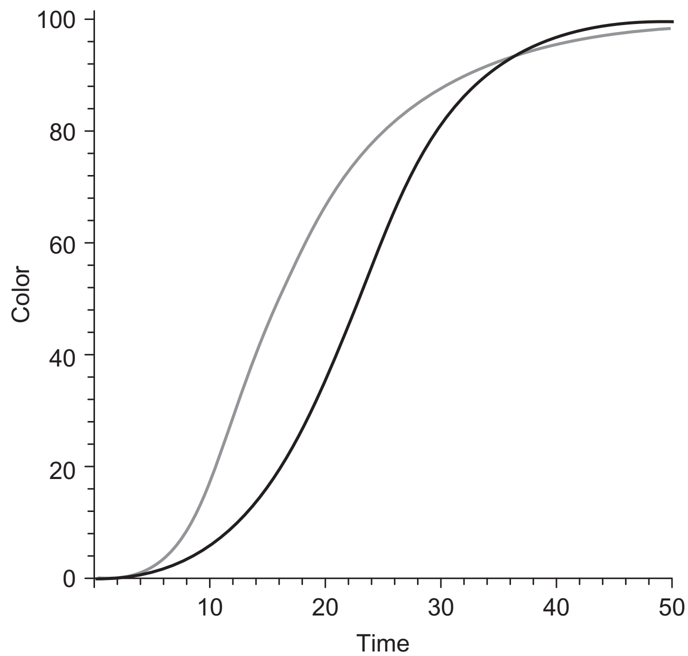

FIGURE 15.3

Behavior of the symmetrical (black line) and asymmetrical (gray line) sigmoidal function according to Eqs 15.1 and 15.3, using $Col_{max} = 100$ and $Col_{min} = 0$. All parameter values and time units are arbitrarily selected.

Heaton and Marangoni (1996) and van Boekel (1999, 2000) provided extended descriptions of the mechanisms involved in color changes in horticultural products, in terms of the concentrations of different coloring compounds. Schouten et al. (2002) applied part of that mechanism to describe the color changes in cucumbers (expressed in RGB value from computer imaging) including the sometimes observed deepening of the green color in the early part of storage in the dark.

Firmness

Changes in firmness of horticultural products can be caused by a plethora of reactions. For fruit of deciduous trees, the major cause of softening is pectin degradation. For fruit from shrubs and herbs and for vegetables (like currants, strawberries, grapes) the major cause is moisture loss. But firmness and changes in firmness of the horticultural products cannot be attributed to a single cause. A possible mechanism is depicted in the following simple reaction scheme:

$$\begin{aligned} F_1 &\xrightarrow{k_{f,1}} decay \\ F_2 &\xrightarrow{k_{f,2}} decay \\ F_3 &\xrightarrow{k_{f,3}} decay \end{aligned} \qquad \text{(Eq. 15.5)}$$

where F_1, F_2 and F_3 are possible sources of firmness. The observed firmness is then related to the total of all items involved. Not all of the sources of firmness have to change under the same conditions (temperature, controlled atmosphere). For some of them the rate of change is so small that no change can be observed in the period of study. The application of the fundamental rules of chemical kinetics and the solution of the derived differential equations for constant external conditions (e.g., temperature) yields an equation for changes in firmness over time:

$$F = F_{1,0} \cdot e^{-k_{f,1} \cdot t} + F_{2,0} \cdot e^{-k_{f,2} \cdot t} + F_{3,0} \cdot e^{-k_{f,3} \cdot t} \qquad \text{(Eq. 15.6)}$$

All three reactions in Eq. 15.5 can obey different relations with temperature (i.e., the Arrhenius relation, but with different parameter values). Equation 15.6 indicates that at different storage temperatures (changing the rate constants) an apparently completely different behavior is observed. Figure 15.4a shows an example for some imaginary fruit stored at seven temperatures (0−30°C in 5°C increments) using parameter values from Table 15.4. At low temperatures, only the first reaction actually takes place, while at higher temperatures the second reaction also starts to develop due to the higher activation energy (Ea). The third reaction is kept constant ($k_{f,3}$ is zero). Figure 15.4a indicates a change in asymptotic end value with increasing temperatures, while maintaining an apparent exponential behavior for each series separately. This behavior is frequently found in measured data, but is only rarely taken into account.

All kinds of variation on this central mechanism (Eq. 15.5) can occur. In horticultural products, almost all reactions are catalyzed by some enzyme (*Enz*). When the enzyme activity is (virtually) constant during storage, the results are like those depicted above. However, batches of different origin or different stages of maturity may have different levels of enzyme activity. Consequently, the apparent rate of change (i.e., the specific rate constant times the enzyme activity) may vary from batch to batch, depending on, for example, growing conditions and maturity at harvest. This complex mechanism can be represented simply as:

$$\begin{aligned} F_1 + Enz &\xrightarrow{k_{f,1}} decay + Enz \\ F_2 + Enz &\xrightarrow{k_{f,2}} decay + Enz \\ F_3 + Enz &\xrightarrow{k_{f,3}} decay + Enz \end{aligned} \qquad \text{(Eq. 15.7)}$$

The result is an equation similar to Eq. 15.6, but including the rate constants multiplied by the actual enzyme activity. Each reaction, however, could also be catalyzed by different enzymes. In that case the situation rapidly gets very complex. The approach to achieving a feasible model, however, is highly similar to the mechanism shown in Eq. 15.7.

A completely new situation arises when the enzyme activity is not constant during storage, but, for example, increases. The mechanism of enzyme change

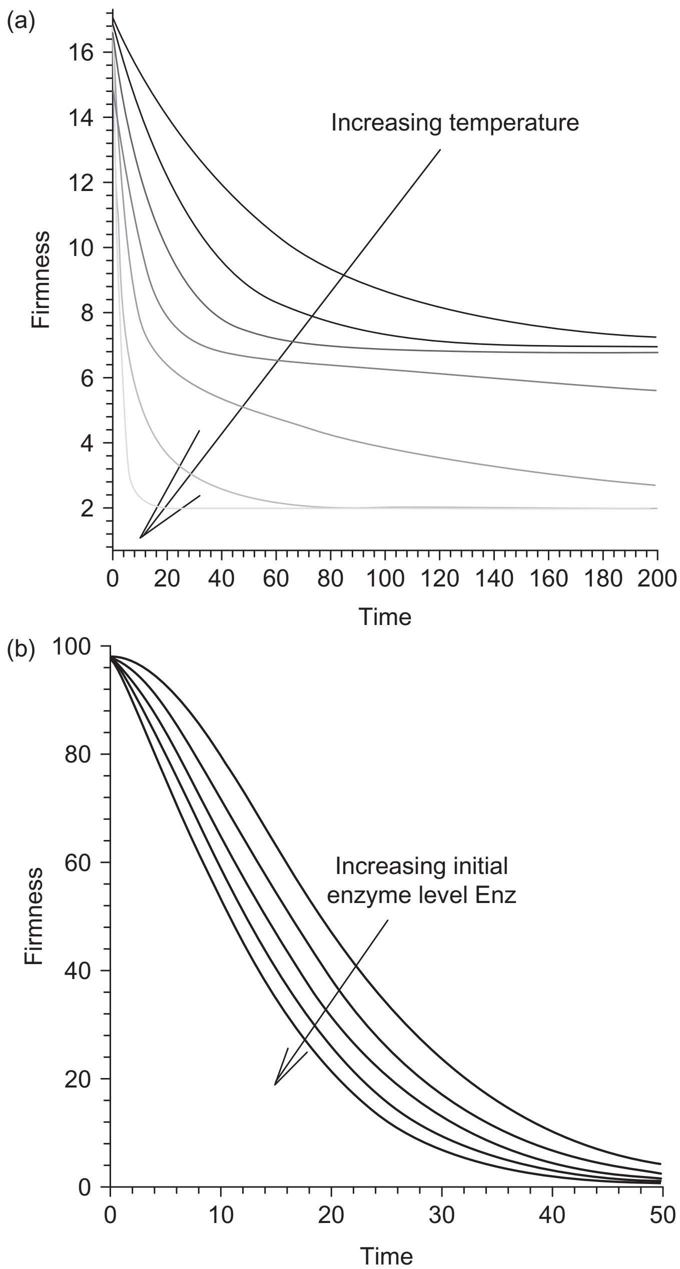

FIGURE 15.4

Firmness behavior according to Eq. 15.6 based on parameter values as shown in Table 15.4. (a) Different levels of temperature. The model includes different sources of firmness, that start changing only at higher temeratures, reflected in the different level of the asymptots as the time increases. (b) Different levels of initial enzyme activity, indicating the increasing rate of decay with increasing enzyme activity, thereby changing the apparent behavior of softening (from sigmoidal to exponential).

Table 15.4 Parameter Values for Eq. 15.6 used for Simulation in Figure 15.4a

Reaction	$F_{x,o}$	$k_{f,x}$	Ea_x
1	10	0.2	80
2	5	0.01	250
3	2	0	0

Note: Dimensions and values selected completely arbitrary.

Table 15.5 Simulation Parameters (Eq. 15.8 and Figure 15.4b).

Parameter Name	Value
F_0	100
$Enz_{pre,0}$	1
Enz_0	0–0.41
k_f	0.1
k_e	0.05

Note: Dimensions and values selected completely arbitrary.

will have a profound effect on the observed behavior. A possible mechanism is shown in Eq. 15.8:

$$\begin{aligned} F + Enz &\xrightarrow{k_f} decay + Enz \\ Enz_{pre} &\xrightarrow{k_e} Enz \end{aligned} \qquad \text{(Eq. 15.8)}$$

where F is again the firmness (only a single source is considered to keep it simple), k the rate constants and Enz the available enzyme activity. The subscript "pre" indicates a precursor, f indicates firmness and e enzyme. Figure 15.4b shows an example of increasing initial levels of Enz activity using parameters values shown in Table 15.5. With higher levels of Enz_0, the enzyme activity at the moment of harvest, the firmness breakdown does resemble the normally found exponential behavior. On the other hand, when the level of initial enzyme activity is very low, the behavior resembles the sigmoidal behavior, frequently modeled using the logistic curve (Eq. 15.1). For example, such behavior was found in ripening nectarines (Tijskens et al., 2007).

Another possible situation is when one of the reactions in Eqs 15.5 or 15.7 is inhibited by controlled atmosphere (CA) and the other is not. CA slows physiological aging reactions in many fruits and vegetables by decreasing the product's respiration. Application of CA conditions would then lead to a behavior as depicted in Figure 15.4, but now not a function of temperature, but of the intensity of the CA condition. Tijskens modeled the change in firmness of Golden Delicious apples in different CA regimes in 1979. The findings were used in a simulation application for Elstar apples (Tijskens et al., 1999). Additional details regarding the modeling of respiration and its effects on the quality of horticultural products can be found in Hertog et al. (1999), Hertog (2001), Schouten et al. (2004b) and the references cited therein.

Gwanpua et al. (2013) presented an extended study of the effects and management of the biological variation in firmness of different apple cultivars in a supply chain, as related to the maturity at harvest, and temperature, controlled atmosphere conditions and endogenous ethylene concentration during storage conditions. The main stochastic variables, explaining the biological variation, were identified as the initial firmness and the rate constants for firmness breakdown and ethylene production.

Glucosinolates in broccoli

Breakdown products of glucosinolates protect against carcinogenesis, mutagenesis, and other forms of toxicity of electrophiles and reactive forms of oxygen. Consequently, glucosinolates are assumed to be healthy. Schouten et al. (2008, 2009) developed a model of the behavior of several glucosinolates in broccoli during postharvest storage and related this to preharvest growth conditions, storage temperature and conditions of CA storage.

Upon disruption of the tissue, the enzyme myrosinase (MYR) comes into contact with gluosinolates (GLS), and starts the decay of the latter compounds.

$$\begin{aligned} &\mathrm{nil} \xrightarrow{kM} \mathrm{MYR} \\ &\mathrm{Myr} + \mathrm{GLS} \xrightarrow{kG} \mathrm{MYR} \end{aligned} \qquad \text{(Eq. GLS1)}$$

Since tissue needs to be disrupted for myrosinase to be available, the activity of this enzyme at $t = 0$ can safely be assumed to be zero. Applying the rules of basic kinetics, the differential equations for this system can be deduced, and solved for constant external conditions (Eq. GLS2):

$$\mathrm{GLS} = \mathrm{GLS}_0 \cdot e^{-\frac{kG \cdot kM \cdot t^2}{2}} \qquad \text{(Eq. GLS2)}$$

The initial level of GLS (at time = zero) will vary according to the same mechanism on the preharvest condition. Expressing this variable as a time shift factor (Δt) results in an expression that describes the behavior of glucosinolates during both growth and storage:

$$\mathrm{GLS} = \mathrm{GLS}_{ref} \cdot e^{-\frac{1}{2}(kGM_{pre} \cdot \Delta t^2 + kGM \cdot t^2)} \qquad \text{(Eq. GLS3)}$$

with Δt the biological shift factor, kGM the combined rate constants kG and kM and kGM_{pre} the combined rate constant at mean growing conditions (12°C). Δt is the time to change GLS from the initial value (GLS_0) to the reference value

(GLS_{ref}). The rate constant kGM depends on temperature according to the Arrhenius function, and on the applied CA conditions (relative respiration RR Eq. GLS4), characterized by the relative respiration, i.e., the ratio between the O_2 consumption under the actual conditions relative to the consumption in regular air at the same temperature (Tijskens, 1995; Hertog et al., 1999).

$$RR = \frac{Km_{O_2} \cdot 21 \cdot \left(1 + \frac{0}{Kmu_{CO_2}}\right)}{Km_{O_2} \cdot O_2 \cdot \left(1 + \frac{CO_2}{Kmu_{CO_2}}\right)} \quad \text{(Eq. GLS4)}$$

The levels of glucoraphanin (GR), glucobrassicin (GB), neoglucobrassicin (neo-GB) and 4-methoxyglucobrassicin (4-MetGB) were determined by HPLC during storage of broccoli heads at 5, 10 and 18°C and several combinations of CO_2 and O_2 levels. All data were analyzed per compound combined for all levels of temperature and CA conditions simultaneously. Explained parts obtained (R^2_{adj}) ranged from 70% (4-MetGB) to 92% (GR).

Figure 15.5 shows the behavior of glucoraphanin (GR), based on the estimated values shown in Table 15.6. The major effect of temperature can clearly be noticed, compared to the smaller effect of CA conditions. The latter only become important or effective in the lower O_2 region (bottom right). The maturity state, expressed as biological shift factor (Δt), however, exhibits the largest effect (only five days' difference in Figure 15.5, top left) in defining the initial values of the glucosinolates.

Color in the apple orchard

The effects of crop load and fertilization (Tijskens et al., 2009) and location in the canopy (Unuk et al., 2012) on the color development of individual apples on the tree during the last couple of months before harvest were assessed non-destructively. Data were analyzed using the logistic color model (Eq. 15.1), expressing the initial color in biological shift factor Δt. The data over several seasons (2001, 2002, 2009) and cultivars (Braeburn, Fuji, Gala and Golden Delicious) obeyed the same model including the kinetic parameters.

All variation observed could be attributed to the biological shift factor estimated for each individual fruit. The differences in estimated values and standard deviation of the biological shift factor proved to be useful for interpreting the effects of the different treatments and conditions. Explained parts (R^2_{adj}) reached quite extraordinary levels of about 95% for all combinations of cultivar, season or treatment. Figure 15.6 shows an example of Braeburn apples growing at different locations in the canopy.

B Models for batches

Dealing with general patterns and variation in measured properties or attributes is, in its basic premises, the technical goal of modeling. The previous few years have

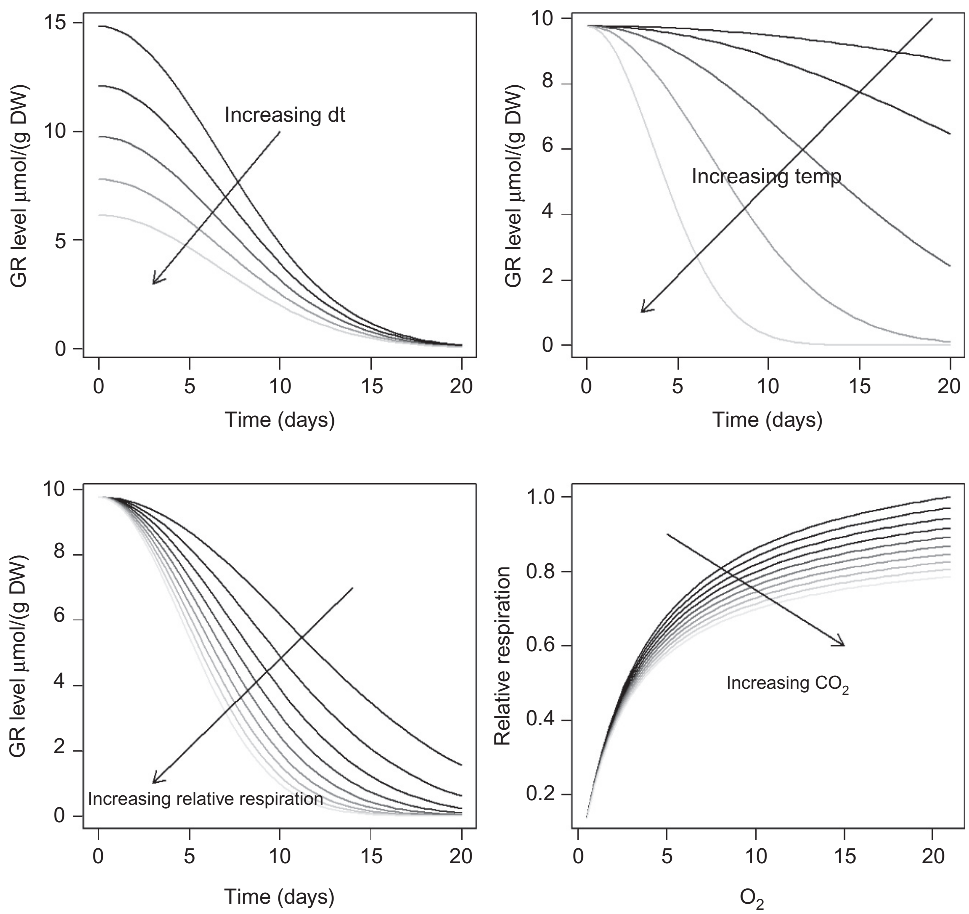

FIGURE 15.5

Behavior of glucoraphanin. Top left: as a function of time for different values (from 23.5 to 28.5 days) of the biological shift factor (Δt); top right: for different temperatures (5–25°C); bottom left for different values of the relative respiration (from 0.2 to 1); bottom right: behavior of the relative respiration versus level of oxygen for different levels of CO_2 (0–10%).

Table 15.6 Parameter Values Glucosinolate Analysis for Glucoraphanin (GR)

Parameter	Units	Value
Km_{O2}	kPa	3.62
Kmu_{CO2}	kPa	31.54
kGM_{ref}	$mol^{-1} \bullet day^{-1}$	0.0289
EGM	$kJ \bullet mol^{-1}$	164.9
GLS_{ref}	$\mu mol \bullet (g\ DW)^{-1}$	100
Mean Δt	day	26.02
Stand dev Δt	day	1.23

Source: Schouten et al. (2009).

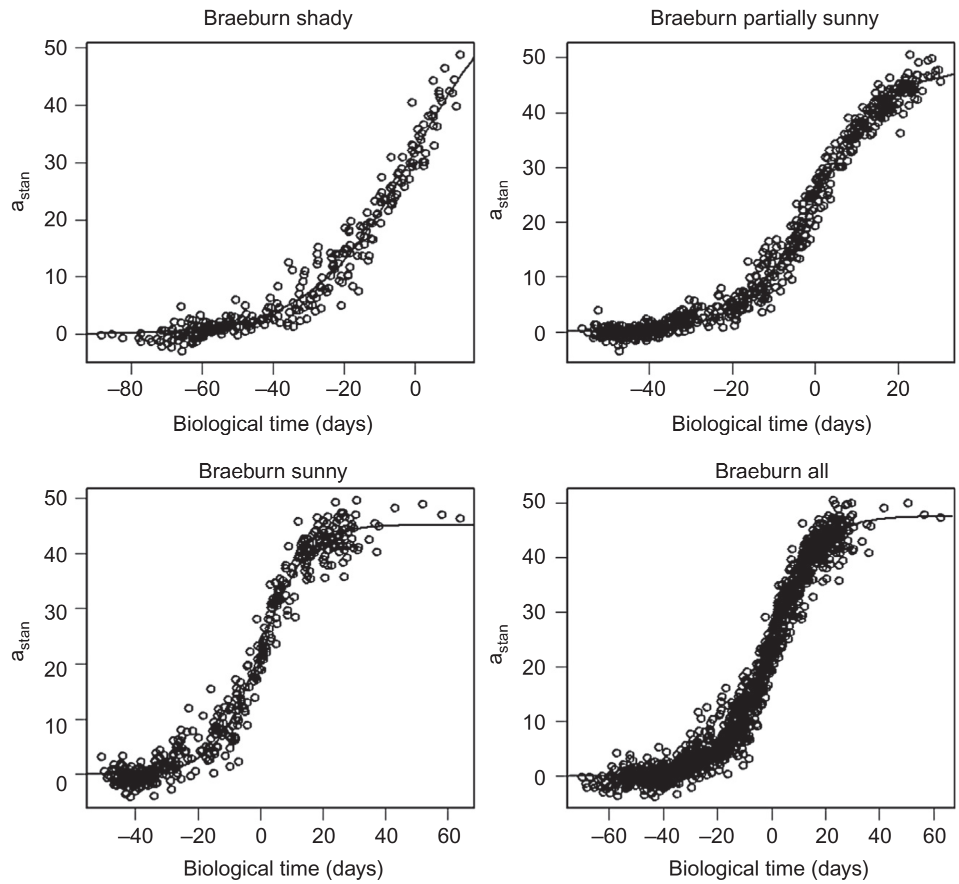

FIGURE 15.6

Example of color development (a*) as a function of biological time for Braeburn apples growing in shady, partially sunny and sunny locations in the canopy, and all combined (bottom right) for the season 2009. Parameter values are shown in Table 15.7. Standardization is performed (astan = a − amin) to avoid the effect of different ranges of changes between the treatments. Note the different ranges of the *x*-axis as determined by the effect of the biological shift factor, different for each individual.

Table 15.7 Results of the Analysis of a* per Season, Combined for all Locations in the Canopy

	Parameters				Admin Info		
CV	**Col_{min}**	**Col_{max}**	**k_{col}**	**Δt**	**R^2_{adj}**	**N_{obs}**	**N_{gr}**
Braeburn	−16.44	31.16	0.0023	−48.92	0.98	1429	120
Fuji	−20.23	28.06	0.0011	−53.43	0.96	1630	118
Gala	−6.71	37.20	0.0029	−31.41	0.95	1194	109

seen the emergence of a new type of model: batch models. This type of model describes the variation resulting from slightly different conditions during growth for all individuals with a common growth history ("batch"). This variation is known as biological variation and may be described as the composite of biological properties that differentiate individuals in a batch (adapted from Tijskens et al., 2003).

In fruit and vegetables, biological variation is often larger in magnitude than other sources of variation, such as random and systematic errors related to data gathering (observational errors, technical variation). Until recently, however, biological variation has been neglected for various reasons. Tijskens et al. (2003) describes how, in practice, variation in properties has been addressed by sorting and grading with emphasis on uniform production. However, uniform production methods do not produce batches with zero biological variation because small spatial or temporal variation in growth conditions cannot be avoided. Hertog et al. (2004) mentioned that if all fruit were harvested at the same stage of maturity, the variation at harvest would be negligible and would remain negligible throughout the postharvest period. But this is never the case. The problem with sorting and grading is two-fold. First, sorting and grading on (external) quality attributes will only sort on the current quality attributes. Limiting variation in the quality attribute by mixing batches will mask information indicating how the variation will develop later in the supply chain. Second, given available commercial technology, sorting and grading is primarily conducted for external attributes. Sorting and grading might reduce the variation in other (internal) attributes (see Chapter 12), but much less than for the external properties (Tijskens et al., 2003).

This section illustrates different aspects of biological variation and its propagation in time, including examples of how these batch models advance the understanding of physiology. Progress has been swift in this area, and it is likely that this overview will be out of date in a few years, but the practical benefits will become clear in the section on globalization.

Batch models combine quality models that describe the change of properties or attributes of individual products over time (see examples in previous sections) with probability theory, which describes the variation in measured properties or attributes as a function of time. Biological variation is a mathematical concept, which can be incorporated into quality models by assuming that the change in quality behavior is deterministic and any biological variation is included as a stochastic deviation of a single individual around the deterministic part (De Ketelaere et al., 2006). For the deterministic part a whole range of (individual) quality models are available in literature.

Incorporating biological age

One approach to obtaining information about biological variation is to adapt an individual model to allow for the estimation of the biological age for each individual fruit or vegetable in a batch. This procedure requires that individuals are measured repeatedly over time using nondestructive measuring techniques. The

EXAMPLE 15.1 FIRMNESS OF TOMATOES

Tomatoes tend to lose firmness according to an exponential function when they have reached commercial size either on or off the plant. Apparently, two sources of variation suffice for tomato firmness: a changing property and an invariable one (see Eq. 15.6). Firmness breakdown occurring over time during postharvest can then be described according to Eq. 15.9:

$$F(t) = (F_0 - F_{fix}) \cdot e^{-k_{f,post} \cdot t} + F_{fix} \qquad \text{(Eq. 15.9)}$$

with F_0 being the firmness at harvest (in N), $k_{f,post}$ (in day^{-1}) the reaction rate constant for the firmness breakdown after harvest and F_{fix} the invariable part (in N). The firmness at harvest, F_0, was assumed to be the result of firmness changes during preharvest. Subsequently, the postharvest firmness change model can then be expressed as a function of the storage time after harvest and the biological age firmness at harvest for constant temperature conditions (Eq. 15.10).

$$F(t) = (F_{ref} - F_{fix}) \cdot e^{-k_{f,post} \cdot t - k_{f,pre} \cdot \Delta t_F} + F_{fix} \qquad \text{(Eq. 15.10)}$$

with $k_{f,pre}$ (in day^{-1}) being the reaction rate constant for the firmness change before harvest, F_{ref} an arbitrary reference firmness and Δt the biological age expressed as the time (in days) necessary for the firmness to change from F_{ref} to F_0. Equation 15.10 expresses the postharvest firmness behavior as a function of the preharvest growing conditions with regard to firmness breakdown, the firmness at harvest, the storage time after harvest and the biological age firmness at harvest (Figure 15.10a,b).

Adapted from Schouten et al. (2007a).

biological age can be defined as the age of the individual relative to an arbitrary reference point (see Example 15.1). The individual model is adapted to allow the estimation of the biological age for each individual fruit as the time necessary for the change in the initial firmness to an arbitrarily chosen reference firmness (Δt_F) and the estimation of all other model parameters in common for the whole batch.

There seem to be two (almost identical) methods for incorporating the biological age. The first method is used by Hertog et al. (2004, 2007b) and Schouten et al. (2007a) who showed by comparing root mean square error plots that most of the variation between tomatoes of the same batch originated from picking at a different initial color. The concept that biological age can be applied to the initial values of a quality attribute or property to develop individual models is shown later in this chapter. The second method is to add the biological age (which is actually the transformed initial condition F_0 to the time frame, using the model under study) to the time variable as a stochastic variable called biological time. This biological time will have a different value for each individual in a batch. This second method has been presented by Tijskens et al. (2003), Tijskens et al. (2007) and De Ketelaere et al. (2006).

Both methods of incorporating biological variance mentioned above can be used to obtain information about the biological variation present in a batch. Using non-linear mixed effects or indexed regression analysis it is possible to estimate

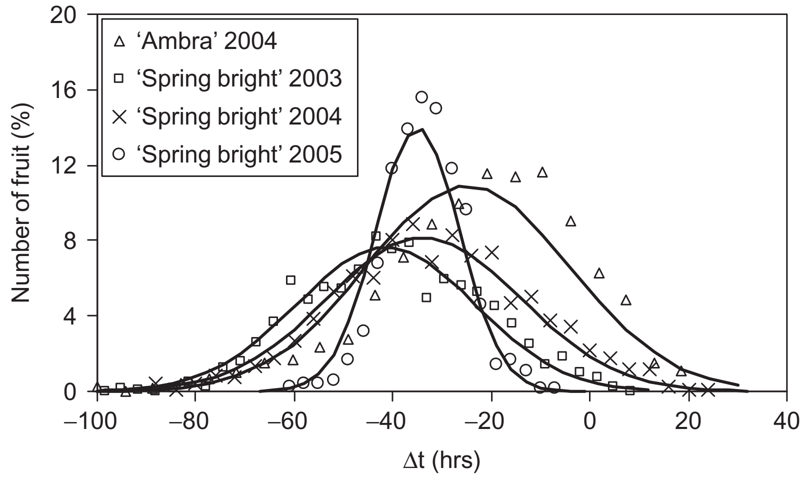

FIGURE 15.7

Distribution of the firmness biological age of nectarines by the absorption coefficient μa measured at 670 nm for four batches, differing in seasons (2003–2005) and cultivars (Ambra and Spring Bright) harvested at commercial maturity.

Source: Tijskens et al. (2007).

the joint model parameters, such as $k_{f,post}$, $k_{f\ pre}$ and F_{fix} in Example 15.1, and all the values for the biological age of the individuals in the batch. Non-linear mixed effects regression analysis assumes implicitly that the variable containing the variation is normally distributed, while for indexed regression no assumption whatsoever is made. This makes the latter more useful in determining that actual distribution of the variable containing the variation. The estimated values, expressed as a biological shift factor (Tijskens et al., 2005b), appear to be distributed according to a normal or Gaussian distribution; for example, the color biological age in tomatoes (Hertog et al., 2004) and the firmness biological age measured by the chlorophyll-related absorption coefficient μ_a of nectarines (Tijskens et al., 2006b, 2007). The distribution of biological age can be characterized by the mean and the standard deviation. It is clear from Figure 15.7 that this approach successfully describes the large differences present between batches, both in the value of the mean and the standard deviation of the biological age distribution.

Biological variation

Another approach to obtaining information about biological variation is to incorporate the finding that the biological age is apparently normally distributed. Information can be obtained in two ways. The first method is preferred when dealing with experimental data that have been classified into (quality) categories (relative frequency data), while the second approach is useful when no classification is used. The first method expresses the batch model as the probability that measurements belong to a certain class (q_a, q_b) of the quality function Q.

Assuming that the biological age (Δt) is normally distributed will result in the following batch model formulation (Eq. 15.11) (Schouten et al., 2004b):

$$\Pr(Q(t) \in (q_a, q_b)) = \Pr(Q(\Delta t) \leq \mathrm{q_b}) - \Pr(Q(\Delta t) \leq \mathrm{q_a}) = \Phi\left(\frac{Q^{-1}(q_a) - \mu}{\sigma}\right) - \Phi\left(\frac{Q^{-1}(q_b) - \mu}{\sigma}\right) \quad \text{(Eq. 15.11)}$$

with Φ the cumulative standard normal distribution function, μ the mean and σ the standard deviation of the (biological age) distribution.

The second method is based on understanding how one variable is affected by the variation in another variable on which it depends. Let us assume that a quality function Q, as a function of biological age, is prone to biological variation. In that case, the probability density P(Q(t)) can be expressed according to Eq. (15.12), assuming that the biological age is normally distributed with mean μ and standard deviation σ (Hertog et al., 2004):

$$P(Q(t)) = P(Q^{-1}(q)) \cdot \frac{\mathrm{d}Q^{-1}(q)}{\mathrm{d}q} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{Q^{-1} - \mu}{\sigma}\right)^2} \cdot \frac{\mathrm{d}Q^{-1}(q)}{\mathrm{d}q} \quad \text{(Eq. 15.12)}$$

From Eq. 15.12 it is clear that the shape of the distribution of measured variables like color, firmness, etc. is highly dependent on the mechanism at work (Q^{-1}) and that it changes with time. The inference of the applicable dedicated equation for a logistic behavior (lower half) is shown in Example 15.2.

When there are large numbers of individual fruits or vegetables in a batch, no differences between the two methods are expected in terms of batch or model parameters. However, when only a limited number of individuals in a batch are available, estimations will depend on the chosen class widths (q_a, q_b). In the latter

EXAMPLE 15.2 METHOD 2 – FIRMNESS BATCH MODEL FOR TOMATOES.

To create a batch model using the second method of firmness behavior, the inverse of the quality function (Eq. 15.10) has to be differentiated with regard to q. The derivative with regard to q is applied in Eq. 15.12 and leads to Eq. 15.14:

$$P(F) = \frac{e^{-\frac{1}{2}\left(\frac{\frac{-\ln\left(\frac{F - F_{fix}}{F_{ref} - F_{fix}}\right) - k_{f,post} \cdot t}{k_{f,pre}} - \mu}{\sigma}\right)^2}}{\sigma\sqrt{2\pi} \cdot (F_{fix} - F) \cdot k_{f,pre}} \quad \text{(Eq. 15.14)}$$

Figure 15.11 shows an example of the propagation of the probability density function assuming the logistic quality function rather than exponential. The distribution changes start (t = 0) as a symmetrical distribution that becomes skewed over time until all tomatoes show only little variation in color (t = 20).

case, the second method will likely result in improved descriptions of the batch variation. However, the first method provides results that are easier to interpret because they are expressed as probability values between 0 and 1, instead of probability density functions that have no upper limit and can easily exceed 1. Both methods are generic in nature, but are limited to those quality functions with an inverse (Q^{-1}), which is the main problem in developing batch models.

Biological variation and quantile regression

Very recently an interesting procedure was presented by a New Zealand group of researchers (Jordan and Loeffen, 2013), entirely based on the ranking of measured data for each measuring time (time sample), already proposed by Galton (1883). That ranking number is subsequently converted into a probability (Eq. 15.13):

$$p = \frac{PN - 1/2}{n_{obs}} \qquad \text{(Eq. 15.13)}$$

where p is the probability, PN the ranking number and n_{obs} the number of observation in each time sample. Applying the derived probability in the quantile function (the inverse of the cumulative distribution, here a normal one, "qnorm" in the statistical package R), the mean and standard deviation of the parameter containing the biological variation (here Δt) can be estimated using a normal nonlinear regression procedure. The main benefit of this system is that it is not only applicable to longitudinal data (obtained by nondestructive measuring techniques) but also to cross-sectional data (obtained by destructive measuring techniques). Moreover, the results can be used directly to estimate dynamically in time the fraction of a batch of products that falls above or below a certain limit of acceptability. The disadvantage is that a large number of replicates need to be measured each time (preferably more than 50), and that the system relies more on the (assumed) correctness of the model applied. Even with non-optimal models, this quantile regression system provides high correlations. The system for estimating the biological variation presented above fails almost completely when the model does not reflect the processes occurring in the product.

Multiple sources of variation

Schouten et al. (2007a) investigated whether the biological age based on (individual) color measurements and those based on (individual) firmness measurements in tomatoes were linked. They found that the mean biological ages between batches from the same greenhouse were strongly linked. Apparently, the biological age based on mean color and biological age based on mean firmness of tomatoes are synchronized per grower, which points at links between the different metabolic pathways that result in synchronized quality attributes. This link between the biological age based on color and on firmness is also apparent when the chlorophyll-related absorption coefficient μ_a was linked to the biological age based on firmness of nectarines (Tijskens et al., 2006b, 2007). The viewpoint that multiple sources of variation may exist was investigated by De Ketelaere (2006) who showed that within a batch of mangoes, next to the biological age based on firmness, also variation is present in the rate of the logistic firmness breakdown process. This is remarkable, because in many deterministic quality models the rate constant of firmness breakdown is considered a constant that only varies between cultivars, not within batches.

Hertog et al. (2007a) proposed an approach to generate batch models with two stochastic variables, for two different sources of biological variation. This was accomplished by extending the second method discussed above to the situation where the quality function Q depends on two co-varying sources of biological variation. The approach was demonstrated on postharvest stem growth data affected by biological variation in the mass of the head and initial length of the central stem of Belgian endive, applying a bivariate normal distribution.

The system based on quantile regressions (Jordan and Loeffen, 2013) can easily be extended to multiple sources of variation, one on the time axis (e.g., the biological shift factor Δt), and one on the y-axis (i.e., technical variation or measuring error), as a geometric mean of both variations. With that approach all variation can be assessed and estimated in one analysis. Frequently explained parts around 99% are obtained, since in principle all sources and types of variation are taken into account.

Application of batch models

Practical applications based on batch models are quickly becoming a reality. For instance, the (logistic) batch model describing the variation in the chlorophyll precursor in cucumbers was shown to have an upper limit in the cultivar specific amount of this precursor (Schouten et al., 2004a). Such information could be used by cucumber breeders to create genotypes with a specific keeping quality. Another application for breeders and participants in a tomato supply chain might be the combination of batch models for color and firmness batch behavior, together with consumer limits, to assess the purchase period for consumers. That period starts when a tomato batch becomes acceptable (from unripe to ripe) and ends when the batch becomes unacceptable (from ripe to overripe) (Schouten et al., 2007b, 2012).

The quantile regressions system (Jordan and Loeffen, 2013) almost naturally presents the results as batch acceptability. The authors claim that the system has been already in commercial use for some time.

Acceptance with biological variance

In both product properties (maturity) and consumer acceptance (liking) of these properties/attributes, biological variation is always present. With color as an example, the variation occurs according to the density function, associated with the logistic behavior (black lines in Figure 15.8). We have to bear in mind that this density function strongly depends on the mechanisms involved in the production and decay of the property under consideration.

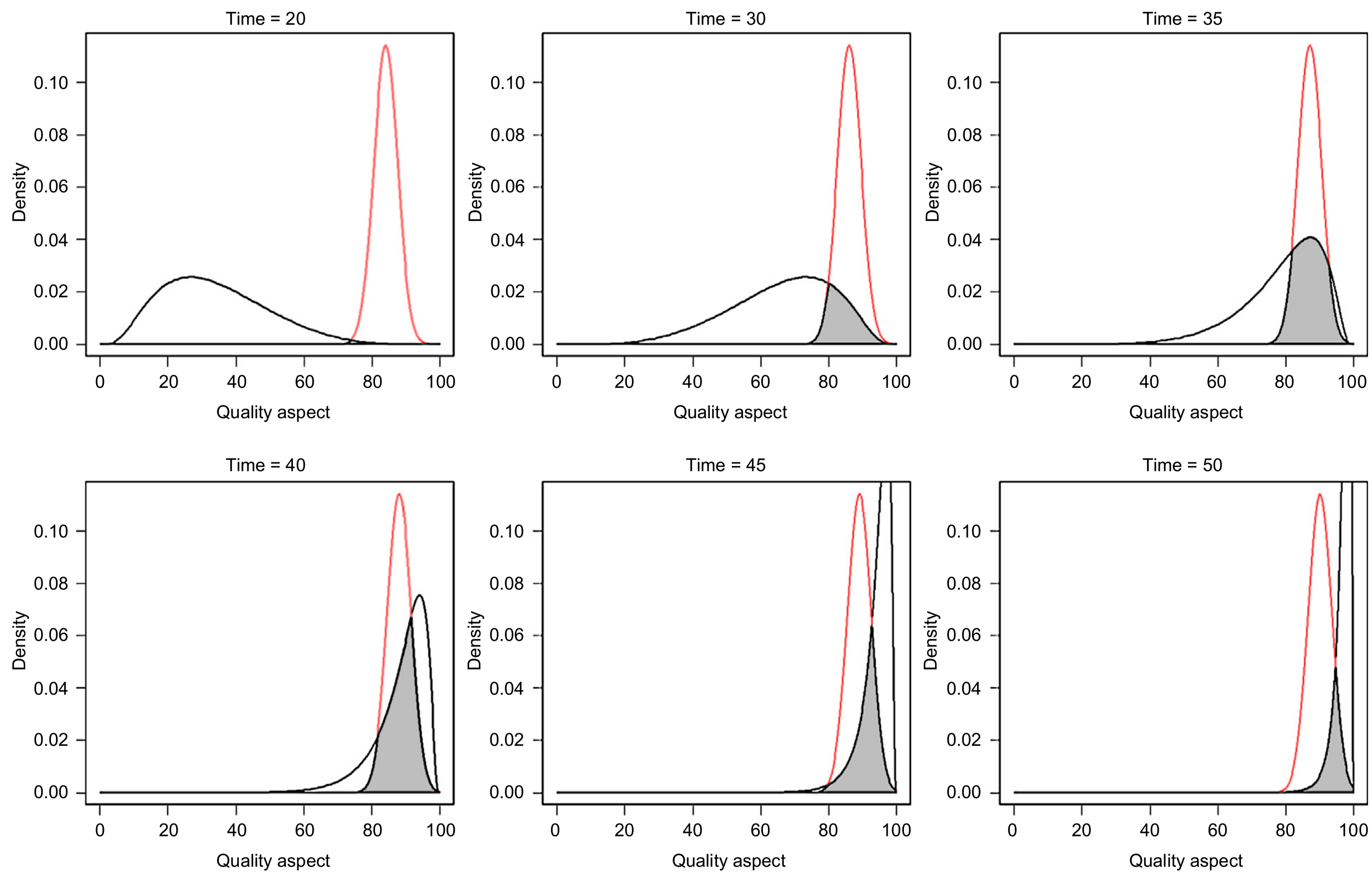

FIGURE 15.8

An example for the intersection (gray area) between product properties (e.g., color, black line) and consumer acceptance (liking, red line) at six different stages of maturity.

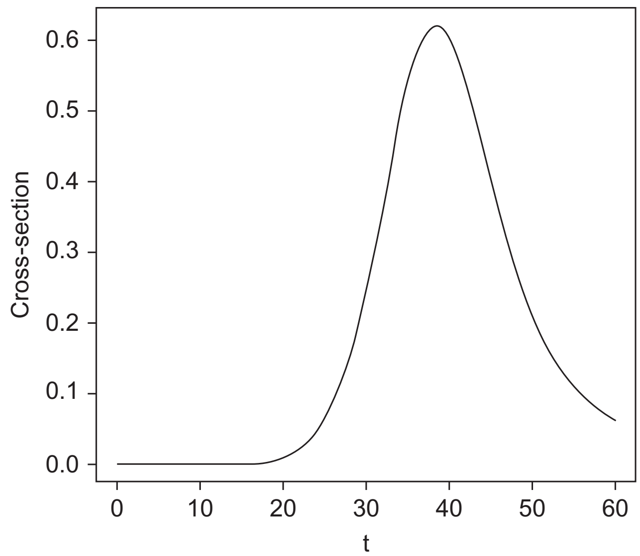

FIGURE 15.9

Behavior of cross-section (gray area in Figure 15.8) between product properties and consumer acceptance (product acceptance interface) as a function of maturation/ripening time.

Assuming that the variation in liking/acceptance in a large group of consumers is more or less normal (red lines in Figure 15.8) and that this liking shifts towards more mature fruit with progressing season, the possibility of selling products to that group of people can be estimated/calculated as the cross-section between the two density curves (product acceptance interface). When the product is green (immature, early season) none of the individual fruit is acceptable to any of the consumers (Figure 15.8, top left). With progressing maturity (indicated by the time in the headers of Figure 15.8), more and more fruit fall within the boundaries of consumer acceptance. At still higher maturity stages (overripe: Figure 15.8 bottom right) the individual fruit become again unacceptable (to the right of the acceptance distribution).

The size of the area of the product acceptance interface therefore changes with time. This is shown in Figure 15.9. So, for every rate of development, and every moment of harvest, a maximum of acceptance exists that can be optimized for the majority of people in a group or segment of the population, to be acceptable. Assessing the variation in maturity of fruit has been successfully done in the last couple of decades. What also needs to be assessed is the variation in liking, or the variation in acceptance limit in a targeted group of people. Schouten et al. (2007b) have already indicated that different segments of consumers have different acceptance limits: consumers liking ready to eat fruit have a higher acceptance limit for firmness than consumers who like to keep their fruit over the weekend. However, those acceptance limits were based on small scale consumer

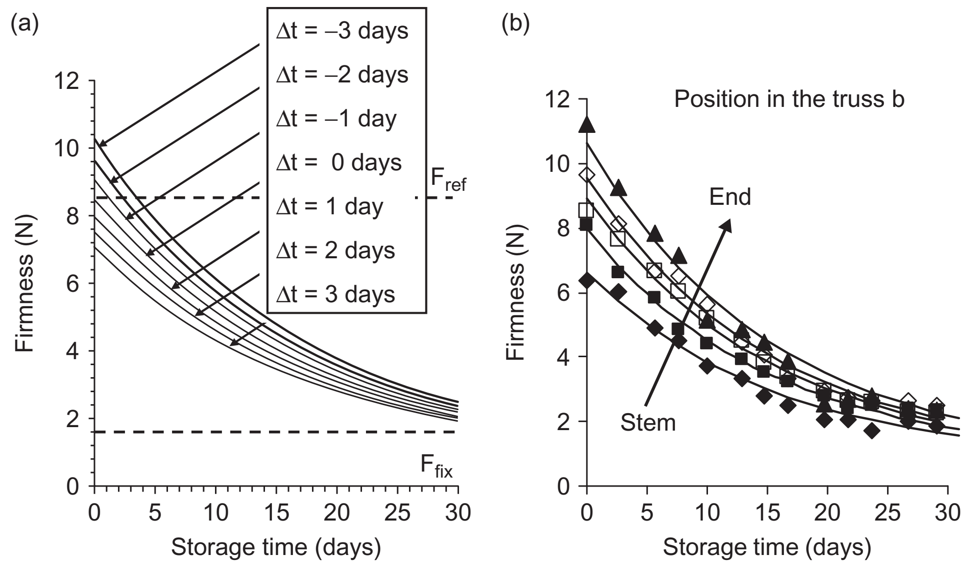

FIGURE 15.10

(a) Simulated firmness behavior over time of tomatoes stored at 16°C as a function of the maturity at harvest. Harvest maturity varies from minus three to plus three days which reflects the normally encountered variation in harvested fruit. (b) The observed (measured) and expected (simulated) values for five tomatoes as a function of their location in the truss at the plant: the closer the tomatoes grow near the plant, the more mature they are compared to the tomatoes further away.

Adapted from Schouten et al. (2007a).

research so that variation could not be taken into account. How to assess this variation among consumers, and what the shape of the distribution (normal or skew) will be, remains to be determined. Certainly the traditional use of statistics for analyzing consumer preferences will change drastically. But a major increase in reliability is to be expected.

C Models for growth

The modeling of quality attributes and quality related product properties during growth is not well developed. In general, quality attributes important for postharvest handling of fruit and vegetables play a minor role in the production phase, except for the floriculture. Attention is devoted to yield, absence of defects and management of the plantation, orchard or greenhouse. In fact, the control of quality and taste is mainly reduced to selecting an appropriate cultivar. Hardly anything is known how postharvest quality actually grows.

However, the growing conditions in open fields are highly variable due to weather and inability to control rainfall, sunlight or day length. Open field conditions make it very hard to pinpoint the active processes, to study them in isolation

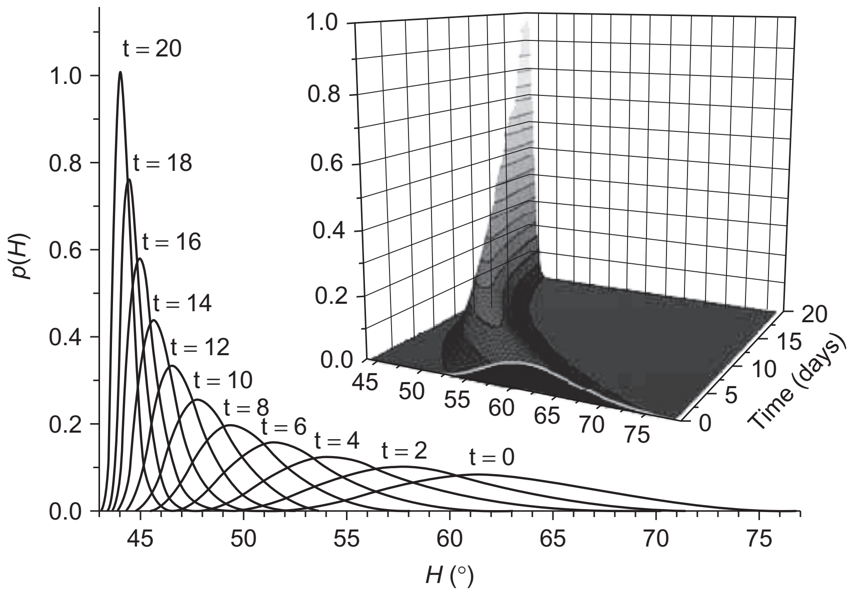

FIGURE 15.11

Propagation of the probability density function for the color p(H), expressed as Hue (H) for tomatoes stored at 15°C every other day (main plot), or as a gradually changing density over time (insert).

Source: Hertog et al. (2004).

and to construct mechanistic models from that knowledge. Nevertheless, preliminary trials (Tijskens and van Kooten, 2006) have revealed that progress can be expected from a thorough problem decomposition and from modeling in a mechanistic way instead of the traditional statistical approach. The empirical temperature sum has been used successfully and can be connected to summed rate constants of occurring reactions (Tijskens and Verdenius, 2000).

D Models for globalization

The globalization of fruit and vegetable supply chains has been occurring for quite some time. Globalization offers major advantages, but also considerable disadvantages (Phillips, 2006). However, the need to understand how the different regions and different seasons across the world affect quality and quality behavior (Tijskens et al., 2006a; Banks, 2006) has been neglected. Such understanding and integration requires a fundamental approach that incorporates the relevant behavior of the product, both in the preharvest and in the postharvest realm. Quality differences induced by different cultivars, growing sites, soil types, climate and weather have to be merged and combined into a single description to be applicable in a global supply chain. Because traditional modeling approaches are unsuitable for accommodating this integration of knowledge, we have to turn to modeling that is based on available knowledge of the processes that occur in the produce and initiate or cause the phenomena observed: a systems approach.

The concept of biological variation may, from a scientific point, be linked directly to certification issues. Food safety and product quality is increasingly controlled during the production process and in supply chains through the development and implementation of food safety and quality programs such as EUREPGAP, HACCP, IFS (International Food Standard), BRC (British Retail Consortium), or GHP (Good Hygiene Practices). Traceability (see Chapter 17) of batches is a prerequisite for these programs. Knowledge of how quality attributes or properties of batches change helps supply chain partners understand why sometimes batch behavior differs from expectations based only on mean values.

The models elaborated above may seem over expanded and too complex for the intended simple target. An application targeting a global supply chain, however, has to account for effects of growing region, management, cultivar and the influence of other conditions affecting the behavior of batches from all over the world. In addition, models for practical applications should include various preferences and likings (Van Kooten and Kuiper, 2009; Schouten et al., 2012) of the different consumers (see also above *Acceptance with biological variance*) across the world. The latter part is still largely out of reach, although some interesting developments are taking place in combining process oriented quality change models and models of consumer acceptance with economic aspects for entire supply chains (Schepers et al., 2004; Schepers and van Kooten, 2005).

A simple example of a model of the effects associated with different growing regions and management procedures on the quality and quality behavior in a globalized fruit and vegetable supply chain can be found in the maturity at harvest. The effects of harvest maturity on product behavior can be manifold. In its simplest form, harvest maturity merely induces a shift in the biological time, without fundamentally altering the behavior of the aspect studied (Tijskens et al., 2005b). Based on a simple exponential breakdown (Eq. 15.10), the system of biological shift factors allows the standardization of graphical representations (see, for example, Figures 2 and 3 in Tijskens et al., 2005b).

Venus et al. (2013) presented an extended application to assess and manage product losses in the supply chain of tomatoes in Africa, based on remote sensing by satellites, and estimating the microclimate conditions inside open trucks. Remote sensing (e.g., NDVI and NAI levels) seems to offer a huge potential in monitoring changes in all kinds of properties, important for agriculture and horticulture.

The principle of biological shift factor (Δt in Eq. 15.10) has been applied to the firmness (Lana et al., 2005) and color (Lana et al., 2006; Schouten et al., 2010; Farneti et al., 2013) of fresh whole and cut tomatoes, the color of bell peppers (Tijskens et al., 2005b) and apples (Tijskens et al., 2008, 2009, 2010b; Unuk et al., 2012). The system of biological shift factor has the additional advantage that the values of the biological shift factor (encountered until now) are normally distributed. An exciting development is described in Tijskens et al. (2006b, 2007;

Eccher Zerbini et al., 2009; Rizzolo et al., 2009) indicating that the actual biological shift factor of nectarines could be measured directly by time-resolved spectroscopy. In the long run, the addition of biological variation resulting from the product that originates in different regions of the world will provide a means of developing models applicable in a globalized fruit and vegetable supply chain.

A generic approach to generating a batch model that accounts for dynamic temperature scenarios, proposed by Hertog et al. (2007b), provides an example of how to link biological variation methodology and globalization/certification into practical applications,. The concept is based on the transformation of the actual time to "physiological time" or "biological time" that converts the batch model into a version based on differential equations. The conversion includes dynamic changes in temperature. The dynamic approach is important because temperature fluctuations in supply chains are the norm. One application area could be telemetric monitoring (using RFID technology and temperature loggers) in truck/reefer transport to inform chain managers about the quality status based on the current temperature and the effect it is has on the propagation of the biological age distribution of each batch.

V Conclusions and future developments

A decomposition of a problem into the constituting processes leads to the identification of plausible mechanisms occurring in the product. In using these mechanisms to build models, all available theoretical knowledge can be used. The application of fundamental rules, for example chemical kinetics, allows these mechanisms to be expressed in the form of differential equations. These differential equations can (sometimes) be solved analytically under constant external conditions. When the conditions are not constant, or when the differential equations are too complex to be solved, the differential equations can be used to solve the problem in a numeric fashion. The practical and empirical knowledge and product expertise and available data are merely used to calibrate the developed models.

This chapter shows not only that problems in horticulture can and may be tackled by this system, but it also shows that the method of process oriented modeling opens new alleys to include the omnipresent biological variation into the system. To model supply chains, especially global supply chains, the addition of the biological variation of product batches originating from a large number of growing conditions is of utmost importance.

The technical equipment to make this approach more feasible than it is currently will be developed further: more powerful computers, more powerful simulation packages, but especially important, more suitable nondestructive measuring techniques to measure repeatedly the same individuals for a more extended set of attributes.

Moreover, statistical procedures are being developed and will be developed in the near future that account for the biological variation in the analysis of data gathered by destructive methods, which are currently by far the most abundant methods.

By applying process oriented models in statistical analysis of experimental data, an increase in estimation reliability from, e.g., 70% to 90% and higher, can be obtained frequently. The use of the technique of multi-response-multi-variate statistical analysis will increase and further improve the understanding of the problem and enhance the physiological basis of the systems approach in modeling.

Bibliography

Banks, N., 2006. Picking winners. Acta Hortic. 712 (I), 113–120.

Batt, P.J., 2006. Fulfilling customer needs in agribusiness supply chains. Acta. Hortic. 699, 83–89.

Bavay, C., Symoneaux, R., Maître, I., Kuznetsova, A., Brockhoff, P.B., Mehinagic, E., 2013. Importance of fruit variability in the assessment of apple quality by sensory evaluation. Postharvest. Biol. Technol. 77, 67–74.

Benner, M., Geerts, R.F.R., Linnemann, A.R., Jongen, W.M.F., Folstar, P., Cnossen, H.J., 2003. A chain information model for structured knowledge management: towards effective and efficient food product improvement. Trends Food Sci. Technol. 14 (11), 469–477.

Berna, A.Z., Lammertyn, J., Buysens, S., Di Natale, C., Nicolaï, B.M., 2005. Mapping consumer liking of tomatoes with fast aroma profiling techniques. Postharvest. Biol. Technol. 38, 115–127.

Botonaki, A., Polymeros, K., Tsakiridou, E., Mattas, K., 2006. The role of food quality certification on consumers' food choices. Br. Food J. 108 (2), 77–90.

Brückner, B., 2006. Addressing consumer notions and individuality. Acta. Hortic. 712, 121–130.

Crisosto, C.H., Crisosto, G.M., Metheney, P., 2003. Consumer acceptance of 'Brooks' and 'Bing' cherries is mainly dependent on fruit SSC and visual skin color. Postharvest. Biol. Technol. 28, 159–167.

Crisosto, C.H., Crisosto, G., Neri, F., 2006. Understanding tree fruit quality based on consumer acceptance. Acta. Hortic. 712, 183–190.

De Ketelaere, B., Stulens, J., Lammertyn, J., Cuong, N.V., De Baerdemaeker, J., 2006. A methodological approach for the identification and quantification of sources of biological variance in postharvest research. Postharvest. Biol. Technol 39, 1–9.

de Wijk, R., Rasing, F., Wilkinson, C., 2003. Texture of semi-solids 2: sensory flavor-texture interactions for custard desserts. J. Texture. Stud. 34 (2), 131–146.

de Wit, C.T., 1968. Theorie en Model (in Dutch). Inaugural Speech. Veenman, Wageningen, NL, 13 p.

de Wit, C.T., van Keulen, H., 1972. Simulation of Transport Processes in Soils. Pudoc, Wageningen, NL, 100 p.

Eccher Zerbini, P., Vanoli, M., Rizzolo, A., Jacob, S., Torricelli, A., Spinelli, L., et al., 2009. Time-resolved reflectance spectroscopy as a management tool in the fruit supply chain: an export trial with nectarines. Biosyst. Eng. 102, 360–363.

Farneti, B., Schouten, R.E., Qian, T., Dieleman, J.A., Tijskens, L.M.M., Woltering, E.J., 2013. Greenhouse climate control affects postharvest tomato quality. Postharvest. Biol. Technol. 86, 354–361.

Fearne, A., Barrow, S., Schulenberg, D., 2006. Implanting the benefits of buyer–supplier collaboration in the soft fruit sector. Supply Chain Manag. 11 (1), 3–5.

Galton, F., 1883. Inquiries into Human Faculty and its Development. Macmillan, London.

Gwanpua, S.G., Verlinden, B.E., Hertog, M.L.A.T.M., Van Impe, J., Nicolai, B.M., Geeraerd, A.H., 2013. Towards flexible management of postharvest variation in fruit firmness of three apple cultivars. Postharvest. Biol. Technol. 85, 18–29.

Heaton, J.W., Marangoni, A.G., 1996. Chlorophyll degradation in processed foods and senescent plant tissues. Trends Food Sci. Technol. 7, 8–15.

Hertog, M.L.A.T.M., 2001. Improving modified atmosphere packaging through conceptual models. In: Tijskens, L.M.M., Hertog, M.L.A.T.M., Nicolaï, B.M. (Eds.), Food Process Modeling. Woodhead Publishing, Cambridge, UK.

Hertog, M.L.A.T.M., 2002. The impact of biological variation on postharvest population dynamics. Postharvest. Biol. Technol. 26, 253–263.

Hertog, M.L.A.T.M., Peppelenbos, H.W., Evelo, R.G., Tijskens, L.M.M., 1999. A dynamic and generic model of gas exchange of respiring produce: the effects of oxygen, carbon dioxide and temperature. Postharvest. Biol. Technol. 14, 335–349.

Hertog, M.L.A.T.M., Lammertyn, J., Desmet, M., Scheerlinck, N., Nicolaï, B.M., 2004. The impact of biological variation on postharvest behavior of tomato fruit. Postharvest. Biol. Technol. 34, 271–284.

Hertog, M.L.A.T.M., Scheerlinck, N., Lammertyn, J., Nicolaï, B.M., 2007a. The impact of biological variation on postharvest behavior of Belgian endive: the case of multiple stochastic variables. Postharvest Biol. Technol. 43, 78–88.

Hertog, M.L.A.T.M., Lammertyn, J., Scheerlinck, N., Nicolaï, B.M., 2007b. The impact of biological variation on postharvest behavior: the case of dynamic temperature conditions. Postharvest Biol. Technol. 43, 183–192.

Hertog, M.L.A.T.M., Verlinden, B.E., Lammertyn, J., Nicolaï, B.M., 2007c. OptiPa, an essential primer to develop models in the postharvest area. Comput. Electron. Agric. 57, 99–106.

Hertog, M.L.A.T.M., Rudell, D.R., Pedreschi, R., Schaffer, R.J., Geeraerd, A.H., Nicolaï, B.M., et al., 2011. Where systems biology meets postharvest. Postharvest. Biol. Technol. 62 (3), 223–237.

Hewett, E.W., 2006. Progressive challenges in horticultural supply chains: some future challenges. Acta Hortic. 712 (I), 39–49.

Jordan, R.B., Loeffen, M.P.F., 2013. A new method for modelling biological variation using quantile functions. Postharvest. Biol. Technol. 86, 387–401.

van Keulen, H., de Wit, C.T., Lof, H., 1976. The use of simulation models for productivity studies in arid regions. In: Lange, O.L., Koppen, L., Schulze, E.D. (Eds.), Ecological studies analysis and synthesis, vol. 19. Springer Verlag, Heidelberg, pp. 408–420, ISSN 0070-8356.

Kramer, A., Twigg, B.A., 1983. Quality Control in the Food Industry, third ed. AVI Publishing Co., Westport, CT, USA.

Lana, M.M., Tijskens, L.M.M., van Kooten, O., 2005. Effects of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest. Biol. Technol. 35, 87–95.

Lana, M.M., Tijskens, L.M.M., van Kooten, O., 2006. Effects of storage temperature and stage of ripening on RGB color aspects of fresh-cut tomato using video image analysis. J. Food Eng. 77, 871−879.

Morris, C., Young, C., 2000. 'Seed to shelf', 'teat to table', 'barley to beer' and 'womb to tomb': discourses of food quality and quality assurance schemes in the UK. J. Rural. Stud. 16, 103−115.

Moskowitz, H.R., 2005. Psychophysical thinking in business: products and concepts. J. Sens. Stud. 20, 389−396.

Ostan, I., Poljšak, B., Simčič, M., Tijskens, L.M.M., 2009. Nutrition for the selfish gene. Trends Food Sci. Technol. 20, 355−365.

Ostan, I., Poljšak, B., Simčič, M., Tijskens, L.M.M., 2010. Appetite for the selfish gene. Appetite 54, 442−449.

Passioura, J.B., 1996. Simulation models: science, snake oil, education, or engineering? Agron. J. 88, 690−694.

Phillips, L., 2006. Food and globalization. Annu. Rev. Anthropol. 35, 37−57.

Reay, P.F., Lancaster, J.E., 2001. Accumulation of anthocyanins and quercetin glycosides in 'Gala' and 'Royal Gala' apple fruit skin with UV-B-Visible irradiation: Modifying effects of fruit maturity, fruit side, and temperature. Sci. Hortic. (Amsterdam) 90, 57−68.

Rico, D., Martín-Diana, A.B., Barat, J.M., Barry-Ryan, C., 2007. Extending and measuring the quality of fresh-cut fruit and vegetables: a review. Trends Food Sci. Technol. 18, 373−386.

Rizzolo, A., Vanoli, M., Eccher Zerbini, P., Jacob, S., Torricelli, A., Spinelli, L., et al., 2009. Prediction ability of firmness decay models of nectarines based on the biological shift factor measured by time-resolved reflectance spectroscopy. Postharvest. Biol. Technol. 54 (2009), 131−140.

Schepers, H., van Kooten, O., 2005. Profitability of ready to eat strategies: towards model-assisted negotiation in a fresh produce chain. In: Ondersteijn, C.J.M., Wijnands, J.H. M., Huirne, R.B.M., van Kooten, O. (Eds.), Quantifying the Agri-Food Supply Chain. Proceedings of the Frontis Workshop on Quantifying the Agri-food Supply Chain. Frontis series, Wageningen, The Netherlands, 22−24 October 2004. <http://library.wur.nl/frontis/quantifying_supply_chain/09_schepers.pdf>.

Schepers, H.E., van Henten, E.J., Bontsema, J., Dijksterhuis, G.B., 2004. Tactics of quality management and promotions: winning consumers for fresh exotic produce. In: Bremmers, H.J., Omta, S.W.F., Trienekens, J.H., Wubben, E.F.M. (Eds.), Dynamics in Chains and Networks. Wageningen Academic Publishers, pp. 568−582.

Schouten, R., Van Kooten, O., Van Der Vorst, J., Marcelis, W., Luning, P., 2012. Quality controlled logistics in vegetable supply chain networks: how can an individual batch reach an individual consumer in the optimal state? Acta. Hortic. 936, 45−52.

Schouten, R.E., Tijskens, L.M.M., van Kooten, O., 2002. Predicting keeping quality of batches of cucumber fruits based on a physiological mechanism. Postharvest Biol. Technol. 26 (2002), 209−220.

Schouten, R.E., Jongbloed, G., Tijskens, L.M.M., van Kooten, O., 2004a. Batch variability and cultivar keeping quality of cucumber. Postharvest Biol. Technol. 32, 299−310.

Schouten, R.E., Veltman, R.H., De Wild, H.P.J., Koopen, T.J., Staal, M.G., Tijskens, L.M.M., 2004b. Determination of O2 and CO2 permeance, internal respiration and fermentation for a batch of pears (cv Conference). Postharvest. Biol. Technol. 32, 289−298.

Schouten, R.E., Huijben, T.P.M., Tijskens, L.M.M., van Kooten, O., 2007a. Modeling quality attributes of truss tomatoes: linking color and firmness maturity. Postharvest. Biol. Technol. 45/3, 298–306.

Schouten, R.E., Huijben, T.P.M., Tijskens, L.M.M., van Kooten, O., 2007b. Modeling the acceptance period of truss tomato batches. Postharvest. Biol. Technol. 45/3, 307–316.

Schouten, R.E., Zhang, X., Tijskens, L.M.M., Van Kooten, O., 2008. The propagation of variation in glucosinolate levels as effected by controlled atmosphere and temperature in a broccoli batch. Acta. Hortic. 802, 241–246.

Schouten, R.E., Zhang, X., Verkerk, R., Verschoor, J.A., Otma, E.C., Tijskens, L.M.M., et al., 2009. Modelling the level of the major glucosinolates in broccoli as affected by controlled atmosphere and temperature. Postharvest. Biol. Technol. 53 (1–2), 1–10.

Schouten, R.E., Natalini, A., Tijskens, L.M.M., Woltering, E.J., van Kooten, O., 2010. Modelling the firmness behaviour of cut tomatoes. Postharvest. Biol. Technol. 57 (1), 44–51.

Simane, B., van Keulen, H., Stol, W., Struik, P.C., 1994. Application of a crop growth model (SUCROS-87) to assess the effect of moisture stress on yield potential of durum wheat in Ethiopia. Agric. Syst. 44 (3), 337–353.

Sloof, M., 2001. Problem decomposition. In: Tijskens, L.M.M., Hertog, M.L.A.T.M., Nicolaï, B.M. (Eds.), Food Process Modeling. Woodhead Publishing, Cambridge, UK, pp. 19–34.

Sloof, M., Tijskens, L.M.M., Wilkinson, E.C., 1996. Concepts for modeling quality of perishable products. Trends Food Sci. Technol. 7, 165–171.

Steyn, W.J., Wand, S.J.E., Jacobs, G., Rosecrance, R.C., Roberts, S.C., 2009. Evidence for a photoprotective function of low-temperature-induced anthocyanin accumulation in apple and pear peel. Physiol. Plant. 136, 461–472.

Thornley, J.H.M., 1976. Mathematical Models in Plant Physiology. A Quantitative Approach to Problems in Plant and Crop Physiology. Academic Press, London, GB, 318 p.

Tijskens, L.M.M., 1979. Texture of Golden Delicious apples during storage. Lebensmittel-Wissenschaft-und-Technologie 12 (3), 138–142.

Tijskens, L.M.M., 1995. A model on the respiration of vegetable produce during postharvest treatments. In: Proceedings International Conference on AGRI-FOOD Quality, June 1995, Norwich, United Kingdom, pp. 322–327.

Tijskens, L.M.M., 2000. Acceptability. In: Shewfelt, R.L., Brückner, B. (Eds.), Fruit and Vegetable Quality: An Integrated View. Technomic Press, USA, pp. 125–143.

Tijskens, L.M.M., 2004. Discovering the Future: Modeling Quality Matters. Ph.D. Thesis. Wageningen University, ISBN 90-8504-017-5.

Tijskens, L.M.M., Luyten, H., 2004. Modeling food texture. In: Kilcast, D. (Ed.), Texture in Food. vol. 1: Solid Foods. Woodhead Publishing, Cambridge, UK.

Tijskens, L.M.M., Polderdijk, J.J., 1996. A generic model for keeping quality of vegetable produce during storage and distribution. Agric. Syst. 51, 431–452.

Tijskens, L.M.M., Hertog, M.L.A.T.M., Nicolaï, B.M. (Eds.), 2001. Food Process Modeling. Woodhead Publishing, Cambridge, UK.

Tijskens, L.M.M., Verdenius, F., 2000. Summing up dynamics: Modeling biological processes in variable temperature scenarios. Agric. Syst. 66/1, 1–15.

Tijskens, L.M.M., van Kooten, O., 2006. Theoretical considerations on generic modeling of harvest maturity, enzymes status and quality behavior. Int. J. Postharvest Technol. Innov. 1, 106–120.

Tijskens, L.M.M., Sloof, M., Wilkinson, E.C., van Doorn, W.G., 1996. A model of the effects of temperature and time on the acceptability of potted plants stored in darkness. Postharvest Biol. Technol. 8, 293–305.

Tijskens, L.M.M., Hertog, M.L.A.T.M., Van Schaik, A.C.R., De Jager, A., 1999. Modeling the firmness of Elstar apples during storage and transport. In: International Symposium on Effect of Preharvest and Postharvest factors on Storage of Fruits and Vegetables, August 1997, Warsaw, Poland, Acta Horticulturae 485, 363–372.

Tijskens, L.M.M., Konopacki, P., Simčič, M., 2003. Biological variance, burden or benefit? Postharvest Biol. Technol. 27, 15–25.

Tijskens, L.M.M., Schepers, H., van Kooten, O., 2005a. Modelling for quality assurance. In: Kanlayanarat, S., McGlasson, W.B. (Eds.), Proceedings of the APEC Symposium on Assuring Quality and Safety of Fresh Produce, August 1–3, 2005, Bangkok, pp. 23–33.

Tijskens, L.M.M., Heuvelink, E., Schouten, R.E., Lana, M.M., van Kooten, O., 2005b. The biological shift factor. Biological age as a tool for modeling in pre- and postharvest horticulture. Acta. Hortic. 687, 39–46.

Tijskens, L.M.M., Lin, W.C., Schouten, R.E., 2005c. Predicting harvest labour allocation in bell pepper production. Acta. Hortic. 682, 1435–1442.

Tijskens, L.M.M., van Kooten, O., Schouten, R.E., 2006a. Modeling for globalization. In: Conference MQUIC, 7 August 2006, Bangkok. Acta Horticulturae 712, 51–58.

Tijskens, L.M.M., Eccher Zerbini, P., Vanoli, M., Jacob, S., Grassi, M., Cubeddu, R., et al., 2006b. Effects of maturity on chlorophyll related absorption in nectarines, measured by non-destructive time-resolved reflectance spectroscopy. Int. J. Postharvest Technol. Innov. 1, 178–188.

Tijskens, L.M.M., Eccher Zerbini, P., Schouten, R.E., Vanoli, M., Jacob, S., Grassi, M., et al., 2007. Assessing harvest maturity in nectarines. Postharvest. Biol. Technol. 45/2, 204–213.

Tijskens, L.M.M., Konopacki, P.J., Schouten, R.E., Hribar, J., Simčič, M., 2008. Biological variance in the colour of Granny Smith apples. Modelling the effect of senescence and chilling injury. Postharvest. Biol. Technol. 50 (2–3), 153–163.

Tijskens, L.M.M., Unuk, T., Tojnko, S., Hribar, J., Simčič, M., 2009. Biological variation in the colour development of Golden Delicious apples in the orchard. J. Sci. Food. Agric. 89 (12), 2045–2051.

Tijskens, L.M.M., Ostan, I., Poljšak, B., Simčič, M., 2010a. Consumers and food choice, quality, nutrition and genes. Acta. Hortic. 880, 29–38.

Tijskens, L.M.M., Schouten, R.E., Konopacki, P.J., Hribar, J., Simčič, M., 2010b. Modelling the biological variance of the yellow aspect of Granny Smith apple colour. J. Sci. Food. Agric. 90 (5), 798–805.

Tomlins, K., Manful, J., Gayin, J., Kudjawu, B., Tamakloe, I., 2007. Study of sensory evaluation, consumer acceptability, affordability and market price of rice. J. Sci. Food. Agric. 87, 1564–1575.

Unuk, T., Tijskens, L.M.M., Germšek, B., Zadravec, P., Vogrin, A., Hribar, J., et al., 2012. Effect of location in the canopy on the colour development of three apple cultivars during growth. J. Sci. Food. Agric. 92 (12), 2450–2458.

van Boekel, M.A.J.S., 1999. Testing of kinetic models: usefulness of the multiresponse approach as applied to chlorophyll degradation in foods. Food Res. Int. 32, 261–269.

van Boekel, M.A.J.S., 2000. Kinetic modeling in food science: a case study on chlorophyll degradation in olives. J. Sci. Food Agric. 80, 3–9.

van Boekel, M.A.J.S., Tijskens, L.M.M., 2001. Kinetic modeling. In: Tijskens, L.M.M., Hertog, M.L.A.T.M., Nicolaï, B.M. (Eds.), Food Process Modeling. Woodhead Publishing, Cambridge, UK.

Van Dijk, C., Tijskens, L.M.M., 2000. Mathematical modeling of enzymatic reactions as related to the texture of fruits and vegetables after storage and mild preheat treatments. Chapter 8. In: Alzamora, S.M., Tapia, S.M., López-Malo, A. (Eds.), Design of Minimal Processing Technologies for Fruit and Vegetables. Aspen Publishers Inc., USA, pp. 127−152.

Van Kooten, O., Kuiper, E., 2009. Consumer acceptability in flower chains: How can we determine what the final customers really want? Acta. Hortic. 847, 17−26.

Venus, V., Asare-Kyei, D.K., Tijskens, L.M.M., Weir, M.J.C., de Bie, C.A.J.M., Ouedraogo, S., et al., 2013. Development and validation of a model to predict postharvest losses during the transport of tomatoes in West Africa. Comput. Electron. Agric. 92, 32−47.

Wierenga, P.J., De Wit, C.T., 1972. Simulation of heat transfer in soils. Soil Sci. Soc. Am. Proc. 34, 845−848.

CHAPTER

16 The Supply Value Chain of Fresh Produce from Field to Home: Refrigeration and Other Supporting Technologies

Malcolm C. Dodd[a] and Jacobus J. Bouwer[b]

[a]*Department of Horticultural Science, Stellenbosch University, Stellenbosch, South Africa.*
[b]*Koos Bouwer Consulting, Welgemoed, Cape Town, South Africa*

I Introduction

This chapter discusses the need for cold chains to satisfy global food requirements. It explains how these are also value chains. Refrigeration is the most useful and powerful technology currently available to maintain quality as well as the nutritive and financial value of fresh produce. The best way to manage a cold supply chain to ensure optimum produce quality is to measure the temperatures at every link within the chain. In so doing, visibility will be created of the temperature management and if protocols are not being met corrective action can be taken. It must be remembered that postharvest technology can only maintain the quality of fresh produce after picking. To improve the quality of produce at harvest it is necessary to consider preharvest factors that impact on produce quality during and after harvest (Hewett, 2006).

Fresh produce is an essential part of mankind's daily diet. As such there is a food security requirement to ensure that all outlets globally for fresh produce, from street vendors, informal and formal markets and supermarkets in the developing world, to formal markets and supermarkets in the developed world are always stocked with healthy food. With the expanding world population and the growth of the global middle class, the demand for fresh produce is increasing at a rate of some 6% per annum. This essential need requires the transportation of fresh produce from growing areas in remote parts of countries to nearby cities as well as between countries via transcontinental and intercontinental cold supply chains. A systems approach to these essential cold logistical chains reveals that there are several technologies that need to be integrated to support a cold chain.

Postharvest Handling.

Each of these technologies must be combined to ensure maximum efficacy and benefit to the product. According to the FAO “Food security exists when all people at all times, have physical, social and economic access to sufficient safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life”. These ideals can only be achieved for the fresh produce component of the food basket by maintaining the integrity of the produce through keeping it cold. It is important to remember that fresh produce is still alive after it has been harvested. It is not possible to improve the nutritional quality of the product after it has been harvested, but the rate of deterioration of this product can be reduced. To achieve this, a cold chain must be created.

II The cold chain

A cold supply chain may be defined as follows: “A cold chain is the seamless movement of chilled fresh produce from production area to market through various storage and transport mediums without any change in the optimum storage temperature and relative humidity” (Dodd, 2013). The key to the successful utilization of a cold chain is the uninterrupted exposure of the product to the appropriate temperature of chilled air and percentage level of relative humidity (RH). It must be remembered that the maximum quality of the fresh produce is at the moment when it has been harvested. The highest monetary value (Table 16.1) is when that produce reaches the market place. Fresh produce is alive when picked and must be kept at the lowest possible temperature and highest RH to maintain freshness as long as possible. There are many critical steps which need to be taken to maintain the quality of the foodstuff. The complexity of this chain is illustrated in Figure 16.1. At each link there is a handover of responsibility and the value of the product increases.

However, the full value is only realized when the product is sold to a consumer (see also Chapters 1 and 6). This value can only be achieved if the product is in the best possible condition. An illustration of the increase in value of a perishable product along a cold chain, which is also a value chain is shown in Table 16.1.

Maintaining the product quality along this supply chain is dependent upon several supporting technologies like refrigeration, packaging and track and trace systems. These technologies rely on the coordination of activities between service providers through the services of logistics suppliers. The fundamentals of a cold supply chain are the same for short-distance transport from farm to a local city compared to transcontinental and intercontinental markets. However, the complexity of the chain increases with distance, change of transport or storage mode, shipping transportation, border crossings and intergovernmental phytosanitary certification.

This chain is only as strong as its weakest link. When there is a weakness or error in one of the links or at the interface between these links, the integrity is

Table 16.1 Cost Centers and US $ Values within a Fruit Value Chain of a 12.5 kg Carton of Apples from a Production Area in the Western Cape Region of South Africa Exported to a Supermarket in the United Kingdom

Cost Center	US $ Value	% of the Cost in the Chain
Sale price	25.00	100.00
Supermarket	7.00	28.00
UK transport	0.60	2.40
Importers commission	1.23	4.92
UK logistics	1.85	7.40
Freight (reefer container)	4.98	19.92
Insurance	0.10	0.40
Exporters commission	0.72	2.88
Port costs	0.32	1.28
Cargo dues	0.06	0.24
Transport to port	0.30	1.20
Finance charges	0.14	0.56
Hortgro levies	0.04	0.16
Perishable Product Export Control Board sea levy	0.05	0.20
Packaging materials	1.58	6.32
Packing cost	1.61	6.44
Farm costs	2.40	9.60
Net farm income	2.02	8.08

Source: Dodd (2012).

compromised. The whole supply chain invariably falls apart, the value of the product is not realized and the food stuff goes to waste. According to Katzorke and Lee (1998), problems develop at the interfaces of supply chains and the best way to overcome these challenges is to ensure good management. This management must be with the fundamental understanding that "controlling product temperature and reducing the amount of time the product is at less-than-optimal temperatures are the most important methods of slowing quality loss in perishables" Thompson et al. (2002). The management of cold chains is often difficult because of their inherent complexity and the lack of communication and visibility between the service providers at each link. Many service providers work in silo situations and, according to Mallik (2010), they cannot see past their own business concerns. This leads to a breakdown of communication and integrity of the supply chain (see also Chapters 1 and 6). The visibility within the cold supply chain is thus lost, and production and purchasing schedules become compromised. In addition the velocity of the supply chain is reduced, which can compromise marketing plans. According to Christopher and Lee (2001), the three basic

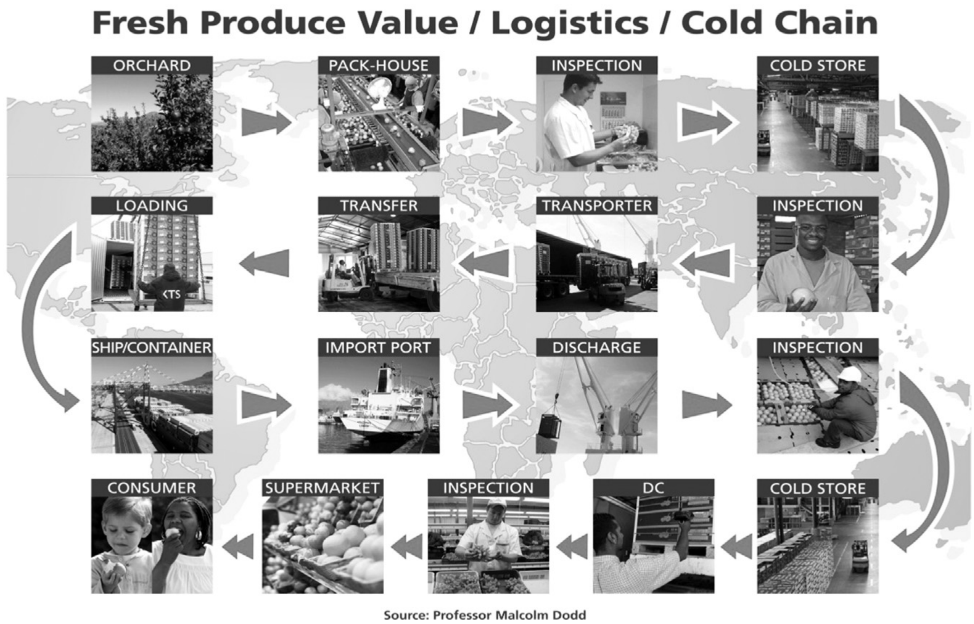

FIGURE 16.1

Illustration of the links in an intercontinental cold supply chain.

principles for increasing supply chain efficiency are to use streamlined processes, reduce inbound lead times and lessen the time spent on non-value processes. Many cold chains are not managed with the aforementioned principles being foremost in the protocols. Temperature and RH fluctuations within the supply chain can occur either during the storage or shipping phases or critically at the change of storage or transport medium. These fluctuations are additive in nature in the way they impact the respiration of the produce. Once a temperature break occurs, the air temperature increases with a concomitant decrease in RH. This results in the product respiration increasing and possible water loss due to a high vapor pressure deficit between the product and the storage air. When the product is placed back under refrigeration the respiration rarely returns to the level it was at prior to the break and the product weight loss due to moisture loss cannot be regained (Wills et al., 1998).

III Logistics

Logistics is one of the key disciplines to ensuring efficient cold supply chains. Luo and Findlay (2002) describe logistics as the process of planning, implementing and controlling the efficient flow and storage of goods, services and related information from point of origin to point of consumption to meet customers' requirements. In the case of fresh fruits and vegetables, this business process is complicated by the overlaying of the need for the supply chain to be chilled by refrigeration. Any break in this supply chain will result in a compromising of the temperature and RH control leading to a reduction in the quality and value of the produce. The only way to ensure that best practice is followed is through good management. This requires an understanding of the guiding principles of a cold chain, namely:

1. The produce must be cooled as soon as possible after harvest as the highest quality is at the time of harvest. Thereafter, the produce will commence the aging process and as a consequence loose both nutritive and monetary value (see also Chapters 10, 12 and 14).
2. The appropriate packaging must be used. This will serve the function of holding the produce in discreet units whilst preventing damage due to rubbing or bruising.

When considering the design of the packaging it must be borne in mind that the chilled air is supplied to remove the heat of respiration (vital heat) from the product. In order to be able to do this efficiently, the chilled air should come into direct contact with the produce to remove the heat by convective cooling, the latter being the most efficient means of cooling. If the chilled air does not come into direct contact with the produce then the vital heat gets conducted across the packaging or whatever else is acting as a barrier between the air and the produce. The heat is then removed from the surface of the barrier by the chilled air in a process known as conductive cooling. This is a much less efficient method of cooling than convective cooling (Dehghannya et al., 2010). In convective cooling the chilled air comes into direct contact with the produce and as a result the heat is removed more efficiently. Air delivery systems vary according to the storage or transport medium. The packaging must allow for sufficient air to move across the produce. Land-based forced air pre-cooling facilities mainly have horizontal air flow delivery systems. Therefore, there must be some ventilation holes in the sides of the packing cartons. Refrigerated road transport vehicles have top air delivery systems, which cause the chilled air to move through the load in a vertical direction. Similarly, in specialized reefer ships and refrigerated shipping containers the air is delivered in a vertical direction. Thus, the base and the top of packing cartons must have sufficient ventilation holes to allow for movement of the chilled air over the produce.

The efficacy of maintaining the product at the correct temperature and RH depends upon the use of suitable packing material, which is stacked in such a way as to ensure the movement of chilled air over the product (Wills et al., 1998). Packaging must, therefore, be well ventilated with apertures placed on all six sides of the carton.

The heat that has to be removed from either storage or transport systems emanates from several sources:

1. The vital heat from the product itself.
2. External heat ingress from solar radiation through the insulation.

The quality of the insulation is, therefore, critical. It is also important to ensure that no water seeps into the insulation as this will compromise the efficiency of the insulating material.

On road vehicles, besides solar radiation on the roof and side walls, there is also the reflected heat off the road surface onto the base of the unit. Once again the quality of the insulation is critical. There must also be no way that heat can bridge the insulation through bolts that hold the insulated body onto the chassis.

A Temperature management in the supply chain

The most important prerequisite for managing the integrity of a cold supply chain is to measure the air temperature or product temperature from end to end. This entails the collection of relevant data, such as temperatures of the storage air or produce, over a period of time in packing facilities, cold stores or distribution centers. Where the integrity is compromised management steps can be taken to rectify the breaks. By ensuring that a cold chain operates at the ideal temperature, fresh produce can be kept in the best possible condition and waste reduced to a minimum.

There are many temperature recording systems available, which offer varying levels of feedback. The challenge in using these devices is the need to recover them from the shipment to capture the data. Radio-enabled systems do offer the advantage that data is uploaded onto the internet without the recorder having to be physically retrieved and data captured. However, the effort in recovering the recorders is invaluable as the data contained therein provides a view of the actual temperature experienced by the produce in that particular section of the supply chain.

B Factors to consider

Supply chains can be long and complicated with many service providers having to work in concert to ensure the movement of product from grower to consumer. Some research has been conducted in this specialized area and it is important to note this work as it enables a fuller understanding of the business process. In the United Kingdom, a study on fresh produce supply chains by Fearne and Hughes (1999) showed that there were several forces driving a successful supply chain. These comprised five key areas, which they listed as:

1. Competent staff to maintain relationships by open and appropriate communication with key customers.
2. Ongoing investment despite tighter margins.
3. Volume growth to help fund the ongoing investment.
4. Measurement and control of costs.

5. The introduction of innovation in the way of conducting the business and level of service.

These five findings are relevant to all fresh produce supply chains but, unforunately, are often not applied, particularly the need for communication both upstream and downstream. This is because the supply chain is not "owned" by one vertically integrated business, but made up of many businesses, which supply a specialized service (see also Chapters 1 and 6).

Many of the operators in the various links in a cold supply chain are unaware of the complexity of the chain. An example being a product like broccoli, which experiences 39 steps along the cold supply chain with as many as 23 different operators and 21 stages involved from harvest to the consumer. Murphy (2005) reports that to maintain product temperature as close as possible to the ideal for that product is essential despite all the fluctuating temperatures in the environment along the supply chain. The key to success is to maintain a consistent temperature and apply the FIFO (first in, first out) and FEFO (first expire, first out) principles.

Another recent development has been the focus on tracability to assist with product recalls and the threat of bio-terrorism. Conventional barcodes are still used in some situations but, more often, the general identification number (GIN) is used. This enables anyone within the supply chain to access information about, among others factors orchard, postharvest treatments, packhouse used, shipping details and receiver. Tracability is becomming increasingly important in this age of consumer protection legislation (see also Chapter 17). Bollen et al. (2006) discuss this and illustrate the benefits of a good tracability management system within a fresh cold supply chain. This is especially relevant when there are issues of quality at the end of the supply chain (see also Chapter 18). The consignment can be traced back to its origin and a reason established for the poor quality, that is assuming it is a production, rather than temperature related quality issue. Another system that allows for unit-level identification is HarvestMark, which allows for produce to be traced back to origin and, with the requisite access, anyone can see the information pertaining to the load via a cell phone or the internet.

To address poor outcomes, it is becoming increasingly important to record temperatures right across the supply chain. Many logistics companies will place an independent temperature recorder on a pallet of fruit being exported in a shipping container. They recover this recorder at the end of the voyage to validate the shipping temperatures. Although this is a good idea, it does not address the issue of having a view of the temperaures downstream from that point. This is important as the produce is continually aging and possesses less resilience against temperature abuse as it does so. The solution to this is to use radio-enabled devices and ensure a radio network at every location where a change of storage or transport occurs. This will allow the capture of data right along the supply chain without having to recover the data recorder. This allows for an overview of the temperature controls along the chain.

This level of sophistication is difficult to achieve in developing countries despite the potential high return on investment with horticultural products. This is due to the high establishment costs, variable market prices, weather dependence and high perishability (see also Chapter 10).

IV Picking and packing

Considering that lowering the respiration rate of fresh fruit and vegetables is the most effective way of maintaining nutritional integrity and quality and, thus, value (Jones, 1996; Thompson and Kader, 2004), the use of refrigeration is essential. Placing the product under cooling as quickly as possible after harvest is essential. Hardenburg et al. (1986) report that this preserves the product quality by:

1. Lowering of the respiration rate by slowing down enzyme activity;
2. Inhibiting the growth of decay causing enzymes;
3. Reducing water loss;
4. Limiting ethylene production.

It must be remembered that fresh produce is still alive after it is picked and this means that it is still respiring. This is a biochemical process in which energy reserves such as sugars are drawn upon to create energy for the life processes, and during this reaction the heat of respiration occurs. It is very important to manage the temperature of the produce as this will, in turn, regulate the respiration rate and, thus, storage and shelf life of the product. To achieve this all the steps in the cold chain must be carefully monitored and managed. This begins with the picking of produce, which should be done as early in the day as possible to ensure that the field heat is as low as possible. The produce should be kept out of direct sunlight and, if possible, be covered with wet fabric to enhance evaporative cooling. Wire-bound or nailed wooden crates or wax impregnated fiberboard cartons can be used to pack product that is to be handled in water or ice for cooling.

Other packing methods require that the produce be taken to a packing facility where upon arrival the produce should be cooled as soon as possible after grading and trimming (see also Chapters 9 and 10). At the packing facility the produce should be placed in a chilled room set at ±18°C (just above the prevailing dew point) to allow for convective cooling to dew point. Alternatively hydro-cooling can be used for a variety of fruits and vegetables, whereby the produce is placed in water-tolerant containers and placed in a racking system and chilled water is showered over it. The seven-eighths cooling time for small products like cherries can be as short as 10 min. With larger produce, like melons, the time could be up to 1 h. In general hydro-cooling is up to 10 times faster than forced air cooling. However, it cannot be used on some products that are delicate and sensitive to wetting.

The produce should then be graded and packed as soon as possible (Fraser, 1998). Thereafter, it should be force air cooled down to the optimal temperature for that produce. A list of the correct temperatures for vegetables and fruits is shown in Tables 16.2 and 16.3, respectively.

Reducing the produce temperature is the best way of maintaining product quality because it slows the respiration rate and reduces the rate of ethylene production. Additionally, the rate of moisture loss will be slowed down as will the growth of microorganisms (see also Chapter 11). It is a general rule of thumb that for every hour of delay from picking to cooling, one day of shelf life is lost. In addition to hydro-cooling the other form of cooling in use is room cooling, where the produce is placed in a cold store and the produce cools slowly and non-uniformly though the conductive cooling process. This should not be considered a means of getting the produce to set point temperature. The best way to get produce to set point temperature apart from hydro-cooling is forced air cooling. This is a technique which, inside a cold store set at the ideal set point, uses high capacity fans and tarpaulins to suck chilled air through the stacks of pallets and, thus, the packaging and over the produce. Rapid and even cooling is achieved by convective cooling of the produce. Pulling the air, rather than blowing it through the stack of produce is preferable, as it achieves an even airflow and, consequently, even cooling.

Top icing is a simple technique using crushed ice placed in suitable containers on top of the produce. The freezing water/ice slurry moves by gravity through the produce stack and cools it. This is an effective technique for dense product such as broccoli that is difficult to cool with forced chilled air. There is an additional advantage with this technique in that it helps remove subsequent respiratory heat. It is calculated that 1 kg of ice can cool 3 kg of produce (Sargent et al., 1989). The downside is that there is a lot of cold water to remove from the storage area or transport vehicle.

Vacuum cooling is another technique that is effective on products like leafy vegetables. The produce is placed inside a vacuum chamber and sealed. A vacuum is drawn, which causes water to evaporate off the surface of the produce. Through the physical process called the latent heat of evaporation, heat is removed from the produce. The higher the surface to volume ratio of the product the more effective the cooling, particularly if the produce is pre-sprayed with water. The downside of this technique is the high investment cost of the vacuum tube and pump.

When planning the process of pre-cooling produce there are several factors to consider:

1. The density of the produce and how tightly it nests together in the container. The denser the product the more difficult and time consuming is the pre-cooling process.
2. The packaging must be designed to ensure that the open surface area in the form of ventilation holes or slots is sufficient. These slots must be orientated

Table 16.2 Shelf Life and Compatibility Information of Fresh Vegetables[1] ✓

Vegetables	Temperature			Relative Humidity (RH)			Ethylene		Chilling or Freezing Sensitive[2]	Shelf Life (days)
	0–3°C	5–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Alfalfa sprout	✓					✓				14–42
Artichoke	✓					✓				10–16
Arugula	✓					✓		✓		5–7
Asparagus	✓					✓		✓		10–21
Basil		✓			✓			✓		5–7
Beans; fava, lima	✓					✓				7–14
Beans; snap, green, wax		✓			✓				C	7–10
Beet	✓					✓				120–150
Belgian endive	✓					✓		✓		10–14
Bitter melon			✓		✓				C	10–14
Bok choy	✓					✓		✓		7–10
Boniato			✓		✓			✓	C	180–270
Broccoli	✓					✓		✓		10–14
Broccoflower	✓					✓		✓		14–21
Brussels sprouts	✓					✓		✓		21–28
Cabbage	✓					✓		✓		90–180
Cactus leaves (nopales)		✓			✓					7–10
Calabaza		✓			✓				C	60–90
Carrot	✓					✓		✓	F	28–180
Cassava			✓		✓					21–28
Cauliflower	✓					✓		✓	F	14–21

Celeriac	✓					✓			180–240
Celery	✓					✓	✓	F	35–49
Chard	✓					✓	✓		
Chayote		✓			✓		✓	C	
Chinese cabbage	✓					✓	✓		60–90
Chinese turnip	✓					✓			120–150
Collard	✓					✓	✓		
Corn; sweet, baby	✓					✓			5–8
Cowpea (Southern pea)		✓			✓				
Cucumber		✓			✓		✓	C	10–14
Cut vegetables	✓					✓			14–21
Daikon	✓					✓	✓		120
Dry onion			✓		✓			F	180–350
Eggplant		✓			✓		✓	C	10–14
Endive-chicory	✓					✓	✓		14–21
Escarole	✓					✓	✓		14–21
Fennel	✓					✓	✓		10–14
Garlic	✓			✓					90–210
Ginger			✓		✓			C	60–90
Green onion	✓					✓	✓		7–10
Herbs (not basil)		✓				✓	✓		5–7
Horseradish	✓					✓			240–350
Jerusalem artichoke	✓					✓			180–350
Jicama			✓		✓			C	60–90
Kailon	✓					✓	✓		
Kale	✓					✓	✓		10–14

(*Continued*)

Table 16.2 (Continued)

Vegetables	Temperature			Relative Humidity (RH)			Ethylene		Chilling or Freezing Sensitive[2]	Shelf Life (days)
	0–3°C	5–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Kiwano (horned melon)		✓			✓				C	
Kohlrabi	✓					✓				45–60
Leek	✓					✓		✓		60–90
Lettuce	✓					✓		✓	F	14–21
Lettuce, Romaine	✓					✓				14–21
Long bean		✓								
Malanga		✓			✓			✓	C	
Mint	✓					✓		✓		
Mushroom	✓				✓					5–7
Mustard greens	✓					✓		✓		
Onion	✓			✓						30–180
Okra		✓			✓			✓	C	7–10
Parsley	✓					✓		✓	F	30–60
Parsnip	✓					✓				90–120
Peas	✓					✓		✓	F	7–10
Pepper; bell		✓			✓				C	14–21
Pepper; hot	✓			✓						14–21
Potato		✓			✓				C	56–140
Pumpkin			✓	✓					C	84–160
Quince	✓					✓				60–90
Radicchio	✓					✓				14–21
Radish	✓					✓			F	10–21

Rutabaga	✓					✓			120–180
Rhubarb	✓					✓			14–28
Salsify	✓					✓			90–120
Satsuma	✓				✓				56–84
Scorzonera	✓					✓			
Shallot	✓					✓	✓		180–240
Snow pea	✓					✓	✓		
Spinach	✓					✓	✓	F	10–14
Sprouts	✓				✓				5–10
Squash; Summer, (soft rind)		✓				✓	✓	C	7–14
Squash; Winter, (hard rind)		✓		✓				F	30–180
Sweet pea	✓					✓	✓		
Sweet potato			✓		✓		✓	C	120–210
Swiss chard	✓					✓	✓		7–14
Taro (dasheen)			✓		✓			C	90–120
Tomatillo		✓			✓			C	21
Tomato; green			✓		✓		✓	C	21–28
Tomato; ripe, partially ripe		✓			✓		✓	C	7–14
Turnip	✓					✓			120
Turnip greens	✓					✓	✓		10–14
Waterchestnut	✓					✓			30–60
Watercress	✓					✓	✓		14–21
Winged bean		✓			✓				
Yam			✓		✓		✓	C	180–240

[1]*Information compiled from Ashby (1995), McGregor (1989), Boyhan et al. (2004), and Thompson and Kader (2004).*
[2]*C for both chilling and freezing sensitive and F for freezing sensitive.*

Table 16.3 Shelf Life and Compatibility Information for Fresh Fruits[1]

Fruits	Temperature			Relative Humidity (RH)			Ethylene		Chilling Sensitive[2]	Shelf Life (days)
	0–2°C	7–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Apple	✓				✓		✓			90–350
Apricot	✓				✓		✓			21–28
Atemoya			✓				✓		c	14–21
Avocado; ripe	✓				✓		✓			14–21
Avocado; unripe		✓			✓			✓		28–42
Babaco		✓			✓					28–56
Banana			✓		✓		✓		c	21–35
Barbados cherry	✓				✓					14–21
Blackberry	✓				✓					7–14
Blueberry	✓				✓					10–18
Boysenberry	✓				✓					2–5
Breadfruit			✓		✓		✓			14–21
Cactus pear; tuna		✓			✓					28–56
Caimito	✓				✓					21–35
Calamondin		✓			✓					14–28
Canistel			✓		✓		✓			10–21
Cantaloupe		✓			✓		✓		c	14–21
Carambola		✓			✓					21–35
Casaba melon			✓		✓					21–28
Cashew apple	✓				✓					

Cherimoya			✓	✓	✓		c	14–21
Cherry; sweet	✓			✓				14–28
Coconut	✓			✓				90–150
Cranberry		✓		✓			c	60–120
Crenshaw melon			✓	✓	✓			14–21
Currant	✓			✓				14–21
Custard apple		✓		✓	✓			
Date	✓			✓				240–350
Dewberry	✓			✓				
Durian; ripe		✓		✓	✓			
Elderberry	✓			✓				14–21
Feijoa		✓		✓				
Fig	✓			✓				7–10
Fresh-cut fruits								
Gooseberry	✓			✓				
Granadilla		✓		✓	✓			
Grape	✓			✓				56–180
Grapefruit			✓	✓		✓		28–56
Guava		✓		✓	✓		c	7–21
Honeydew melon			✓	✓	✓			14–21
Jaboticaba			✓	✓				
Jackfruit			✓	✓				
Juan canary melon		✓		✓	✓			

(Continued)

Table 16.3 (Continued)

Fruits	Temperature			Relative Humidity (RH)			Ethylene		Chilling Sensitive[2]	Shelf Life (days)
	0–2°C	7–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Kiwifruit	✓				✓		✓	✓		90–150
Kumquat		✓			✓					
Lemon		✓			✓			✓	c	120–180
Lime		✓			✓			✓		42–56
Limequat		✓			✓					7–10
Loganberry	✓				✓					
Longan	✓				✓					21–35
Loquat	✓				✓					21–28
Litchi	✓				✓					
Mamey			✓		✓		✓			21–35
Mandarin		✓			✓				c	21–28
Mango; ripe		✓			✓		✓			14–28
Mangosteen			✓		✓		✓		c	35–49
Nectarine	✓				✓					
Olive		✓			✓				c	90–120
Orange		✓			✓					60–90
Papaya			✓		✓		✓		c	14–21
Passion fruit		✓			✓				c	14–35
Peach	✓				✓		✓			14–28
Pear (Asian & European)	✓				✓					60–180

Pepino		✓		✓			
Persian melon			✓	✓	✓		
Persimmon			✓	✓	✓		35–84
Pineapple		✓		✓		c	14–28
Plantain			✓	✓	✓	c	21–35
Plum; ripe	✓			✓	✓		14–28
Plumcot; ripe	✓			✓	✓		
Pomegranate	✓			✓		c	
Prune	✓			✓	✓		
Pummelo		✓		✓			30–60
Quince	✓			✓	✓		60–90
Rambutan			✓	✓			14–21
Raspberry	✓			✓			5–7
Sapodilla			✓	✓	✓		35–56
Sapote			✓	✓	✓		14–21
Soursop			✓	✓	✓		7–10
Strawberry	✓			✓			7–14
Sugar apple		✓		✓			14–21
Tamarillo		✓		✓		c	35–63
Tamarind		✓		✓			42–63
Tangelo		✓		✓		c	21–35
Tangerine		✓		✓			14–28
Ugli fruit		✓		✓			
Watermelon			✓	✓			14–21

[1]*Information compiled from McGregor (1989), Ashby (1995), Boyhan et al. (2004), and Thompson and Kader (2004).*
[2]*c for both chilling and freezing sensitive.*

to ensure that the chilled air can move freely over the produce. The direction of air flow in land-based cold stores is always horizontal, whereas in specialized reefer ships and refrigerated shipping containers the movement is in a vertical direction. The slots must be orientated to accommodate both these storage considerations.

3. The volume to surface area of the produce, as the lower the ratio, the faster the cooling. For example, cherries cool faster than melons. However, the packaging configuration must also be considered as grapes are small with a high volume to surface ratio, but they are usually packed inside a liner bag to keep sulfur dioxide in and around the produce and keep the RH high. Therefore, to balance the needs of providing a barrier film and allowing chilled air in, micro-perforations must be placed in the film. A tradeoff between moisture control and speed of cooling has to be established.
4. The distance the chilled air has to move must be considered: the shorter the distance, the faster the cooling. In shipping containers there is a drop off in cooling efficiency along the length of the container.
5. The volume of air used: the higher the volume of air the faster the cooling.

The industry has a standard term to describe the time of pre-cooling, this being the $\{7/8\}^{th}$. cooling time. This describes the time taken to force air cool product from the starting produce pulp temperature down to 87.5% ($\{7/8\}^{th}$.) of set point. This is a convenient descriptor of the practical temperature the product will reach with the set point. It must be remembered that the product temperature will never reach the set point temperature because of the internal vital heat of the produce. This means that if the desired pulp temperature of something like an apple is 0°C, then the set point will need to be −1.0°C to achieve it. To illustrate this, an example may be used of a freshly harvested peach with a pulp temperature of 32°C being cooled by 28°C and reaching 4°C in 9 h. In this case the $\{7/8\}^{th}$ cooling time is 9 h. The final $\{1/8\}^{th}$ cooling will follow but at a much slower rate. It must be remembered that the higher the pulp temperature at the commencement of cooling and the lower the set point, the longer the time it takes to cool the product. The $\{7/8\}^{th}$ cooling time will, in theory, take three times as long to achieve as the {1/2} cooling time. Therefore, the same peach that took 9 h to cool to 4°C would take only 3 h to reach 16°C, the {1/2} cooling time. If everything else remained the same the $\{7/8\}^{th}$, cooling time would be 7.5, 4.5, 3 and 1.5 times longer than the {1/4}, {3/8}, {1/2} and {3/4} cooling times, respectively.

The above must be kept in mind when considering the pre-cooling of produce, as subtropical and tropical produce can be sensitive to chilling injury (Hung, 1993) (see also Chapter 10). The physiological characteristics of the produce will affect the postharvest handling. Produce such as broccoli, asparagus, sweetcorn, leaf lettuce and mushrooms with very high respiration rates must be cooled as soon as possible after harvest (within 90 min) and as rapidly as possible. Most of these crops are hydro-cooled, iced or vacuum cooled. They can also be force air cooled provided high air speeds are used and there is control over the RH. The latter is a most important consideration to reduce the danger of dehydration. Produce with a high respiration rates at harvest such as blueberries, raspberries, strawberries, sweet cherries, snap beans and head lettuce should be cooled as quickly as possible after harvest and at least within 3 h. Moderately respiring products such as apples, pears, cabbage, cantaloupes, celery, peaches, nectarines, plums and peppers should be cooled within 5 h to reduce quality loss and ensure maximum storage or shelf life.

The packaging used for the product is important for three reasons:

1. Keeping the product in discrete manageable units that are easily labeled in order that the content can be traced.
2. Holding the produce in such a way as to ensure there is no bruising or friction damage caused during handling and long distance transportation.
3. Enabling the free movement of chilled air across the produce through suitably shaped and positioned vents.

In selecting the type of packing to be used, the three aforementioned characteristics must be considered along with the length and complexity of the supply chain. The longer the supply chain, the greater the number of fork-lift movements and changes in storage and transport medium. Each change places the produce at risk of being damaged through shock or compression; therefore, the packing must be robust enough to withstand these forces, but still enable the three characteristics without costing too much. Compromises are often sought in balancing these attributes, and often the choice is made for cheaper packaging which does not have the strength to withstand the rigors of transport and handling. The result is packaging that collapses, and in so doing, damages the produce and reduces or destroys its value. In all decision making around what products or materials to use in the supply chain, it is important to default to what is fit for purpose rather than what is the cheapest. Cheap packaging does not necessarily translate into cost-effective packaging, as the physical and financial loss experienced on damaged produce due to compression damage or similar, far outweighs the higher cost of better-quality packaging.

V Transportation equipment

The following types of refrigerated transportation equipment are available:

1. Road trucks and trailers;
2. Air cargo containers;
3. Trailers for road, rail and roll on/ roll off ocean transport;
4. Rail box cars;
5. Specialized reefer vessels;
6. Reefer shipping containers.

In almost all cases the refrigeration system in all but the air freight containers is achieved with vapor-compression refrigeration with HFC refrigerants (IIR, 2003).

A Road trucks and trailers

In the cold supply chain distribution system, the road transport vehicles are refrigerated and the refrigeration capacity is specified to maintain temperatures, not to pull temperatures down. It is, therefore, essential to the maintenance of the cold chain to only load the transport vehicles with produce that is within the specified temperature range. This requires that the cold store or distribution center manage the temperatures within the prescribed protocol. The condition of the insulation and design of the air distribution systems in the transport equipment are important, as is the loading pattern of the produce within the vehicle. If any of these parameters are not within their specification, the temperatures and RH levels will not be correct and the produce quality will not be maintained (Ashby, 1995).

Refrigeration systems in road vehicles are diesel powered with the ability to plug into local electrical grids when parked in depots. In the smaller road transport vehicles (up to 4 m long) the refrigeration can be powered by the vehicle engine. In larger vehicles or semi-trailers (4−9 m) the refrigeration is powered by its own diesel engine. In some cities, where noise restrictions are in place, refrigeration in trucks is achieved through the use of eutectic plates. These plates are frozen in a depot and then placed in the vehicle body before loading to provide the chilled air for the duration of the transport. Upon returning to the depot, the plates are removed and re-frozen for the next load. In some instances, the trailer compartment can be separated into two sections with different temperatures. This is achieved by having an internal insulated movable wall with two evaporator units set to different temperatures. The chilled air is delivered horizontally at the roof height of the truck or trailer from the front-mounted refrigeration unit. This delivery system is sometimes aided by canvas chutes hung from the roof in long trailers to ensure that some of the chilled air reaches the rear of the trailer. The important consideration with all road transport is that the refrigeration capacity is sized to the cubic capacity of the storage area, and that it has the capacity to maintain temperatures, not to reduce them. The product must be loaded at the correct temperature and the refrigeration will maintain that temperature.

B Air freight

Dry ice, in the form of solid carbon dioxide, can be placed in special trays or compartments within the cargo area and provide cool air to control the temperature. Fresh produce must never come into direct contact with dry ice or it will be damaged. Wet ice is used in some instances in containers placed on top of the pallets. In this case, the packaging must be water resistant and there must be a means of draining the subsequently produced water out of the vehicle. In the case of airfreight, some airlines do permit the use of ice. However, it must be placed inside a sealed polyethylene bag inside a leak proof container and also have a moisture-absorbent pad. Gel refrigeration uses frozen containers of chemical eutectic gel to maintain temperature within the airfreight container. This is the preferred refrigeration system of most airlines.

C Sea freight

There are two ways of transporting perishable products by sea; specialized refrigerated ships and marine reefer containers, which are transported by container ships. In both these transport media the refrigeration equipment is driven by electricity. In the holds of vessels and in reefer containers the chilled air is delivered through the floor in a vertical direction. It is, therefore, essential that the pallets and cartons have air vents positioned in such a way as to allow for free movement of air to allow for efficient cooling. Temperature management in reefer containers is difficult because of the poor airflow at the door end of the container. This can exacerbate issues with shelf life and ripening of sensitive produce like stone fruit. There are ways of mitigating the uneven airflow (Dodd and Worthington-Smith, 2006).

VI Systems for produce in grocery stores and display cases

Fresh produce delivered to supermarkets and grocery stores must immediately be placed in a cold room set at the appropriate temperature and relative humidity. Ideally there should be, as proposed by Kader and Thompson (2001), three storage rooms with settings of 0–2°C, 7–10°C and 13–18°C with the RH of 85–95%. These storage rooms should have good air circulation and fresh air exchange to maintain the correct temperature and limit ethylene build up. To maintain fresh produce shelf life into the homes of consumers, refrigeration must be maintained. This procedure often does not occur inside grocery stores or supermarkets. Products such as citrus and apples are often placed on displays rather than in refrigerated cabinets. Refrigerated display cabinets should be well maintained and have an easy to read, accurate thermometer.

To protect the produce from excessive moisture loss, automatic sprayers are installed in many display cabinets, particularly those containing loose leafy vegetables. Kader and Thompson (2001) have published a list of products that will benefit from a misting system. Many supermarkets report significant shrinkage displayed at the front portion of display cabinets because the area is out of reach of the chilled air and mist. The large variation of air temperatures recorded within a typical supermarket display cabinet can be seen in Figure 16.2. This is a link in the supply chain that needs innovation to rectify the poor temperature management.

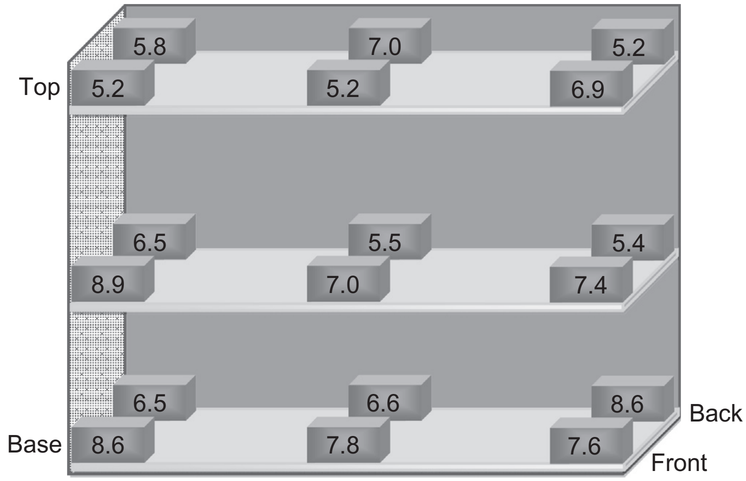

FIGURE 16.2

The range of air temperatures recorded in a typical "refrigerated open throat" display cabinet used in a supermarket. The delivery set point was 2.0°C.

This wide range of temperatures, which are much higher than the set point explains why shelf life of produce often does not meet the sell by date. Produce loss due to wilting, drying and not being at optimum set point is estimated at $1.00 per 30 cm of display cabinet per day. Some supermarkets utilize covers that are pulled down over fronts on the display cabinets overnight. Lighting such as Promolux produces true colors and produces less heat and radiation, thus adding less heat load to the refrigeration.

The cold chain can best be managed with hard data about the actual temperatures occurring along the supply chain. An example of the insights that can be gained by measuring temperatures in the different segments of the supply chain can be seen in Figure 16.3. This shows air and produce temperatures from a distribution centre through a long road trip into a chiller at the back of a store and inside a refrigerated display cabinet. The temperature in this example is well managed in the Distribution Centre and during the road transport. However, during the time in the display cabinet there are numerous occasions when the temperature goes out of the desired protocol due to the defrost cycle. It is of interest to see how closely the product temperature follows the delivery air temperature.

A Home refrigerators

Keeping perishables cold in the domestic environment is essential for maintaining their quality. These refrigerators come in a variety of sizes and are usually set at a compromise temperature of between 4°C and 5°C. Sealed cooler drawers are provided in most modern units to try and manage a higher RH for the benefit of vegetables. An evolving technology is the fitting of RFID within the refrigerator

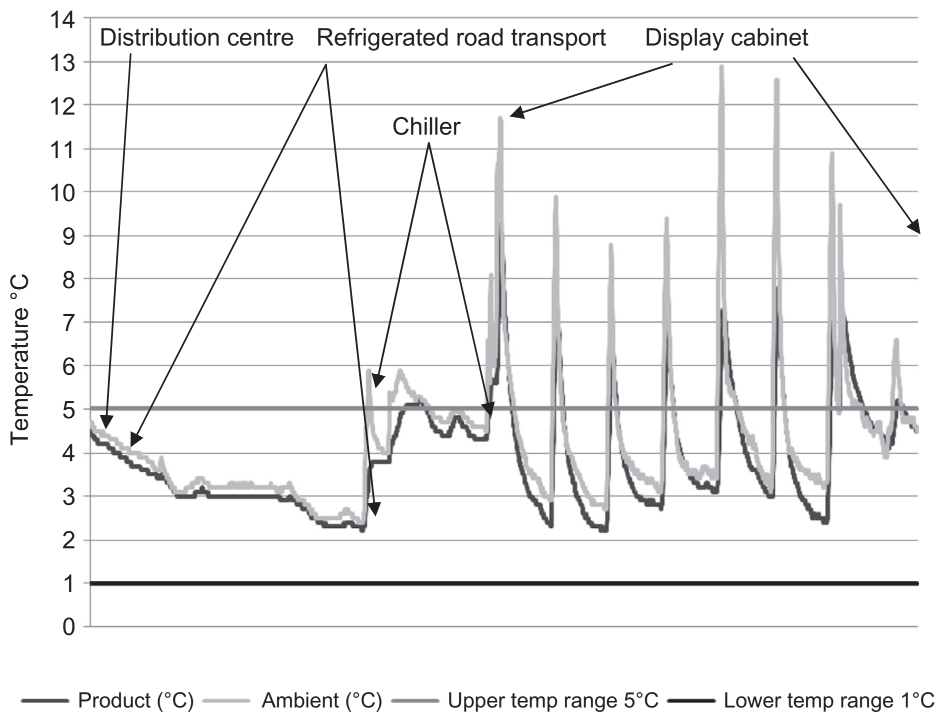

FIGURE 16.3

Graph of air temperature and product pulp temperature (for broccoli) from a distribution center through a long-distance refrigerated transport to a back of store chiller and into an "open throat" refrigerated display cabinet. Data segmented into storage and transport links in the cold supply chain.

that is linked to reusable recorders which enables the checking of product temperatures and shelf life.

VII Summary of the cold chain

As has been illustrated, maintaining the cold chain is essential for the preservation of product quality and gaining maximum value out of the supply chain. This cold chain begins on the farm when the produce is harvested and ends in the home when the produce is consumed. Overviews of fruit and vegetable storage and transport systems can be found in the *Encyclopaedia of Agriculture, Food and Biological Engineering* (Hellevang, 2003; Hellickson, 2003; Tao, 2003). In general, any procedure to reduce or eliminate breaks in the cold chain will have a positive impact by maximizing the quality and shelf life of the produce. Temperature management is the most important means of managing fresh produce quality. There is an optimum storage temperature and RH level for all products as shown in Tables 16.1 and 16.4 (which were created from information available in

Table 16.4 Relative Humidity at Various Storage Temperatures as Affected by the Temperature Difference (TD) Between the Store Room Temperature and the Evaporator Refrigerant Exhaust Temperature

Temperature Difference (TD) in °C	RH (%) at Various Store Room Temperatures		
	0°C	1.6°C	3.5°C
1	95.8	96.1	96.1
2	91.2	92.3	92.4
3	87.1	88.7	88.8
4	83.0	84.7	85.3
5	79.4	80.9	82.0

the literature). In addition it is important to note the chilling and ethylene sensitivity, as well as which products can be mixed together on the same pallet or stored together in the same cold store. Compatibility and sensitivity tables have been developed by McGregor (1989) for fresh produce during storage and transport.

VIII Supporting technologies

In taking a systems approach to a process it is necessary to have a view and understanding of the technologies that support it. Hence with a cold supply chain the most important technology is that of refrigeration. It is necessary that people working in cold supply chains have an understanding of the principles and mode of action of refrigeration.

A Refrigeration principles

Cooling is the removal of heat from the produce. Heat may be defined as the interaction between systems, which occurs by virtue of their temperature difference when they interface. The temperature of produce is reduced during cooling. The magnitude of the heat interaction is measured in Joules (J) or calories (cal). The increase or decrease in energy of a system during a change of state is numerically equal to the net heat during the process minus the net work during the process.

The laws of thermodynamics are relevant in understanding the mechanics of a refrigeration system. The first law of thermodynamics is recorded by Spalding and Cole (1978) and described as: "When a system executes a cyclic process, the net work is proportional to the net heat". This principle is also known as the conservation of energy, which means that energy cannot be created or destroyed. In any refrigeration system, energy in the form of heat is removed from the produce and discarded into the atmosphere. For the system to work, usually electrical energy is used to drive mechanical devices like compressors and fans, and the sum of the work done by these devices is then also absorbed in the refrigeration system to add to the heat load.

The second law of thermodynamics states that an isolated system will spontaneously evolves towards a state of thermodynamic equilibrium. When two initially isolated systems in separate but nearby regions of space are allowed to interact, they will eventually reach a mutual thermodynamic equilibrium. This principle is applied several times in a refrigeration system, because a refrigeration system relies on a series of heat transfers to transport the heat from the produce via packaging, air, fans, conduits, refrigerants and compressors, to be discarded into the atmosphere.

Refrigeration is a heat removal process. The refrigeration system is the device that enables this process. Various heat exchanges take place during the total process, in which heat is removed from produce and transported via different media until it is rejected elsewhere. The heat-transporting media can be a fluid or a solid. The following example is an illustration. In this example, the cooling cycle is described from the produce as starting point. This is a generic example to illustrate the working of a refrigeration system and can be applied to refrigeration systems in various applications, e.g., a cold store, refrigerated truck, forced air cooling tunnel, reefer vessel, refrigerated shipping container, freezer rooms and display cabinet in shops. For ease of discussion, the application will be described as a cooling chamber. The cooling chamber is the space where the produce is put to be cooled.

Heat in the produce needs to be removed by a transporting medium. In most cases, except for hydro-cooling, the heat is removed by air flowing over the produce. The rate of cooling is determined by the following factors:

1. A larger temperature gradient from the center of the produce to the skin or surface of the produce will increase the rate of cooling.
2. A larger difference in temperature between the surface of the produce and the surrounding airflow will increase the rate of cooling.
3. A higher rate of airflow will contribute to an increase in the rate of cooling as heat is removed at a higher rate.
4. The size of the individual produce units. Heat flows to the surface of the product by conduction and a larger fruit, like an apple, will take longer to dissipate all the heat within it than a smaller fruit such as a grape.
5. The thermal characteristics of the produce, e.g., a thick peel of a citrus fruit, will slow down the rate of conduction.
6. The immediate packaging surrounding the produce, e.g., wrapping of produce acts as another insulating skin.
7. Outer packaging and consolidated loads like pallets also restrict the air movement which removes the heat from the fruit, hence the importance of good carton and palletization design to improve airflow to the produce.

The cool air surrounding the produce is circulated in the cooling chamber by means of fans. The function of the airflow is to collect the heat of the produce and other heat sources and to transport the heat to the heat exchanger. More effective cooling is achieved when the airflow is directed with ducts and plenums to achieve a circular pattern between the produce and the heat exchanger. The heat exchanger in the cold room is the evaporator of the refrigeration cycle.

B The refrigeration cycle

Continuous refrigeration is usually accomplished by a vapor compression system, also known as the simple compression cycle (van Dalfsen, 1989). Such a system has a low pressure (evaporating) side and a high pressure (condensing) side. The refrigerant acts as a transportation medium to move heat from the evaporator (in the cold chamber) to the condenser unit (outside) where the heat is given off to ambient air. The change of state from liquid to vapor and back to liquid allows the refrigerant to absorb and discharge large quantities of heat very efficiently.

High pressure liquid refrigerant is fed through the liquid line towards the cold chamber. A valve controls the feed of liquid refrigerant to the evaporator and, by means of an orifice, reduces the pressure of the refrigerant to the low pressure side. The reduction of pressure causes the refrigerant to boil or vaporize until the refrigerant is at a saturation temperature corresponding to its pressure. The low temperature refrigerant passes through the evaporator coil where it absorbs heat from the cold room causing the refrigerant to continue boiling and vaporize.

The refrigerant vapor leaving the evaporator in the cold room travels through the suction line and accumulator and then on to the compressor inlet. The compressor takes the low pressure vapor and compresses it, increasing both the pressure and the temperature. The hot, high pressure gas is forced into the condenser for cooling. As the temperature of the refrigerant vapor reaches the saturation temperature corresponding to the high pressure in the condenser, the vapor condenses into a liquid and flows back to a receiver to repeat the cycle. The basic units of a refrigeration system are given in the schematic diagram shown in Figure 16.4.

The working of a refrigeration system is better understood when looking at the pressure-enthalpy relationship. The same cycle as described in the previous example is displayed in Figure 16.5 below. Heat from the produce is transported via airflow to the evaporator coils where it is absorbed by the refrigerant between points 1 and 2 on the diagram. The temperature of the refrigerant does not increase when the heat is absorbed because the refrigerant changes phase from liquid to gas at a constant temperature and pressure. Latent heat is absorbed and the enthalpy of the refrigerant increases. The gas is then compressed by the compressor between points 2 and 3 on the diagram. The enthalpy of the refrigerant increases further when electrical energy is used via the compressor to increase the pressure and the temperature of the gas. The superheated gas is cooled in the condenser between points 3 and 4 at a constant pressure. Further heat is removed by the condenser between points 4 and 5, but with no decrease in temperature or

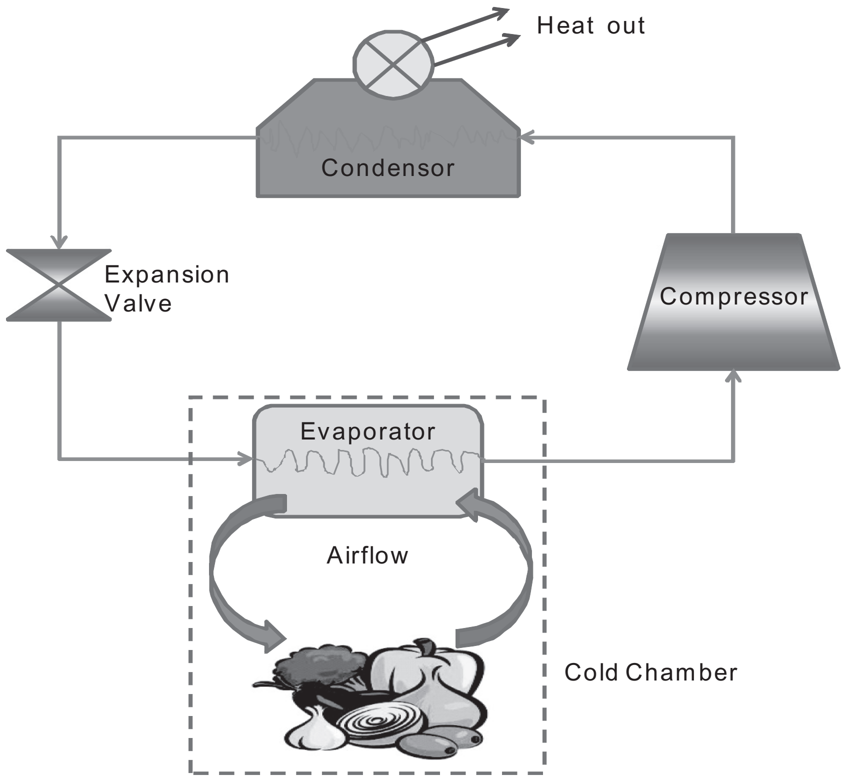

FIGURE 16.4

Diagram of the refrigeration process.

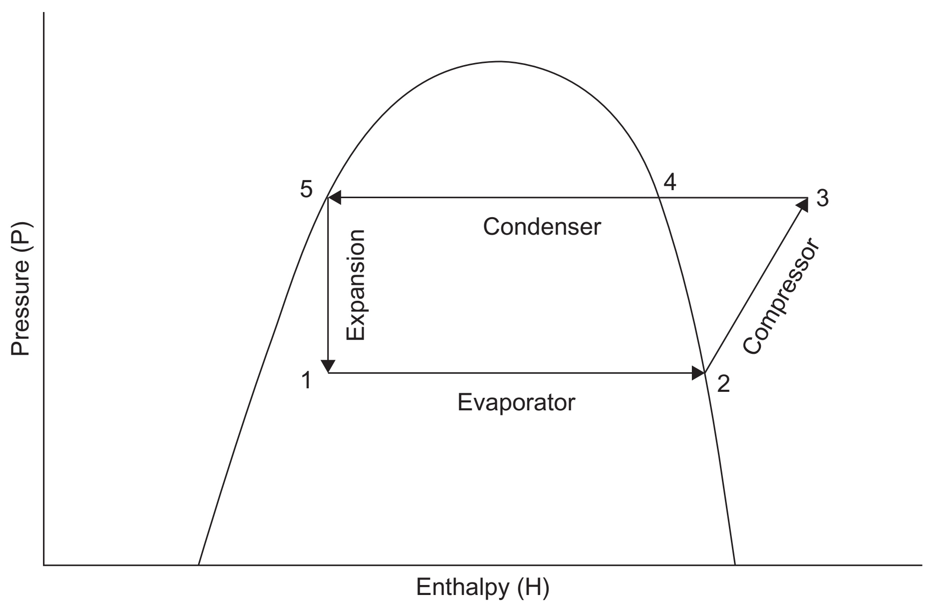

FIGURE 16.5

Enthalpy diagram.

pressure because latent heat is given off to change from gas to liquid. Between points 5 and 1 the refrigerant moves through the expansion valve with no change in enthalpy, but with a reduction in both pressure and temperature.

This cycle demonstrates the efficiency of a refrigeration system. Energy is applied to the system by the compressor with an increase in enthalpy of the refrigerant from point 2 to 3. The enthalpy is then reduced by the condenser between points 3 to 5. That leaves the refrigerant with a capacity to "pick up" enthalpy in the evaporator between points 1 and 3. The efficiency of the system is the ratio of useful enthalpy absorbed (points 1−2) and energy used for this purpose (points 2−3). This ratio is known as the coefficient of performance and for typical systems this ratio is between 3 and 5. This means that for each kW of electricity consumed by the compressor, the refrigeration system can absorb between 3 and 5 kW of heat from the produce. This is a very efficient system and further information regarding the refrigeration cycle can be found in Hung (1991).

C Energy efficiency in refrigeration

External energy is needed in the cold chain for refrigeration purposes. This energy is supplied as electrical energy in cold stores, or by fuel during transportation. Energy is expensive and contributes to the cost of the product, and is also a major source of carbon emissions by the cold chain. These two reasons provide enough motivation to ensure that energy is used as efficiently as possible to maintain the temperature of the produce in the cold chain.

The working of a cold room is displayed simplistically in Figure 16.6. It shows that heat is removed from the cold store by a refrigeration plant and this

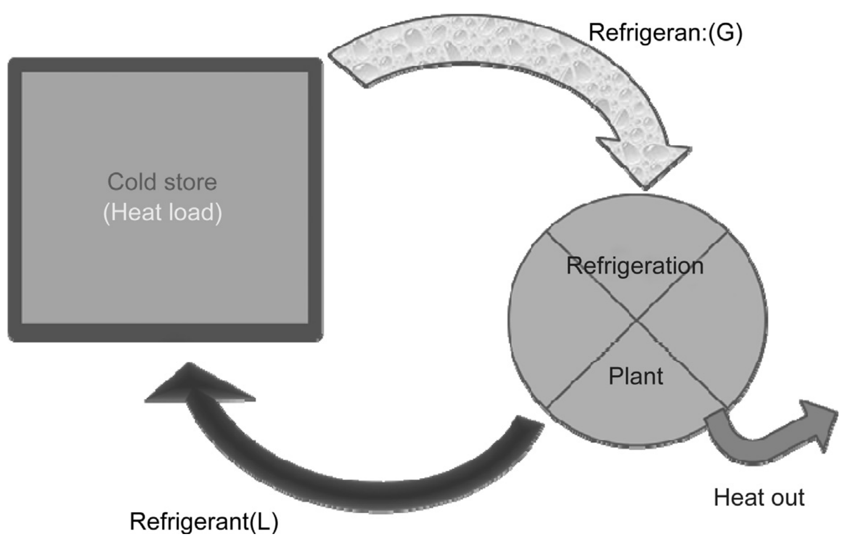

FIGURE 16.6

Refrigeration system.

heat is then discarded into the atmosphere. Energy can be used more efficiently if the following is achieved:

1. Reduce the heat load;
2. Improve the plant efficiency;
3. Harvest the discarded heat and re-use.

These three opportunities are discussed in more detail below.

D Reduce the heat load

The heat load can be reduced by any of the following:

1. The original temperature of the produce. Less energy is used for refrigeration when the original temperature of the product is closer to the target temperature. This can be achieved by harvesting produce during the night or early morning hours. Some produce types can also be stored in a natural cool place to lose some of its field heat before it is put in the cold store for further cooling to lower temperatures.
2. The produce respiration heat. Respiration activity is reduced with cooling. A faster cooling rate will reduce the total respiration heat load.
3. Insulation of the cold room. Heat entering the cold room through the floor, walls, ceiling and roof adds to the heat load. Better insulation can reduce this heat load.
4. Doors are a huge factor in adding to the heat load. When doors are open, warm air enters the cold room. When doors are closed, poor insulation of the doors or improper door seals may contribute to the heat load. Solutions for these are strip curtains, air curtains, automated high speed doors or double door systems.
5. Lighting is a heat source and should be reduced to the minimum. Proximity switches and energy efficient bulbs are possible solutions.
6. Fans are necessary for effective air circulation to transport the heat from the produce to the evaporator unit. Approximately 90% of the fan's electricity consumption is eventually transferred as heat into the cold room. Variable speed drives (VSD) can be used to reduce the fan speed to optimum levels. Energy consumption is reduced with the cube of the ratio between speed and energy as per the affinity laws.
7. People entering the cold chamber are also a heat source. Stock control or other administrative tasks should be done outside the cold chamber if possible.
8. The heat of the forklift trucks add to the heat load. Electrical forklifts are preferred over combustion type forklifts for operating in the cold chambers.
9. The non-utilization of the cold chamber space may increase the heat load when cold chambers are cooled but not utilized efficiently.

E Improve refrigeration plant efficiency

The efficiency of the refrigeration plant can be improved by the following factors given by Wilcox (2010):

1. Reducing the difference between suction and discharge pressures, also known as reducing the lift. Increasing suction pressure and/or reducing discharge pressure increases the efficiency.
2. Selecting larger evaporator coils can lead to increased suction pressure.
3. Increased condenser capacity may lead to reduction in discharge pressures given the effect of outdoor conditions.
4. Improving the part load performance of the refrigeration system. Although all refrigeration systems are designed to meet peak loads, many spend only a few hours at peak load. Hence, part load operation and performance can play a large role in overall efficiency. Examples of improving the part-load performance are fan cycling, Variable Speed Drive (VSD) on fans, improved compressor sequencing, VSD controls on compressors and condensers.
5. Upgrading the refrigeration equipment. Major refrigeration components can be retrofitted with features to improve efficiency. Examples are high-efficiency evaporator coils, more efficient fan blades, evaporator fin designs, premium-efficiency motors, and other changes to improve compressor and condenser efficiency.
6. Improve the refrigeration system design. In addition to selecting the individual refrigeration components, the overall system design can be improved by features such as multi-staging, sub-cooling, defrosting and gas pressure pumping.
7. Computer control systems can be used for controlling the refrigeration system at optimum levels for each particular operating environment.

F Heat recovery

Heat recovery can improve the efficiency in a larger system of which the refrigeration is a part. The hot compressor discharge which is normally discarded into the atmosphere can instead be used for under-floor heating, boiler make-up or for heating plant clean-up water. This heat is then applied for a useful purpose and will save energy at another point, outside the refrigeration system.

G Relative humidity

To maintain the relatively high humidity required for the storage of most fruits and vegetables, emphasis must be given to the design or capacity of the evaporators. To maintain RH of 85−90% at a temperature of 0°C, as recommended by Thompson (2002), the temperature difference between the storage room temperature and the evaporator refrigerant exhaust temperature should not be greater than 3°C. Table 16.4 illustrates the effect of temperature difference and RH that can naturally achieved. To achieve higher RH in cold stores larger than usual evaporator coils would be required.

IX Other technologies

Controlled atmosphere (CA) is utilized mainly in static cold stores for produce with long storage life such as apples and pears. This is used as a complimentary technology to refrigeration. The oxygen levels are reduced from 21% to anywhere between 1% and 3% and carbon dioxide raised from 0.03% to as much as 5%. The engineering to achieve this is fairly complex and thus costly, and so best suited to large land based systems. The refrigeration machine manufacturers who supply the shipping container industry have also developed systems which do work well, but because of their high cost of purchase and maintenance demand a high surcharge. As such the use of this technology is limited to high value commodities such as avocados.

Modified atmosphere (MA) is also a complementary technology to refrigeration, in which the respiration rate of the produce is used to reduce the level of oxygen and raise the level of carbon dioxide in the storage air. This technology may be found in the form of packaging material which is wrapped around the produce or used as a bag. The material will act as a barrier to the ingress of oxygen and prevent the egress of carbon dioxide and water vapor. This enables the buildup of an atmosphere that is different to the storage air, with the oxygen level being lower than 21% and the carbon dioxide level being higher than 0.03%. With this change in atmosphere comes a concomitant slowing down of the respiration rate of the produce. The technology may also be applied in reefer containers by providing a control mechanism for the air exchange vent. By linking a carbon dioxide sensor to a motorized air exchange vent via software, the oxygen and carbon dioxide levels within the container can be managed through the product's respiration and the addition of ambient air. The benefit of this is the storage and shelf life of the produce will be extended because the respiration rate is slowed down. Such systems are to be found on reefer containers with trade names such as Advanced Fresh Air Management and E Auto Fresh.

Another emerging technology is the scrubbing of ethylene out of the air in the storage unit. This can be achieved in two ways:

1. Potassium permanganate based absorbing systems are placed either in small sachets that are distributed across the top of a pallet of produce, or in a tube covered in gauze. The principle of operation is that the air in the storage air moves with the airflow created by the evaporator fans and this moves the air through the absorbent material. This technology is effective but care must be made in choosing suppliers that provide units that have sufficient ethylene absorbent capacity.
2. Ozone generating systems deliver this triatomic form of oxygen into the storage air, where it acts in two ways. The first is to act as a surface sterilant that kills off bacteria and surface growing fungal pathogens. The second is to oxidize the ethylene to carbon dioxide and water.

X Developing trends

In June 2002, the United States Congress passed a new Public Health Security and Bioterrorism Preparedness and Response Act. This Act requires that all food facilities, both domestic and foreign, doing business within the United States or shipping food into the United States must register with the Food and Drug Administration (FDA) (FDA, 2002). The FDA also requires prior notice of shipments going into the United States before shipment. This ruling also applies to other importing markets such as the European Union (EU). This law also requires that those who manufacture, process, pack, transport, distribute, receive, hold or import food must establish and maintain records to enable tracing of the product. To aid in tracing the product, a global trade item number (GTIN) is an internationally recognized protocol for assigning item numbers. This system is used in numerous industries in many countries. The code, which can be held on RFID recorders, can provide an accurate, efficient and cost-effective means of controlling the flow of product. The system is based on a 14-digit numeric code which is now an international protocol. Businesses that use the GTIN protocol will have, through RFID or bar codes, instant access to a complete provenance of the produce in question. In a recent case study, the Produce Marketing Association (PMA) in the United States evaluated the GTIN along the supply chain with a view to improving logistics. The PMA recommends that the fruit and vegetable sector adopt the GTIN as a means of automating traceability and cutting costs.

With the international threat of terrorism ever present, a growing trend is the use of "tamper proof" packaging. This technology, however, is unlikely to gain acceptance in the fresh produce industry, as it is likely to create an atmosphere around the produce that is unsuitable to the maintenance of quality. In addition, as consumers select produce on touch and aroma this technology would interfere with this process.

Labels to brand produce are often annoyingly stuck onto individual pieces of fruit. A new technology that can replace these labels uses laser light to create a label on each fruit. The natural light labeling system developed by Duran Wayland uses a concentrated beam of light to remove the pigment in the outer layer of skin and reveal a contrasting color underneath. This technology can be used to etch logos, PLUs country of origin, lot and batch numbers.

A growing trend is for third party certification with internationally recognized programs such as organic, non-GMO, Fair Trade, BRC and ISO 14000 for environmental issues, Good Agricultural Practice and Good Management Practices (see also Chapter 8). There are also systems such as HACCP and ISO 22000 for food safety and ISO 9000 for food quality. Another program called Safe Quality Food (SFQ) is a management program that incorporates GAPs, GMPs, HACCP and Codex requirements. It is a fully integrated food safety and quality management protocol specific to the food industry. It is recorded that over 4000 companies operating in the Asia-Pacific, Middle East, US, Europe and South America have implemented SFQ. These systems all in their own way add to the integrity of the produce being supplied.

Bibliography

Ashby, H., 1995. Protecting perishable foods during transport by truck. USDA Handbook (No. 669.).

Bollen, A.F., Ridden, C.P., Opara, L.U., 2006. Traceability in postharvest quality management. IJPTI. Int. J. Postharvest Tech. Innov. 1 (1), 93–105.

Boyhan, G.E., Hurst, W.C., Kelley, W.T., Krewer, G.W., Taylor, K.C., 2004. Postharvest handling and transportation of fruits and vegetables. Anonymous. Anonymous. The University of Georgia. Cooperative Extension Services Fact Sheet (100).

Bureau of Labor Statistics U.S., 2006. Truck transportation and warehousing. Department of Labour. Career Guide to Industries (2006–07 Ed). <http://www.bls.gov/oco/cg/cgs021.htm>.

Christopher, M., Lee, H.L., 2001. Supply Chain Confidence: The Key to Effective Supply Chains Through Improved Visibility and Reliability. Vatera Inc, Global Trade Management.

Dehghannya, J., Ngadi, M., Vigneault, C., 2010. Mathematical modelling procedures for airflow. heat and mass transfer during forced convection cooling of produce: a review. Food Eng. Rev. 2, 227–243.

Dodd, M.C., 2012. Costs in a fruit export supply chain. ISHS, Scripta Horticulturae, 14. Harvesting the Sun, A Profile of World Horticulture, pp. 32.

Dodd, M.C., 2013. Identifying and rectifying temperature and humidity abuse in various fruit supply chains from South Africa to the United Kingdom. World Cold Chain Conference. 22–23 May 2013. Impact Convention Centre, Bangkok, Thailand.

Dodd, M.C., Worthington-Smith, P.S., 2006. Managing airflow in reefer containers benefits fruit quality. In: Proceedings IIR-IRHAC, Auckland, New Zealand, 2006.

Engedi, J., 2007. New traceability technology for fresh produce. HarvestMark (10-Jul). <http://www.harvestmark.com/news.html>.

FAO, 2010. FAO. The Millenium Development goals report. <http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2010/MDG_Report_2010_En.pdf> (accessed 15.11.13).

FDA, 2002. Public health security and bioterrorism preparedness and response act of 2002. Anonymous. Anonymous. <http://www.fda.gov/oc/bioterrorism/bioact.html> (accessed 26.02.14).

Fearne, A., Hughes, D., 1999. Success factors in the fresh produce supply chain: insights from the UK. Supply Chain Manag. 4 (3), 120–128.

Fraser, H.W., 1998. Tunnel Forced-Air Coolers for Fresh Fruits and Vegetables. Ontario Ministry of Agriculture and Rural Affairs.

Hardenburg, R.E. Watada, A.E., Wang, C.Y., 1986. The commercial storage of fruits, vegetables and florist and nursery stocks. USDA/ARS. Agricultural Handbook (66).

Hellevang, K., 2003. Vegetable storage system. In: Heldman, D.R. (Ed.), The Encyclopaedia of Agricultural, Food, and Biological Engineering. Marcel Dekker, Inc., New York, NY, USA, pp. 1116–1123.

Hellickson, M.L., 2003. Fruit storage systems. In: Heldman, D.R. (Ed.), The Encyclopaedia of Agricultural, Food, and Biological Engineering. Marcel Dekker, Inc., New York, NY, USA, pp. 422–424.

Hewett, E.W., 2006. An overview of pre-harvest factors influencing postharvest quality of horticultural products. Int. J. Postharvest Tech. Innov. 1 (1), 4–15.

Hung, Y.-C., 1991. Food freezing. In: Hui, Y.H. (Ed.), Encyclopaedia of Food Science and Technology. John Wiley & Sons, New York, NY, USA, pp. 1041–1050.

Hung, Y.-C., 1993. Latent damage: a systems perspective. In: Shewfelt, R., Prussia, S. (Eds.), Postharvest Handling: A Systems Approach. Academic Press, Inc., pp. 211–224.

IIR, 2003. Refrigerated transport: progress achieved and challenges to be met. The 16th informatory note on refrigerating technologies. <http://www.iifiir.org/en/doc/1014.pdf> (accessed 16.07.13.).

Jones, S., 1996. When time is of the essence. Prog. Grocer 75 (2), 105.

Kader, A.A., Thompson, J.F., 2001. Grocery store display storage. Perishable Handl. Q. 107, 6–7.

Katzorke, M., Lee, B.W., 1998.Creating world class supply chains. In: 41st APICS International Conference Proceedings, pp. 107–110.

Luo, W., Findlay, C., 2002. Analysis of logistics service sector in China: implications of accession to the WTO. In: Paper prepared for the Authors Workshop on WTO Accession and Poverty Reduction, Beijing, China, October 26–27.

Mallik, S., 2010. Customer service in supply chain management. In: Bidgoil, H. (Ed.), The Handbook of Technology Management: Supply Chain Management, Marketing and Advertising, and Global Management, vol. 2. first ed. John Wiley & Sons, Hoboken, New Jersey, p. 104.

McGregor, B.M., 1989.Tropical Products Transport Handbook. USDA Handbook (No. 668.).

Murphy, J.V., 2005. Earthbound farm gets a fresh solution for its perishables supply chain. Anonymous. Anonymous. Glob. Logistics Supply Chain Strateg. November, 2005.

Sargent, S.A., Talbot, M.T., Brecht, J.K., 1989. Evaluating precooling methods for vegetable packing house operations. Proc. Fla. State Hort. Soc. 101, 175–182.

Spalding, D.B., Cole, E.H., 1978. Engineering Thermodynamics, third ed. Arnold.

Tao, Y., 2003. Fruit transport system. In: Heldman, D.R. (Ed.), The Encyclopaedia of Agricultural, Food, and Biological Engineering. Marcel Dekker, Inc., New York, NY, USA, pp. 425–430.

Thompson, J.F., 2002. Psychometrics and Perishable products. Post Harvest Technology of Horticultural Crops. University of California, Agricultural and Natural resources, Publication 3311.

Thompson, J.F., Kader, A.A., 2004. Wholesale distribution centre storage. USDA Agricultural Handbook. In: The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks (No. 66).

Thompson, J.F., Mitchell, F.G., Kasmire, R.E., 2002. Cooling horticultural commodities. Post Harvest Technology of Horticultural Crops. University of California, Agricultural and Natural resources, Publication 3311.

Van Dalfsen, B., 1989. Refrigeration principles. Farm Structures Fact Sheet. Ministry of Agriculture and Food, British Colombia, Canada.

Wilcox, M.E.A., 2010. Industrial Refrigeration – Best Practice Guide. Cascade Energy.

Wills, R., McGlasson, B., Graham, D., Joyce, D., 1998. Postharvest. Water loss and Humidity. An Introduction to the Physiology and Handling of Fruits, Vegetables and Ornamentls. UNSW Press.

This page intentionally left blank

CHAPTER

Traceability in Postharvest Systems

17

A. Frank Bollen[a] **and Jean-Pierre Emond**[b]

[a]*Zespri International Ltd, Mt Maunganui, New Zealand,* [b]*Electro-Optical Systems Laboratory, Georgia Tech Research Institute, Atlanta, Georgia, USA*

I Introduction

Traceability is an expected attribute of the modern postharvest system. Traceability is a well coordinated and well documented movement of product and documented activities associated with the product, from producer, through a chain of intermediaries, to the final consumer. When this book was first published, the emphasis was on how the components of the postharvest system interacted and in turn, the impacts of these interactions on other parts of the system. It is a sign of how well systems and supply chain thinking has embedded within this sector of the international economy that it is now important to include a discussion on an activity that helps to integrate and bind a supply system from end-to-end, the activity of traceability.

This chapter introduces the concept of traceability in the context of an industrialized supply chain and the reasons for its emergence as a critical component of the modern food supply system (Hobbs, 2004). There are a number of limits on the ability of the postharvest system to provide accurate traceability and these issues are discussed, along with an introduction to identification technologies and information systems, which support traceability.

While traceability is primarily driven by the need to provide information to buyers and consumers, there are opportunities to leverage this required activity to provide information feedback to improve performance in other parts of the chain, and some of these are discussed at the end of this chapter. There is no exact, single definition of traceability and it has a wide number of different meanings, which depend on the industry sector in the supply chain, and the perspectives of both the suppliers and users of the information. The definition, therefore, varies slightly through the course of the following discussion.

A Drivers of traceability

The drivers for traceability can be separated into two main categories. Bollen et al. (2006) defined these drivers as "hard" or "soft" traceability requirements.

Postharvest Handling.

Hard traceability requirements are those with which international or domestic marketers of perishable products are required to comply to meet regulatory or international trade treaty obligations. These include issues such as trace back for food safety, trace forward for market access or compliance with production standards (see also Chapters 3 and 8) and the meeting of security requirements (Zaske, 2003). Soft requirements do not control the ability to trade, but can have significant impacts on the economics of particular supply chains. These can include improving performance of supply chains (see also Chapters 1 and 6), meeting changing consumer needs or responding to the requirements of third parties such as retailers or importers.

Food safety

The European Union (EU) and North America have two of the most industrialized food sectors in the world. In these economies, consumers are generally well removed from the producers of their food. This separation necessitates consumers, or in many cases retailers acting on their customer's behalf, to have confidence in the supply chain to deliver safe food. This confidence is continually being shaken by media exposure of large and small food scares. Major international food safety issues have included Bovine Spongiform Encephalopathy (BSE) in the UK (Pettitt, 2001) and Canada/United States (Ward et al., 2005), dioxin in Belgium (Opara, 2003) and the presence of horse meat in beef burgers in Europe (The Guardian, 2013; SGS, 2013). Added to this have been smaller scale or local concerns over other food hazards including microbial, physical and chemical hazards in the food supply. Finally of concern to a large proportion of the world's consumers is the presence of genetically modified organisms (GMO) in their food supply (EU, 2006; Nilsson et al., 2004).

While many of these food scares relate to issues with meat supply there has been a spillover of concern to other foods, such as fresh and minimally processed fruit and vegetables. The major consumer concern (Opara, 2003) in this area is the use of agrichemicals and the possible existence of high levels of pesticide on fruit and vegetables. All these concerns need to be addressed through some form of traceability or audit system.

The EU has been particularly proactive in adopting a highly regulated regime for ensuring food safety. This has resulted in a number of prescriptive traceability requirements, such as EU Regulation No. 178/02 (EU, 2002; Giacomini et al., 2001) which requires (Article 18) that there is an obligation of whole supply chain traceability on all food stuffs and animal foods as well as traceability to all farms (SGS, 2013). The EU has also implemented regulations to specify how GMOs are to be traced through the food supply system (EU, 2006).

In the postharvest area, the United States has taken the approach that individual businesses can derive competitive advantage through their own individual information and traceability systems. The emphasis is placed on the ability to respond to trace back and food safety issues rapidly and efficiently (Golan et al., 2004). Added to this is the incentive to reduce legal liability in the event of some trace back issue which encourages the development of appropriate systems (Hobbs and Young, 1999).

Production standards

As well as the requirements for a safe food supply, there is a growing consumer awareness of the effects that agricultural production techniques are having on the environment. Several large supermarket chains are now adopting sustainable production standards to control and monitor production practices (Tesco, 2013; Wal-Mart, 2013). These are being used both as an assurance service to their customers as well as competitive points of differentiation. The outcome of these activities is the development of minimum production standards and good agricultural practice (GAP) protocols, which control certain activities of an orchard or farm. These programs generally require "activity" traceability in the form of information such as proof of fertilizer, pesticide and water applications. Increasingly these will start to include other issues such as carbon footprint and energy use. While much of the above can be considered soft traceability requirements, many of these are likely to become embedded in regulations over time.

The supply of product to other countries, or out of state, often involves the need to provide evidence that the product conforms to the importing country or state's quarantine regulations. Increasingly, quarantine regulations require evidence of product conforming to certain production practices or postharvest treatments, in conjunction with independent auditing and inspection regimes.

Common to all these issues is the need to capture information on production activities and trace these forward through the supply chain alongside the products. The technologies developed for precision agriculture offer the opportunity to dramatically improve the quality of the production related data (McBratney et al., 2005a; Hoownicki, 2004). Precision agriculture involves the capture of spatial, temporal and quantitative information on production activities such as spraying or fertilizer applications (Demmel et al., 2002) as well as crop quality and production measurements (McBratney et al., 2005b). All data is collected with a spatial location (usually GPS measured) so that it can then be displayed on maps using a geographical information system (GIS). This level of information is all electronically stored and is readily available to the traceability system in different formats and levels of detail.

Security

The third area with hard traceability requirements which must be met to trade across international boundaries is the increasing need for secure track-and-trace systems for international trade (Bollen et al., 2004). The requirements for traceability in the shipping and airfreight sectors, particularly into the United States, require registration of goods several days prior to shipping. This can have detrimental impacts on highly perishable products, which require shipping on short time frames.

Consumers

Some consumer concerns over food safety and sustainable production are, as already discussed, addressed through the provision of regulatory frameworks. These are consumer concerns that were soft requirements for traceability but have now become hard requirements.

Outside of regulatory protocols (see also Chapter 8), it is retailers who assume the bulk of the responsibility to assure their customers of product quality, safety and sustainability. At this level, individual supermarkets or branded marketers will require traceability systems that deliver information and product that support particular businesses' market positioning.

Part of these soft traceability requirements is the ability to segregate the market, and the products in the market to meet consumer expectations. This involves the segregation of inherently variable biological products into a number of more consistent lines which requires trace forward of information on these products and their attributes (Bollen et al., 2006). In order to incentivize growers to produce product, or packers to segregate product, to meet market specifications it is also useful to trace back or feedback market performance to producers.

Supply chain performance

Supply chains can gain commercial advantage from their ability to use traceability information for a number of purposes, one of which is to meet internal operational and performance improvements (Pierce and Cavalieri, 2002) (see also Chapter 6). Typically the traceability systems in the postharvest cool chain have been used to improve cool store stocking and management, speed product location and improve planning and picking operations for shipping (see also Chapters 16 and 18). New opportunities exist to use non-destructive measurement technologies (see also Chapter 13) to assist in quality monitoring and the prediction of quality changes to further improve these operations by providing better information on matching product quality to current pricing to optimize returns, and identifying lines for early or late shipping based on their storage potential.

The multiple sharing of information between businesses necessitated by some traceability requirements can also have spin-off benefits for whole chains as transparency increases (see also Chapter 1). This leads to the improving vertical integration of supply chains which lead to more efficient food supply systems (Hobbs and Young, 1999).

Feedback to producers

An often overlooked opportunity for traceability systems (Bollen et al., 2003) is to provide feedback to producers. Postharvest systems generally involve a sorting and grading process (see also Chapter 12). At this point all produce is individually measured. By linking this quality information to the individual bin or trailer and tracking this from a specific orchard location, it is possible to provide feedback to producers on the quality and variation in quality and yield across their farm or orchard. Such an application is discussed further at the end of this chapter.

B Definitions of traceability

The complexities of the supply chain for perishable products mean that a succinct definition of traceability is difficult. ISO 9000:2005 (ISO, 2005) defines traceability within a business entity as the ability to retrace the history, use or location of an entity using recorded data based on some unique identification. Giacomini et al. (2001) suggested a useful extension to this definition is to include the movement of product between businesses.

In the context of a food manufacturing system, Moe (1998) defined traceability as "... the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales" which was defined as *chain traceability*. Moe further defined *internal traceability* as all product batches and activities within one-step of the chain. This work built on the work of Kim et al. (1995) who had stated that "... the fundamental and necessary core in an ideal traceability system is the ability to face both products and activities".

As Bodria (2002) observes, the obligation of traceability is unique in that the responsibility to provide traceability is shared by all businesses involved in a particular supply chain. So, traceability requires the unique identification of products and processes coupled with information systems which are able to deliver relevant information to meet trace forward or trace back requirements. This all has to occur across several business boundaries.

In its fullest sense, traceability is a subset of quality systems, which are in turn a subset of information systems. Traceability is essentially about information flows within a postharvest system. Opara (2003) identified three types of traceability that are relevant in a postharvest system.

Production and postharvest system traceability

Production and postharvest activities traceability involves providing information on GAP activities linked to the production process. Of particular interest is information on the use of fertilizers, pesticides and water use, as well as social considerations such as labor conditions. This will increasingly expand to include evidence of sustainable production systems and energy efficiency. Similarly there is a requirement to provide information on postharvest activities such as drenching, washing, dips, additives or agrichemicals used. It is expected that these traceability requirements will grow to consider energy use and energy type (renewable on non-renewable) for cool chain and transport activities. This type of information traceability is associated with components of Good Manufacturing Practice (GMP) protocols.

Pest, disease and GMO traceability

Quarantine required traceability involves the ability to trace and record activities in order to assure importers that no prohibited pests or diseases or GMOs are introduced to the market through implementation of programs that monitor disease incidence, pest incursion or accidental GMO release. Also, if an event does occur, traceability systems are required to be able to respond and locate all possibly affected product as well as to assure markets that no product is sourced, or in some cases even transits through, areas and exclusion zones around any such an incident.

Product traceability

Product traceability is the ability to identify product at any stage in the supply chain, as described by ISO 9000:2005 (2005). The identification of the product and its traceability is the primary and an integral component of other information or activity based forms of traceability discussed above. Product traceability is the core component of the system, as it is not possible to access information on certain products if the product itself is not able to be traced. Product traceability is the major topic of the remainder of this chapter.

II Theory of traceability in postharvest systems

A Identifiable units

A critical component of the traceability information system is the identification system and the definition of the unit that can be uniquely identified. Moe (1998), using the terminology defined by Kim et al. (1995), defined the unit, or batch, that could be traced as the traceable resource unit (TRU). The TRU has to be a unique unit and must have characteristics that are different from all other TRUs. This definition of the TRU arose from the domain of the quality system and Kim et al. (1995) take traceability to be backwards in time only.

As already discussed, a broader definition of traceability for the postharvest system requires tracing of products as well as activities. Bollen et al. (2007) has, therefore, defined a broader term, the identifiable units (IUs) which adhere to the uniqueness requirements defined by Moe (1998), but have the additional attributes; they can be abstractions or aggregates, they apply to resources, products or activities and there exist parent-child relationships within any IU structure. Figure 17.1 shows a set of typical IUs in the postharvest system for fruit. There are several points in the supply chain where much of the transformation of IUs occurs, initially at packing where fruit is placed into packs which go onto pallets and into trucks, etc., and eventually at retail where the reverse occurs (Figure 17.1).

B Traceability is not absolute

The postharvest system can be split into three parts, in terms of traceability. At the packinghouse, product is placed into packaging and onto pallets. From this stage in the process product is well identified and can generally be traced through

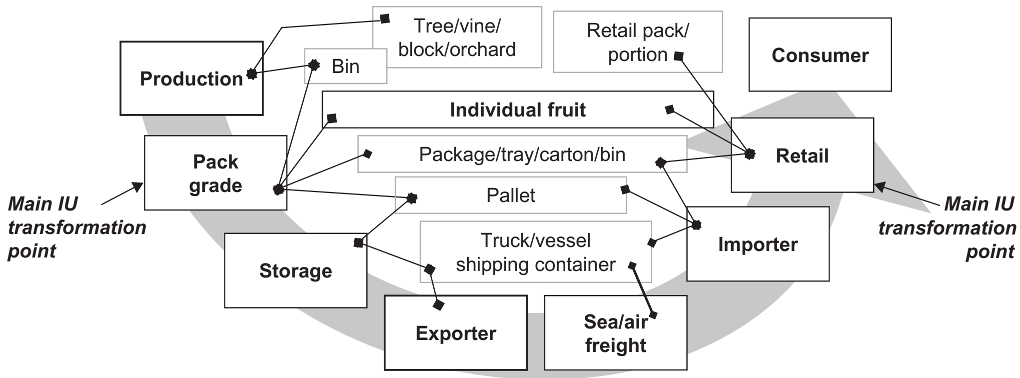

FIGURE 17.1

Typical Identifiable Units (IUs) in a postharvest system.

Source: Bollen et al. (2007).

the logistics chain. Through this part of the system it is possible to achieve complete traceability, provided adequate recording of activities and product movement is carried out. Once the pallets and packs are broken down, traceability becomes less accurate as product is mixed and the systems used tend to be less robust. This is also the case from the orchard until the point at which the product is packed. So, the system is characterized by a central component of high traceability sandwiched between two components of low traceability. While it is common in discussions of traceability to assume absolute traceability, in fact in the context of the entire postharvest system, traceability will never be absolute.

A traceability system can be described by different sizes of IU, which is termed the granularity of the traceability. At the coarsest level of granularity, a fruit or vegetable may be traceable to a state or country of origin, or perhaps an individual farm or orchard, whereas finer levels include individual shipments, pallets or packs. The ultimate level of traceability would be individual fruit, but currently there are no practical systems that enable traceability at this level.

The processing operations such as cleaning, sorting, grading of fruit in a packing house involve taking fruit from definable IUs, such as individual bins picked in the orchard, and handling these as a continuous stream. The packing house generally, but not always, splits the fruit into batches of common product (from the same orchard, or orchard block). These batches are packed in sequence through the facility and tracked onto the final pallets. Often there may be different grower's fruit on the same pallet and the individual growers are generally identified on the packs, but in many cases this is simply a generic grower ID that is not specifically linked to a batch. There are also likely to be packs at the changeover from one batch to another that are filled with fruit from both batches. Traceability in this case relies on both the pallet IU, which will generally be linked to a batch, as well as having grower IDs associated with this IU. Trace back, however, would require manual identification of individual packs as there is no potential to link these into a traceability information system without a unique pack ID.

C Precision of traceability

The degree of granularity of the IUs defines the precision of traceability possible in a postharvest system. Large IUs may only enable traceability to the level of country of origin. Small IUs such as bins or individual packs may enable traceability to an individual packinghouse, or perhaps orchard, or even an area (block) within an orchard. Granularity is however not the sole determinant of precision.

Bollen et al. (2007) conducted some studies of traceability and fruit mixing through an apple packing facility. Various mixing and packinghouse operational setups were modeled (Riden and Bollen, 2007) to estimate levels of precision possible from a typical medium sized apple processing operation. In these papers, the precision of traceability was formally defined as the ratio between IUs at two points in the postharvest system. The two points defined were the input the packinghouse (bins with approximately 2400 fruit and the output (packs containing 36, 80, 150 or 220 fruit).

The average precision measured in one example was 3.6 bins per pack (8400 fruit). By tripling the size of the input unit (essentially a bin trailer with three bins) the ratio was improved to 2.0 "triples" per pack (14,400 fruit), but precision was reduced as tripling the size of the input unit did not result in tripling the ratio. At the level of the IU of a production run Riden and Bollen (2007) estimated a traceability precision to only 136,800 fruit. It is useful, therefore, to trace with a fine level of granularity as this improves the potential precision of system traceability.

D Tracking

Tracking is the ability to trace product as it moves forward through the supply chain. At any individual process in the system it is possible to describe the magnitude of a tracking activity as a measure of the number of output units that derive from each input unit (Riden and Bollen, 2007). That is to say, "how many output units need to be tracked to know where all product from an input unit has gone?" At the level of a batch it is possible to simply count all pallets and part pallets linked to the particular batch. As the size of the IU gets smaller tracking becomes more complex.

For example, with the apple packinghouse studied, the incoming quantity of fruit from one bin would have filled approximately 20 packs. Because the fruit is sized and placed in different "count" packs, the fruit from each bin was calculated to be spread over 35–40 packs assuming there was no mixing in the system. If realistic levels of mixing in the in-feed system, across the water dump, brushes and sorting tables, as well as mixing at the packing lanes were factored in, then the fruit from each bin was estimated to be spread over 100 packs.

E Tracing

Tracing is the ability to trace back up the supply chain. Riden and Bollen (2007) defined the magnitude of a tracing activity as the number of input units that might potentially belong to each output unit from any segment of the supply chain, which can be stated as, "how many input units need to be found that directly link with a particular output unit of interest?" At the level of a batch it would be all batches associated with a particular pallet. For the apple packinghouse studied by Riden and Bollen (2007), tracing precision was measured as the ratio of input bins per output pack. Packs with an uncommon fruit size (large or small fruit) were found to be supplied by fruit from six to 13 bins and that the amount of in-feed mixing had little effect on this ratio. Packs with a common fruit size had a much better ratio of 1 to 3 bins per pack and this was predominantly affected by in-feed mixing. Only 5% of packs contained fruit sourced from only one bin, and so the ability to trace from one bin to one pack is not common. The ability to trace back up the supply chain is therefore significantly affected by both the proportion of product segregated into a particular grade, but also mixing within the system.

F Tolerances and purity

While the concept of there being tolerances within a traceability system is unusual, there are times where this is appropriate. The allowance of some error (tolerance) in the estimate of the source or destination of some product in an IU will be acceptable for traceability applications where quality management or statistical feedback are objectives, as errors due to the presence of other product will be small. By adopting a traceability system with fine granularity and built in tolerances, it is possible to aggregate IUs to a level where absolute traceability is required, if necessary. If it is not possible to reverse engineer such a system if requirements change in the future, it is useful to consider designing traceability systems at fine granularity IUs with built in tolerances.

Riden and Bollen (2007) have also introduced the concept of purity for postharvest system traceability. Purity is an alternative way to consider tolerance. Tolerance describes the certainty of the relationship between packs and bins, for example, and purity describes the degree of membership or dilution that is "allowed" to effectively have one-to-one membership. A 99% purity pack would therefore be a pack where 99% of the fruit is from a particular bin. Purity is a useful concept to apply in sampling processes, as for traceback, it is more useful to sample a pack which has a known composition (e.g., 99% purity) than one that might be difficult to trace back (say only 40% purity).

III Components of traceability systems

A Identification technologies

The basic traceability of product through the postharvest system is achieved by being able to identify each IU with a unique code. There is a vast array of technology providers seeking to provide machine-readable solutions, which become incrementally more reliable than their predecessors (Bollen et al., 2006). There are three main ways of identifying IUs discussed in the following.

Alphanumeric ID

This is still a common system in particular sectors of the supply chain, including on-orchard, in the air and sea freight sectors and at retail. Generally alphanumeric IDs are read by humans and manually recorded into an information system. There is a reasonable chance of errors in this situation and some major international ports use optical character recognition to automatically capture and record sea freight container IDs (Bollen et al., 2004).

Barcode

The barcode is the most successful machine-readable ID system. It has been proven internationally over the last 30 years as a very reliable, low cost system. The system involves printing a label, or directly printing onto a pack, a series of bars and gaps of varying widths. This code is then read and interpreted using a laser to scan the bars. The codes conform to one of a number of standards (GS1, 2007). Code lengths range from eight numerical, 13 numerical through to 48 alphanumeric digits (Figure 17.2). To meet the ever increasing demand for information to be included with the product there is now also a reduced space symbology (RSS) standard for a 2-D barcode which enables 2335 alphanumeric digits to be recorded (GS1, 2007). Barcodes are generally printed with an associated alphanumeric ID for occasions when a human readable ID is needed.

An extension of the 2-D barcode is the Quick Response Code (QR Code; Figure 17.2). The attraction of the QR Code is the use of the black "modules" (black dots in squares) which align the matrix and allow for machine reading on low cost and common devices such as smart phones. The QR Code is often used to provide a link to a web address, but can also be designed to contain a substantial amount of traceable product information.

Radio frequency ID (RFID)

RFID is the most automated technology for identification of IUs in the postharvest system with the ability to read the ID "tag" more readily without the need to

0123 4565
EAN-8
8 Numeric

5 012345 678900
EAN-13
13 Numeric

(00) 0 0123456 123456789 6
EAN-128
48 Alphanumeric

(01)00012345678905
GS1 Datamatrix
3116 Numeric, 2335
Alphanumeric

FIGURE 17.2

Typical barcode styles.

shine a laser directly at the barcode. There are two main categories of RFID technology; passive tags which require a reader to energize them to transmit a signal and active tags which have an internal battery and can transmit a signal when in range of a reader.

The passive RFID technology has two primary components (Figure 17.3). The tag consists of a small chip with on board memory which holds a unique ID (read-only tag) or has the ability to have some information written to the tag (read-write tag). The tag also contains a small radio antenna. The second component is the reader which consists of a pair of antennae with an operating and recording system. When the tag is close to the reader, the reader powers the tag through the tag antennae and the tag reports its information to the reader. There are a number of different tag technologies, some small enough to be embedded in labels on packaging.

Active tag technology (Figure 17.4) is powered, and can transmit data to a reader. This technology is capable of holding more information than simply the unique ID. The main application of the active tag RFID technology is seen in temperature monitoring systems where a battery is required to power the monitoring and logging of temperature information (Ben-Tzur and Ward, 2010). In these systems the tag will communicate with a reader up to several hundred meters away and so such systems are well suited to coolstore and warehouse applications (see also Chapter 16).

The implementation of all types of RFID has been slower than expected as costs and limitation on reader performance (range and reliability) have hampered expansion of the technology. The technology is generally seen at the pallet level. One of the main challenges is that the current RFID systems are designed work either in the frequencies that cannot work near products containing high amounts of water (such as produce) or in frequencies that have short ranges for reading the tags (few millimeters), which makes them unsuitable for portal applications in

FIGURE 17.3

RFID system on orchard bins.

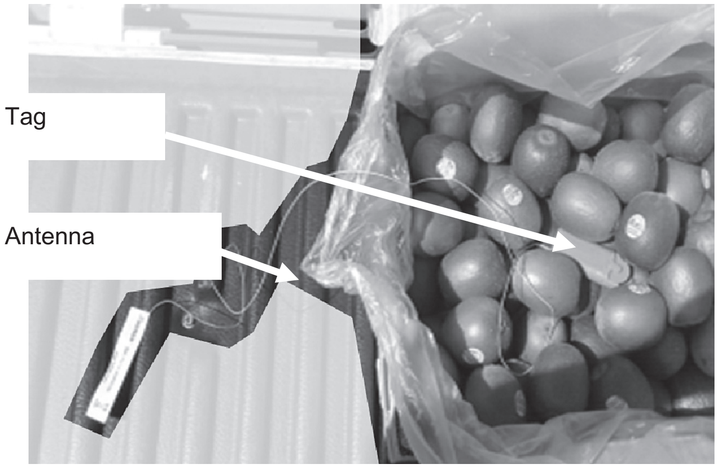

FIGURE 17.4

Active RFID tag in a pack of fruit.

Courtesy BT9 Xsense™ Temperature Monitoring System.

warehouses and distribution centers (Amador et al., 2009). Another significant technical challenge is the use of multiple frequencies around the world. Even though many RFID tags carry multiple frequency antennae, organizations such as the International Association for Standardization (ISO) and EPC Global are working towards creating standards promoting global parity for specific RFID applications; the different regulations with respect to frequency ranges allocated for RFID commercial purposes vary according to the country and complicate global RFID ventures. For example, UHF tags sent in a shipment from the United States (with a UHF frequency allocation between 902–928 MHz) can be read in Europe (frequency allocation of 865–868 MHz) if the tags use the EPC Global Gen-2 standards which specify that readers be able to read along this entire band of the UHF spectrum (Amador et al, 2009).

B Information systems

While it is important to be able to read and identify product throughout the postharvest system, it is the information system that provides the underlying platform for traceability. Unfortunately, the information system in most supply chains is essentially a set of disparate local information systems designed to serve the needs of each individual business. Data is exchanged between businesses as required, using a myriad of data exchange protocols and arrangements (Figure 17.5). Generally information only flows in the same direction as the product. The only information that flows back up the chain is summary data (such as quality performance) or trace back when an issue occurs. The problem with this structure is that the system is only as strong as its weakest link.

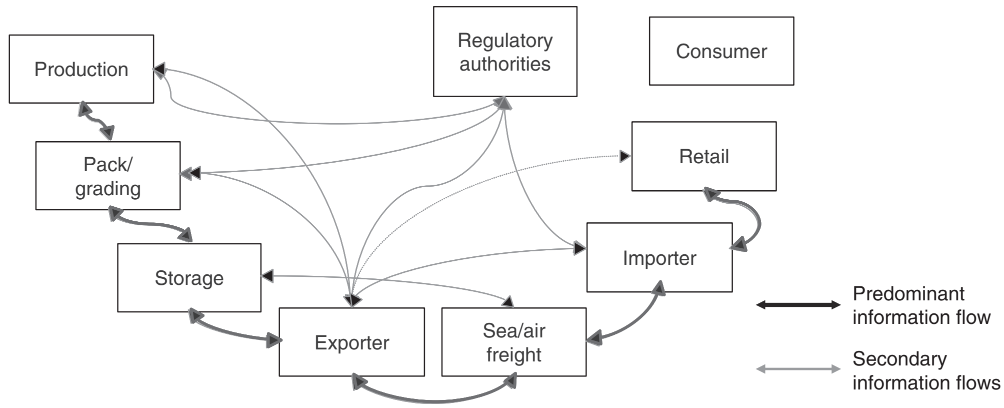

FIGURE 17.5

Formal exchange of information in a generalized postharvest system.

From Bollen et al. (2005).

One solution to this lack of a common data system is to continue to place more data on the tag or label. From an information systems design point of view, this can lead to issues such as multiple copies of data, data being static once written to the tag and not able to be updated, and the transport of a large amount of data which is never used. A preferable design is to use a distributed data base approach where the unique ID on each IU is shared and data from each point of the chain is available to all other parties. Improved data sharing leads to better vertical integration of a postharvest system which enables the businesses involved to share the benefits of improved performance (Hobbs and Young, 1999).

In a study of track-and-trace systems within the Asia-Pacific Economic Community (APEC) region, Bollen et al. (2004) identified that the economies with high "ease of trade" were those with sophisticated information systems. If systems are designed to deliver on supply chain performance then it is relatively easy to provide traceability data, but if a system is inwardly focused on a particular business then it is often difficult, and costly, to meet regulatory traceability requirements.

IV Extended uses of traceability systems

One of the opportunities of the current emphasis on traceability in modern agricultural systems is to use this drive to assist in improving the performance of the entire postharvest system. The preceding sections have discussed how traceability can be partial and if information is considered at this lower level then there are a number of opportunities to exchange information along the supply chain which can potentially benefit the entire system, or at the least benefit individual businesses within the system. Two example opportunities are discussed here.

A Grower feedback tools

In the postharvest system the packinghouse grades fruit and then places it in packs for shipping. Fruit is graded on one or more of a number of attributes such as size, color, firmness, number of defects and dry matter. Growers are paid according to the quality profile of the product packed out. There are usually payment schedules that will reward the production of the desired attributes (e.g., high dry matter, preferred color, large size, etc). Currently the information provided to the grower is summarized at a level that relates to the level of granularity equivalent to the payments, so by day, week, batch, etc. There is an extreme loss in precision, as the fruit has all been individually measured on the grader.

An enhanced traceability system was profiled by Praat et al. (2003), where the location of picking for every bin of kiwifruit was identified and then the fruit was tracked through the packinghouse. Grader data on size and dry matter for all fruit was recorded. Approximately half the information on fruit from each bin was discarded as there was bin-to-bin overlap due to mixing. The remaining fruit data was used to calculate quality statistics for each bin and the resulting information was traced back to the appropriate location in the orchard and mapped on a geographic information system (GIS) similar to that shown in Figure 17.6. The maps can be used by growers to identify areas of their orchard which are performing

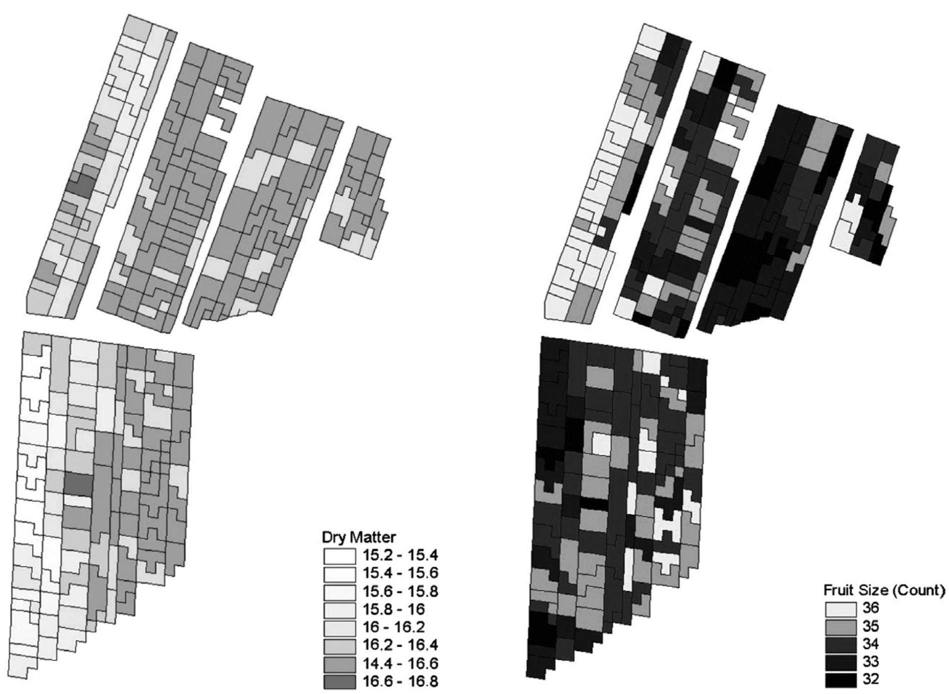

FIGURE 17.6

Typical quality maps for a kiwifruit orchard generated by traceability of the level of each bin in the orchard.

well, or underperforming. The information produced by the traceability system is very useful to the grower and can be generated at marginal cost by the packer. The system also provides a traceability dataset that can be aggregated to whatever the appropriate required level might be.

B Coolchain quality management

One of the most critical measurements that is useful in the management of quality in the postharvest system is the measurement of temperature. Tracing temperature and other environmental conditions represent traceability of activities as opposed to traceability of product. This distinction was discussed earlier. Le Blanc and Vigneault (2006) conducted an extensive review of technologies available for tracking temperature and included inventory management recording systems, such as cool store temperature monitoring, and data loggers (see also Chapter 16). These systems can collectively provide a number of inputs into a traceability system. The use of dataloggers is a simple way to directly link the net effects of a coolchain on a particular product. By using product traceability for all other product that has moved through the same coolchain (spatial and temporal) allows for the association of a coolchain history with a "lot" of product. In general this association is assumed to be other packs in a pallet, or pallets within a shipping container, truck or vessel. There is, however, considerable variation of temperature within these systems, which requires a large number of monitoring points to adequately characterize the coolchain experience.

The use of dataloggers is limiting due to the manual nature of these processes. There have been many temperature tracking pilot projects carried out in recent years into the application of RFID in process traceability and the monitoring of the ambient conditions surrounding food products along the supply chain (Emond and Uysal, 2010; Gaukler and Seifert, 2007; Amador et al., 2009). RFID systems promise many advantages for temperature monitoring and tracking. One advantage is the reduced effort required to read the dataloggers. This saves considerable time and man-hours and decreases the number of errors that can occur with manual systems. Active RFID tags can be read from significant distances and at fast speed, which favors their application in supply chain operations (Raza et al., 1999). Some models of tags can also record more than 10,000 data points at different time intervals with up to five years of continuous logging (Uysal et al., 2011a); ensuring the performance of the sensor in long-duration supply chains particularly if the tags are embedded in reusable pallets, for example.

Ruiz-Garcia et al. (2008) and Amador et al. (2009) suggest that, in order to obtain suitable accuracy, these wireless sensors should be embedded within the load to bring their readings sufficiently close to the pulp temperature of produce, as is the common practice with other conventional logging systems. Amador et al. (2009) demonstrated that ambient temperature recordings throughout a load of pineapples differed from the product core temperatures. This research highlighted one of the concerns of a limitation of probeless RFID technology (Figure 17.4), which is that there is a difference from actual product temperature readings in some of the critical points of the load, where temperature abuse is likely to occur. Uysal (2011c), Emond and Uysal (2010) and Amador et al. (2009) have demonstrated that probeless RFID temperature tags can still be appropriate if the corresponding relationship between their output and the temperature of the product located in the critical positions within a pallet or pack has been established. In many cases this relationship has to be determined for each specific packaging system for each product.

Uysal et al. (2011b) has shown that RFID temperature sensors are an ideal platform to provide information about the product temperature during the entire distribution chain. It is also a relevant underpinning technology to support decision-making tools for suppliers and retailers. By combining a full product temperature history with knowledge of likely product response to these temperatures gives members of the supply chain improved knowledge of their product (Bollen et al., 2013) or product shelf life (Lo Bello et al., 2004; Nunes et al., 2011). In time the quality predictions can be incorporated into the RFID data processing software to provide more intelligence in real-time. For example, retailer distribution centers can automatically retrieve the temperature history of each shipment entering their facilities, while at the same time obtaining an accurate estimate of the remaining shelf life of the produce received. It also provides a way to focus on and target the loads that have been identified as "problematic" rather than rely on random inspections, which can be very time consuming. This also opens the opportunity for distributors to implement more sophisticated product management practices such as "First Expires First Out" (FEFO). Decisions can also be made with regard to a product's distribution potential: produce with longer shelf lives will be sent to distant locations or remain in storage while produce with shorter shelf life will either be destined to nearby stores or discarded, according to the amount of shelf life it still possesses.

In an early demonstration of this new paradigm, Hertog et al. (2008) describes how quality change models can be integrated with full chain temperature traceability systems to allow the prediction of likely quality outcomes at different points along the supply chain. This has been extended further by the European PASTEUR project (Hertog et al., 2013), which demonstrated the use of quality prediction for tomatoes, based on temperatures measured on the side of crates, moving through entire supply chains. Nunes (2008) has also demonstrated that shelf life modeling combined with RFID temperature tracking can accurately predict the residual shelf life of strawberries based on quality limiting factors such as color, firmness, taste or decay.

RFID monitoring systems at a commercial level are now reaching suitable maturity to cover entire global supply chains. Bollen et al. (2013) discuss the issues associated with monitoring 20,000 RFID tags annually in a kiwifruit export chain. The early success of this project has been to enable real-time alerts for pallets at risk due to poor temperature management and the establishment of temperature based benchmarking tools to compare performance. In addition the technology provides a secondary ID tracking and traceability system to link parts of the chain where other tracking systems fail or are not available.

An alternate approach to the detailed monitoring of product temperatures, suggested by Bollen et al. (2003), uses the product tracking system to accurately locate product throughout the postharvest system, and then uses local environmental measurements along with heat transfer modeling to predict product temperatures. The paper discussed an example of apples which were harvested over several days, but packed as a single lot at the packinghouse. The fruit bins were identified in the orchard and a time of harvest recorded. The bins were then traced to the packinghouse and all movements recorded, along with the local environmental conditions (mainly temperature). As fruit was packed the temperature−time history of each bin was calculated and, then, this information associated with the fruit in the final packs. The time−temperature histories were aggregated for each pallet. Some pallets had all fruit with exposure of less than 45 degree-days, whereas other pallets had most fruit in the 45- to 75-degree-day range. Other pallets were identified that had fruit with a very large range of temperature exposure from 15 to 75 degree-days. The different temperature exposures can have marked effects on apple firmness and the traceability system can, therefore, also serve as a method for identifying pallets, which have different potential quality outcomes, and improving postharvest systems responses based on this knowledge.

V Conclusions

The demand for traceability in the postharvest system is expected to continue to grow. This will partially be driven by market demands for better visibility and assurance of food safety as well as a technology push from product identification and information system providers. As the sophistication of the systems increases, the need to be able to trace product in ever smaller units will become important. With reducing size of the identifiable units (IUs), the ability to link two small sized units eventually becomes a statistical problem as it is no longer possible to describe the exact membership of each output unit based on some known input unit. The ability to trace product at this lower level opens up opportunities to add new tools to the information system.

The traceability system is a subset of a postharvest information system and is one of the main activities, which have a responsibility shared across the entire supply chain. Traceability requirements will continue to drive better integration of individual information systems within the supply chain and these will, in turn, lead to better vertical integration of individual supply chains.

Bibliography

Amador, C., Emond, J.-P., Nunes, M.C., 2009. Application of RFID technologies in the temperature mapping of the pineapple supply chain. Sens. Instrum. Food Qual. Saf. 3 (1), 26–33.

Ben-Tzur, I., Ward, G., 2010. Systems approach to reducing waste in the fresh produce supply chain. Acta Hort. 880, 125–136.

Bodria, L., 2002. System integration and certification. The market demand for clarity and transparency – part 2. Presented Club Bologna Meeting, 16 November 2002, Bologna, Italy. Agric. Eng. Int. CIGR Ejournal 4, 1–6.

Bollen, A.F., 2004. Traceability in fresh produce supply chains. In: Proceedings of the International Conference – Postharvest Unlimited Downunder 2004. Acta Hort., 687, pp. 279–288.

Bollen, A.F., Praat, J.-P., Garden, G.M., 2003. Information management for apple quality in the supply chain. In: Quality in Chains – An Integrated View on Fruit and Vegetable Quality. Third International and Multidisciplinary Conference, Wageningen, 6–9 July 2003.

Bollen, A.F., Kissling, C., Emond, J.-P., Brecht, J., McAneney, J., Leake, J., et al. 2004. Sea and Air Container Track and Trace Technologies: Analysis and Case Studies – Final Report. Transportation Working Group of APEC. Project No. TPT01/2002T.

Bollen, A.F., Riden, C.P., Opara, L.U., 2006. Traceability in postharvest quality management. Int. J. Postharvest Technol. Innov. 1 (1), 93–105.

Bollen, A.F., Riden, C.P., Cox, N.R., 2007. Agricultural supply system traceability – part I: role of packhouses and effects of fruit mixing. Biosyst. Eng. 98 (4), 391–400.

Bollen, A.F., Tanner, D.J., Soon, C.-B., East, A.R., Heyes, J.A., Dagar, A., et al., 2013. Wireless temperature monitoring system in a global kiwifruit supply chain. In: VI International Postharvest Conference, Managing Quality in Chains (MQUIC 2013). Acta Hort, in press.

Demmel, M.R., Ehri, M., Rothmund, M., Spangler, A., Auernhammer, H., 2002. Automated Process Data Acquisition with GPS and Standardized Communication – The Basis for Agricultural Production Traceability. 2002 ASAE Annual Meeting Paper Number 023013.

Emond, J-P., Uysal, I., 2010. Food Traceability and Product Recalls: Smart and Dynamic Shelf Life Estimation Using RFID. Auto Identification and Mobile Information Technologies Expo, Chicago.

EU (European Union), 2002. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the european food safety authority and laying down procedures in matters of food safety. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002R0178:EN:HTML> (accessed 30.10.13).

EU (European Union), 2006. GMO Notifications/Authorisations at EU level. <http://www.biosafety.be/gmcropff/EN/TP/AuthorisationsEU.html> (accessed 30.10.13).

Gaukler, G.M., Seifert, R.W., 2007. Applications of RFID in Supply Chains. Trends in Supply Chain Design and Management. Springer, London, pp. 29–48.

Giacomini, C., Mancini, M.C., Mora, C., 2001. Case Study on the Traceability Systems in the Fruit and Vegetable Sector. University of Florida, <http://conference.ifas.ufl.edu/ifsa/papers/e/a17.doc> (accessed 18.06.07).

Golan, E., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K., Price, G., 2004. Traceability in the U.S. Food Supply: Economic Theory and Industry Studies. US Department of Agriculture, Economic Research Service Report No. 830.

GS1, 2007. Barcode types. <http://www.gs1.org/productssolutions/barcodes/technical/bar_code_types.html> (accessed 24.09.07).

Hertog, M.L.A.T.M., Yudhakusuma, R.F., Snoekx, P., De Baerdemaeker, J., Nicolaï, B.M., 2008. Smart tracebility systems to satisfy consumers expectations: International Symposium on the Role of Postharvest Technology in the Globalisation of Horticulture. Acta Hort 768, pp. 407–415.

Hertog, M.L.A.T.M., Vollebregt, M., Unzueta, I., Hoofman, R.J.O.M., Lammertyn, J., 2013. From sensor output to improved product quality. In: VI International Postharvest Conference, Managing Quality in Chains (MQUIC 2013). Acta Hort, in press.

Hobbs, J.E., 2004. Information asymmetry and the role of traceability systems. Agribusiness 20 (4), 397–415.

Hobbs, J.E., Young, L.M., 1999. Increasing Vertical Linkages in Agrifood Supply Chains: A Conceptual Model and Some Preliminary Evidence. Research Discussion paper No. 35. Joint meeting of Canadian Agricultural Economics Society and Western Agricultural Economics Society, Fargo, N. Dakota, July 10–14 1999.

Hoownicki, R., 2004. Prospects of precision agriculture in plant protection. Prog. Plant Prot. 44 (1), 104–113.

ISO (International Standards Organization), 2005. ISO 9000:2005 – Quality Management Systems – Fundamentals and Vocabulary. International Standards Association.

Kim, H.M., Fox, M.S., Gruninger, M., 1995. Ontology of quality for enterprise modelling. In: Proceedings of the IEEE International Workshops Enabling Technologies: Infrastructure for Collaborative Enterprises WET-ICE, pp. 105–116.

Le Blanc, D.I., Vigneault, C., 2006. Traceability of environmental conditions for maintaining horticulture produce quality. Stewart Postharvest Rev. 2 (3), 4.1–4.10.

Lo Bello, L., Mirabella, O., Torrisi, N., 2004. Modeling and evaluating traceability systems in food manufacturing chains. In: Proceedings Thirteenth IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises, WET-ICE'04, pp. 173–179.

McBratney, A., Whelan, B., Ancev, T., 2005a. Evaluating the Benefits from Precision Agriculture: the Economics of Meeting Traceability Requirements and Environmental Targets. Precision Agriculture '05. Paper Presented at the Fifth European Conference on Precision Agriculture, Uppsala, Sweden.

McBratney, A., Whelan, B., Ancev, T., Bouma, J., 2005b. Future directions of precision agriculture. Precis. Agric. 6, 7–23.

Moe, T., 1998. Perspectives on traceability in food manufacture. Trends Food Sci. Technol. 9, 211–214.

Nilsson, H., Tuncer, B., Thidell, A., 2004. The use of eco-labelling like initiatives on food products to promote quality assurance – is there enough credibility? J. Clean. Prod. 12, 517–526.

Nunes, M.C., 2008. Impact of environmental conditions on fruit and vegetable quality. Stewart Postharvest Rev. 4 (2), 1–14.

Nunes, M.C., Delgado, A., Emond, J.-P., 2011. Quality curves for green bell pepper (*Capsicum annuum* L) stored at low and recommended relative humidity levels.

In: Poster Presentation at the IV Postharvest Unlimited Conference, Leavenworth, WA, USA, May 23–26, 2011.

Opara, L.U., 2003. Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects. J. Food Agric. Environ. 1, 101–106.

Pettitt, R.G., 2001. Traceability in the food animal industry and supermarket chains. Rev. Sci. Tech. 20 (2), 584–597.

Pierce, F.J., Cavalieri, R.P., 2002. Globalization and traceability of agricultural production: the role of Mechanization. Presented at the Club of Bologna Meeting, 16 November 2002, Bologna, Italy. Agric. Eng. Int. CIGR Ejournal 4, 1–16.

Praat, J.-P., Bollen, F., Gillgren, D., Taylor, J., Mowat, A., Amos, N., 2003. Using supply chain information: mapping pipfruit and kiwfruit quality. In: Quality in Chains – An Integrated View on Fruit and Vegetable Quality. Third International and Multidisciplinary Conference. Wageningen, 6–9 July 2003.

Raza, N., Bradshaw, N., Hague, M., 1999. Applications of RFID technology. In: IEE Colloquium on RFID Technology, 10(1), 1–5.

Riden, C.P., Bollen, A.F., 2007. Agricultural supply system traceability – part II: implications of packhouse processing transformations. Biosyst. Eng. 98 (4), 401–410.

Ruiz-Garcia, L., Barreiro, P., Robla, J.I., 2008. Performance of ZigBee-Based wireless sensor nodes for real-time monitoring of fruit logistics. J. Food Eng. 87 (3), 405–415.

Sarig, Y., 2003. Traceability of food products. Presented at the Club of Bologna Meeting, 16 November 2002, Bologna, Italy. Agric. Eng. Int. CIGR Ejournal 4, 1–17.

SGS, 2013. EU-wide Meat Testing for Horsemeat. SGS Food Safety Bulletin. <http://www.sgs.com/en/Our-Company/News-and-Media-Center/News-and-Press-Releases/2013/02/EU-Wide-Meat-Testing-Proposed-For-Horse-DNA.aspx> (accessed 30.10.13).

Tesco, 2013. Tesco and Society Report. <http://www.tescoplc.com/index.asp?pageid=81> (accessed 30.10.13).

The Guardian, 2013. How the horsemeat scandal unfolded – timeline. <http://www.theguardian.com/world/2013/feb/08/how-horsemeat-scandal-unfolded-timeline> (accessed 30.10.13).

Uysal, I. Emond, J.-P., Bennett, G., 2011a. Tag testing methodology for RFID enabled temperature tracking and shelf life estimation. In: IEEE International Conference on RFID Technology and Applications, 2011.

Uysal, I. Emond, J.-P., Bennett, G., 2011b. A computationally efficient and scalable shelf life estimation model for wireless temperature sensors in the supply chain. In: International Conference on Modeling & Applied Simulation, 2011.

Uysal, I. Emond, J.-P., Nunes, M.C., Brecht, J.K., 2011c. Remote environmental monitoring and diagnostics in the perishables Supply Chain. US Army Contract W911QY-08-C0135 Final Project Report, 2011.

Wal-Mart, 2013. Making Sustainability Sustainable: Lessons We've Learned <http://news.walmart.com/executive-viewpoints/> (accessed 30.10.13).

Ward, R., Bailey, D.V., Jensen, R., 2005. An American BSE crisis: has it affected the value of traceability and country-of-origin certifications for US and Canadian beef?. Int. Food Agribus. Manag. Rev. 8 (2), 92–114.

Zaske, J., 2003. Mechanization and traceability of agricultural production: a challenge for the future. System integration and certification. The market demand for clarity and transparency – part 1. Presented at the Club of Bologna meeting, 16 November 2002, Bologna, Italy. Agric. Eng. Int. CIGR Ejournal 5, 1–15.

CHAPTER

18 Fruits and Vegetables in International Trade: Forensic Aspects of Cargo Claims

Anna L. Snowdon

University of Cambridge, Wolfson College, Cambridge, UK

Introduction

Horticultural exports constitute the mainstay of the economy in many countries, including both developed and developing nations. High-value commodities may be despatched by air (Pelletier, 2010; Thompson et al., 2004; World Bank, 2009), in the cargo holds of passenger planes, examples being green beans from Kenya and baby sweetcorn from Thailand, both of which are popular items in European supermarkets. For larger consignments, dedicated cargo planes may be used, and this is customary for Israeli products such as tomatoes, peppers and exotic fruits. Globally, however, by far the greatest proportion of fresh produce is carried by land and sea (LeBlanc and Hui, 2005; Tanner and Smale, 2005; Thompson et al., 2002; Vigneault et al., 2009), and it is maritime transport which is the principal focus of the present chapter.

Transport of perishables is more complicated than storage, because of the multiple links in the chain and the many parties involved. A typical example might be a cargo of Ecuadorian bananas, insured by a German underwriter and carried in a Greek ship. The ship might have been built in Japan, registered in the Bahamas, chartered by an Italian fruit trader and be discharging its cargo in Algiers. The vessel would probably be insured by one of the 13 main P&I (Protection and Indemnity) Clubs, nearly all of which have offices in London (a great center for commercial shipping and insurance), Piraeus (Greece, with a strong maritime tradition) and the Far East, with its burgeoning trade.

In earlier years, commodities such as potatoes, onions, garlic and citrus were often shipped in a ventilated space at ambient temperature, but currently the majority of fruit and vegetable consignments are carried under refrigeration. Annual worldwide trade in refrigerated fresh fruits and vegetables was 69 million tonnes in 2002, 97 million tonnes in 2012, and is forecast to be about 110 million tonnes in 2017 (Drewry, 2013). A little over half of the total is sea-borne, though

Postharvest Handling.

with great variation between commodities; for example, only about 20% of tomato cargoes are carried by sea, compared with 99% of exported bananas.

Refrigerated maritime transport

The type of ship traditionally used in this trade is known as a specialized reefer (refrigerated) vessel, in order to distinguish it from freezer vessels used for fish. It typically has either four or five hatch openings, each leading to three, four, or five decks. Each deck may be independently refrigerated, by delivery of cool air beneath perforated deck gratings, or the chambers may be grouped in pairs sharing a common fan system and supply of re-circulated cool air, and a common fresh air ventilation system. Each deck is usually 2.2 m in height, designed to accommodate the standard pallet-load of produce, leaving a few centimetres of head space above the stow (stored product) to allow the passage of return air. Although palletloads are generally built up to 2.1 m, the pallets themselves come in several different sizes, depending on the trade and country involved (ISO, 2009). Deck area is customarily defined in square metres, and stowage factor is expressed as square meters per pallet. Hold capacities are still given in cubic feet; not all cargoes are palletized, and stowage factor can also be expressed as cubic feet per tonne or (for the standard 20 kg banana box) cubic feet per box. The total hold capacities of these vessels are between 100,000 and 600,000 cubic feet, the average size being about 450,000 cubic feet, and they are capable of carrying about 4,000 tonnes of cargo.

As of 2013, the six biggest operators of specialized reefers are Seatrade of Antwerp, Greensea also of Antwerp, ART/Frigoship of Hamburg, Star Reefers of London, NYKCool of Stockholm, and Baltic Reefers of St Petersburg. Between them, the "Super Six" currently operate 233 vessels, some of which are on long-term charter from Greek owners (Drewry, 2013). During the last decade, with the scrapping of aging ships and the limited new builds, there has been a notable reduction in the specialized reefer fleet, which in 2013 numbered about 600 with capacities over 100,000 cubic feet, in comparison with 856 such vessels in 2002. The number is forecast to fall further in the coming decade.

The reason for such a decline in specialized reefer ships is the seemingly inexorable rise in the proportion of perishable cargo carried by 40 foot reefer containers. These are intermodal, able to be transported by road, by rail and by sea, either in purpose-built containerships or on the weather deck of conventional vessels (Alders, 1995; Sinclair, 1999). Depending on pallet dimensions, each can accommodate 20–28 pallets in a range of patterns with varying degrees of unused space. These days all are integral reefer containers, meaning that each container is equipped with its own refrigeration unit, to which electrical power is supplied at sea by the ship and on land by mains power at the port container terminal. In case of a lengthy road journey between packing station and loadport, or between discharge port and final destination, power may be supplied by a clip-on diesel generator set (Maheshwar, 2008).

There are four main manufacturers of reefer units (Carrier Transicold, Thermoking, Daikin, and Maersk Container Industry) and numerous container operators, of which the largest are Maersk headquartered in Denmark, MSC (Mediterranean Shipping Company) based in Switzerland, and CMA-CGM of France. Since the earliest containers were 20 foot, the capacity of a container ship is usually measured in TEU (Twenty Foot Equivalent Units) rather than FEU (Forty Foot Equivalent Units); currently the largest container ships are a quarter of a mile long, with a capacity of over 18,000 TEU, including about 2,000 reefer plugs.

There are a limited number of deepwater ports with the infrastructure to cope with such large vessels, and so container carriage is typified by trans-shipment from one vessel to another at these hub ports, with smaller "feeder" vessels being required for access to more modest ports. Again taking the example of an Ecuadorian banana shipment, the containers might be stuffed (*sic*) (filled) at the inland packing station, despatched by road to the loadport of Guayaquil, connected up to power at the container terminal, subsequently loaded on board a feeder vessel for the brief voyage to Panama, off-loaded at the Pacific port of Balboa, carried by rail across the isthmus (cheaper than the cost of a Canal transit for a large container ship), connected up to power at the Atlantic port of Cristóbal to await trans-shipment on to an ocean carrier, trans-shipped once more at the Spanish port of Algeciras for final carriage on feeder vessels to various ports around the Mediterranean.

Despite the frequent necessity for trans-shipment, there are obvious advantages in containerization, and fully 70% of reefer cargo (which includes meat, poultry and dairy products as well as fruits and vegetables) is currently carried in containers, predicted to rise to 78% by 2017 (Drewry, 2013). In the South African export trade, the proportion of fruit shipped in containers was 30% of the total in 2000, but by 2011 it had risen to 90%, leaving only 10% to be exported in reefer vessels (Dodd, 2013). However, on a global scale it is considered that specialized reefer ships will continue to play a significant role, especially in the banana trade, which involves year-round shipments of large quantities of cargo, and which benefits from direct services and hence shorter transit times than is possible with containers (Drewry, 2013).

For certain commodities, a modified atmosphere (MA) or controlled atmosphere (CA) is a valuable supplement to refrigeration (Kader, 2002; Lawton, 2007). Benefits include reduced respiration rate, reduced ethylene production, and reduced ethylene sensitivity, with the result that ripening of fruits is postponed, and senescence in vegetables is delayed (Thompson, 2010; Yahia, 2009). Furthermore, physiological disorders may be alleviated (e.g., chilling injury in some mango cultivars), and disease development may be suppressed (e.g., fungal rots of blueberries). In the early 1990s, to gain an advantage in the banana trade, the fruit company Chiquita equipped all its own reefer ships with the means of providing a controlled atmosphere in the holds, and also started shipping bananas in controlled atmosphere reefer containers (Roche, 1998). Other companies followed suit, and currently a substantial proportion of bananas in international trade is carried under CA, as also are other commodities such as avocados, mangoes, apples, kiwifruit and stone fruit (Thompson, 2010). Modified atmosphere packaging (MAP) is a valuable alternative for a range of commodities (Varriano-Marston, 2010; Yahia, 2009). The patented Banavac bag (Badran, 1969) is widely used for bananas destined for long voyages (3−5 weeks), in ships and containers which are not equipped to provide CA.

The container companies have promoted various technologies, including both hardware and software innovations, with the aim of saving energy while safeguarding the cargo, improving performance, and thereby reducing environmental impact. There are various ways of controlling the amount of fresh air ventilation in a refrigerated container, and each container company has its own design of automated vent management. It has also proved feasible to run the refrigeration machinery intermittently without jeopardizing the cargo (Lukasse et al., 2013), the QUEST system (QUality and Energy in Storage and Transport) having been developed through collaboration between Wageningen UR Food & Biobased Research, Maersk Line and Carrier Transicold.

Throughout the transit period, in all reefer containers, there is automatic recording of set-point temperature, delivery air temperature (often called supply air temperature), return air temperature and relative humidity, as well as details of the mode of operation of the reefer machinery (Maheshwar, 2008). This information may be downloaded electronically at the end of the voyage, or at any convenient time during the ensuing two years.

Clearly it is also valuable to be able to monitor conditions inside the container whilst the journey is in progress (Jedermann et al., 2009, 2013; LeBlanc and Vigneault, 2006; Ruiz-Garcia et al., 2007). Implementation of such technologies would afford a means of alerting the carrier or cargo owner to potential problems which might thereby be mitigated; furthermore, information gathered could be used to minimize losses by marketing on the principle of FEFO (First Expired, First Out). Fresh fruits and vegetables are characterized by a high degree of inherent variability between batches of the same product, and prediction of storage life of individual batches can be of great value (East et al., 2013). Traceability (Doyon and Lagimonière, 2006; Serem, 2011; Toussaint and Vigneault, 2006) is essential firstly for the health and safety of consumers, in the event of contaminated produce (Lund and Snowdon, 2000), and, in the present context, it can also provide vital evidence pointing towards the cause or causes of deterioration in a cargo during shipment.

III Cargo claims

Whatever the method of carriage, if a consignment is discharged in poor condition, cargo interests (perhaps including the cargo underwriter) may lodge a claim against the carrier (ship owner or container operator). The carrier will normally turn to his P&I Club for assistance in defending the claim (Crane, 2007b). Each party should have appointed an independent surveyor to assess the damage at the time of discharge and assign a cause. Specialists may also be instructed, with a view to obtaining further independent expert opinion.

The strategy is to identify the *pattern of damage*, in order to see whether it is related to pre-shipment factors (Kader, 2013; Manganaris et al., 2008; Valero and Serrano, 2010) or carriage factors (Tanner and Amos, 2003; Tanner and Smale, 2005) or both (Oke et al., 2013; Snowdon, 1994, 2007).

Pre-shipment factors include:

- crop husbandry in relation to disease control (Castelan et al., 2013; Johnson et al., 2013; Snowdon, 1990, 1991);
- weather during the growing season and at harvest (Paliyath et al., 2009; Rees et al., 2012),
- maturity of the crop at harvest (Arpaia et al., 2010; Tchango et al., 1999; Mitra et al., 2011; Saeed et al., 2007);
- handling techniques during and after harvest (de Haan, 2008; Kader, 2013; Michaelides and Manganaris, 2009; Vicente et al., 2005);
- postharvest treatments (Siddiq et al., 2012; Singh et al., 2013; Streif et al., 2010; Yahia, 2011);
- packaging techniques (Delele et al., 2013; Macnish et al., 2012; Pathare et al., 2012; Yahia, 2009);
- lapse of time between harvest and establishment of cooling (de Haan, 2008; Thompson et al., 2008; Yahia, 2010); and
- the appropriateness or otherwise of the shipper's (exporter's) carriage instructions (Alders, 1995; Crane, 2007b; Snowdon, 2010).

Carriage factors include:

- interpretation and application of the shipper's carriage instructions (Punt and Huysamer, 2005; Reid and Serek, 1999),
- duration of the voyage (Snowdon, 2007),
- maintenance or otherwise of the cool chain (CCQI, 2009; Maheshwar and Chanakwa, 2006; Yahia, 2010), and
- stowage (Sinclair, 1999; Thompson et al., 2000).

With regard to stowage, in a conventional vessel responsibility lies with the ship owner, or sometimes with a charterer, depending on the contract of carriage (Alders, 1995; Crane, 2007b). In container carriage, it is the shipper who is responsible for stowage of his goods in the container; the container operating company simply receives the closed box and applies the requested temperature and ventilation parameters (Heap and Marshall, 2003; Maheshwar, 2008).

IV Legal procedure

"Forensic" means "pertaining to the law" and, unless claims can be settled amicably, each party appoints a law firm. The Bill of Lading (signed by the ship's Master as receipt for the cargo) provides the basis for most shipping contracts, which are generally governed by the Hague Rules or Hague-Visby Rules for the

Carriage of Goods by Sea (Alders, 1995; Crane, 2007b; Reynolds, 1992). In English jurisdiction, solicitors for the claimant(s) draw up Particulars of Claim, alleging that the clean Bill of Lading (without remarks) demonstrates that the cargo was "loaded in apparent good order and condition" and, since part of it outturned in poor condition, the carrier must be responsible for the loss and should therefore pay the requested sum, with interest. Solicitors for the defendant carrier then draw up a Defence, maintaining that the vessel's personnel exercised due diligence in carrying the cargo in the required manner, and pointing to Article IV of the Rules which states that the carrier shall not be responsible for "loss or damage arising from inherent defect, quality, or vice of the goods" (Crane, 2007b).

Each party makes a request for disclosure of documents which may illuminate the history of the consignment under dispute. Claimants and their lawyers are sometimes under the illusion that a Phytosanitary Certificate is sufficient proof of "fitness to load", unaware that phytosanitary inspection is designed to prevent the movement of quarantine organisms rather than to provide a statement of suitability to withstand the proposed voyage. More appropriate documents would include details of harvest dates, harvest maturity, postharvest treatments, dates of packing, code numbers of packing stations, dates and times of despatch to the loadport and loading in each deck, dates and locations of stuffing of containers, and inspections by Quality Control personnel in the exporting country. The shipper may also have placed independent temperature recorders on or in the stow at the time of stuffing, and retrieval of such records will provide an indication of the cargo environment during the voyage.

The carrier's lawyers would be expected to disclose Bills of Lading, Cargo Manifest, and shipper's Carriage Instructions. For a conventional vessel, relevant documents would include Vessel Particulars, General Arrangement, Hold Capacities, Stowage Plan, Statements of Fact at loadport(s) and discharge port(s), and a copy of the refrigeration log and deck log. For container shipments, historical tracking and tracing information is sometimes available on the container operator's website, and this can be used in conjunction with temperature data downloaded in electronic form from each container, either at the time of survey or subsequently.

In the event of a large cargo claim it is usual for each party (generally cargo owner as Claimant and carrier as Defendant) to appoint two experts, one with a knowledge of fruit pathology and the other with expertise in marine engineering. It is advantageous if they are instructed in time to attend the discharge and collect evidence for themselves, working in conjunction with local marine surveyors. Frequently, however, experts are appointed by lawyers at a later stage and asked to analyze contemporary documents. In English jurisdiction, experts are required to write an unbiased report, acknowledging that their duty is to assist the court and that this duty overrides any obligation to the client; they must never assume the role of an advocate (Cresswell, 1993; Civil Procedure Rules, 2013).

Expert reports are exchanged between the parties on a given date. Opposing experts meet (in person or else by telephone) to discuss points of agreement and disagreement, and issue a joint statement; supplementary reports may also be exchanged. At this stage Claimant and Defendant often reach an out of court settlement, but otherwise the case may be heard before a High Court judge (whose judgment will be published) or alternatively before an Arbitration Tribunal (whose decision will remain confidential), according to the original contract of carriage between the parties (Crane, 2007a, b). Each side's case will have been prepared by a solicitor belonging to a law firm, and each firm then appoints a barrister (self-employed in "chambers") to act as advocate for that party's view of the case. Witnesses of fact give evidence in person or by way of a witness statement, and expert witnesses are cross-examined by the opposing barrister.

With a view to saving time and costs, it has become more common in recent years to attempt mediation, the principal form of Alternative Dispute Resolution (ADR) (Kelbie, 2008). Mediation involves the use of a neutral third party as facilitator, but if agreement cannot be reached then the parties resort to arbitration or litigation (Crane, 2007a). In the United States, ADR proceeds in a similar fashion. In the event of litigation, however, American jurisdiction requires that, following the exchange of expert reports, expert witnesses make an out-of-court deposition before the opposing attorney (Federal Rules of Civil Procedure, 2010). This is an oral testimony which is taken down by a stenographer, and forms part of the "discovery" process whereby evidence is assembled. If a settlement cannot be reached then the case goes to trial and the witnesses appear before a judge. In both countries a party may occasionally contest the judge's decision by lodging an appeal; there are fewer grounds available for appealing against an arbitration decision (Crane, 2007a).

V Case study

An illustrative example (of a small case which would have been more appropriately dealt with by mediation) involved two containerloads of South African clementines (*Citrus reticulata* Blanco, cv. "Nules") which arrived in poor condition in Rotterdam. They had originally formed part of a consignment of seven containerloads of citrus, of which four comprised oranges and lemons and three comprised clementines. Owing to a serious labor strike in South African ports, there was a hiatus in cargo shipments and three of the containers (two, here called A and B, with clementines and one with oranges and lemons) had been "short-shipped", i.e., had been shut out from the intended vessel and loaded on the next one. The total time between stuffing and unstuffing had thereby been extended from three to four weeks.

The Claimants (cargo interests) asserted that the cargo was in good order and condition upon receipt by the carrier, and that the damaged arrival condition of the clementines resulted from the delay in delivery and/or the Defendant's failure to take reasonable care of the cargo. The Defendant (carrier) pleaded that the hiatus arose because of the protracted dock strike, and that in any case the observed damage to the clementines resulted from "inherent vice" in the fruit, which was not in actual good order and condition at the time of stuffing.

The importer had called in a surveyor to assess the damaged cargo on behalf of the cargo underwriter (insurer); the carrier was alerted but declined to send a counter-surveyor. Examination showed that some of the clementines still had a greenish tinge rather than being fully colored, and that a few were suffering from either rind breakdown or puffiness. However, the surveyor reported that the main problem was decay, described as blister rot, blue-green mold rot, and stem-end rot. He noted that fruits of a certain size from two particular growers had an especially high incidence of rots. Though he did not distinguish between the two container-loads, it could be deduced from the Packing Lists that all the fruit from those two growers had been carried in Container A.

Temperature downloads showed that Container A had experienced three off-power periods, lasting 4, 6 and 3 h, respectively, corresponding to the abortive sending forward for loading, the actual loading on board ship a week later, and the discharge from the vessel on arrival in Rotterdam. Such breaks in the cool chain are unexceptional, and the requested delivery air temperature of 3.5°C had otherwise been well maintained. The rate at which cargo pulp temperatures rise during an off-power period depends on the respiration rate of the commodity, the pattern of stowage, the external ambient conditions, and the insulation characteristics of the container. Clementines have a low respiration rate, and furthermore the first two off-power periods were during night-time hours, when the external ambient temperature in the Cape Town area was between 4°C and 14°C. The clementines would have been pre-cooled, in contrast to oranges and lemons which are sometimes "hot-stuffed".

Container B had experienced off-power periods of 10, 2 and 4 h, and had operated in alarm mode for the whole of the first week, as the delivery air temperature was between 2°C and 3°C instead of 3.5°C. After manual intervention at the loadport container terminal, the correct delivery air temperature was eventually established. The fact that the relative humidity in this container was consistently at or close to 100% suggested that fresh air ventilation had been excessive, although there was no documentation to indicate what degree of vent opening had been requested by the exporter or what setting had been used by the container operator. Despite the non-ideal carriage conditions, when the cargo was surveyed on discharge there was no indication of chilling injury, and the batches of fruit from this container reportedly showed a lower incidence of decay than the batches from Container A.

Blister rot is an early stage of green and blue mold rots caused by *Penicillium digitatum* Sacc. and *P. italicum* Wehmer, respectively. One of the survey photographs suggested the possibility that sour rot might also have been involved; this type of decay is a soft wet rot caused by *Geotrichum citri-aurantii* (Ferraris) Butler, otherwise known as *Geotrichum candidum*, and is one of the main post-harvest problems of citrus in South Africa (Lesar, 2007). Stem-end rot of citrus can be caused by any of several fungi, but the predominant causal organism in South Africa is *Lasiodiplodia theobromae* (Pat.) Griffon & Maubl. which causes diplodia rot. From the survey report the only certainty was penicillium rot, from which it was possible to state that some of the clementines must have sustained mechanical injuries and that postharvest fungicide treatment had been ineffective in preventing wound infection (Erasmus et al., 2011).

The fact that some fruits were greenish and some were deep orange in color suggested that they had been de-greened with ethylene to promote an attractive peel color. A disadvantage of ethylene treatment of citrus fruits is that the stem buttons may become moribund and susceptible to stem-end rot (Arpaia et al., 2010).

Rind breakdown is a limiting factor in the storage life of South African "Nules" clementines, typically appearing about 3−5 weeks after harvest. It is caused by a release of oil from collapsed oil glands in the peel, but rather than resulting from physical damage it seems to be a senescence-related physiological process; incidence increases with use of ethylene de-greening, delay in cooling, and duration of storage (Cronje et al., 2011).

Puffiness is a condition in which an air space develops between peel and pulp, making the fruit liable to split when handled. While puffiness may sometimes develop in fruit still on the tree, this disorder also occurs in storage (Burdon et al., 2007). Advancing maturity, vigor of the tree, and weather (particularly irregular water supply) may all be involved. Japanese research shows that puffiness has a dual origin: shrinking, often to near disappearance, of the albedo from undetermined causes, and swelling of the flavedo from external moisture. Preharvest sprays of growth regulators have provided significant reduction in puffiness, but at the expense of poorer fruit color (Kuraoka et al., 1977). On the one hand, therefore, it has been concluded that this disorder is a function of senescence. On the other hand, researchers have related puffiness to high humidity in storage.

It may be seen from the above that the arrival condition of the clementines had been determined by a multitude of interplaying factors, both pre-shipment and shipboard. Claimants had failed to provide pre-shipment details, but packing codes on the boxes (only a few of which were legible in the photographs) indicated that at least some of the fruit had been harvested and packed more than two weeks before being stowed in the containers. Together with the delay in shipment, this meant that the total postharvest period was approaching the normal storage life of the fruit, leaving it with very little shelf life on return to ambient temperature for marketing. It would have been useful to have had access to out-turn data for the third containerload of clementines which had been shipped on the earlier vessel, as this would have provided an instructive comparison. The fact that there was no claim on the promptly delivered load does not necessarily mean that the out-turn was perfect.

The service provided by the carrier clearly left much to be desired, and the delay would have exacerbated the poor condition of the fruit. With regard to the "short-shipping", however, the judge ruled that, according to the contract of carriage, the carrier had not undertaken to ship the goods on a particular vessel, and was constrained by the situation of the protracted dock strike. The judge found fault with both parties for failing to produce all the relevant contemporary documents (three years having passed since the event), but concluded that the available evidence showed that some of the clementines had been unfit for the proposed voyage. Had they arrived in Rotterdam a week earlier, there would already have been signs of decay, which would have continued to proliferate during marketing.

It is conceivable that in the above case the legal costs exceeded the value of the claim, and most cargo losses reaching court are much larger than this one. There is often a dearth of documentation, however, in spite of the legal requirement for traceability (GS1, 2010). Surveyors can only examine a portion of the cargo, and if patterns of damage are to be ascertained, the documents which are needed are the consignee's Quality Control inspection reports, since each pallet-load is assigned a unique code, which incorporates information as to packing station, pack date, and location in the ship or container.

The most important perishable cargo is bananas. Bananas are shipped hard green, at a carriage temperature of 13.3°C (56°F) and must remain pre-climacteric until they reach the ripening room in the country of destination. The most common cause of loss is premature ripening during the voyage (Snowdon, 2010), and the following is another case study.

The cargo (both underdeck and in reefer containers on deck) comprised Honduran and Guatemalan fruit, undergoing a month-long voyage culminating in discharge in Syria (port of Tartous). The crew had smelled ripening fruit during the Atlantic crossing, and the ship owner suggested boarding the vessel at Gibraltar to investigate the causes and attend the discharge. In Tartous a detailed joint survey took place, by consultants and numerous local surveyors (who brought in assistants to cover the night shift), and the result was the collection of detailed information in the form of box-codes of both sound and ripened cargo discharged from each deck and each container. The cargo owner had made a claim against the vessel for minor infringement of the carriage instructions, but the data collected by the survey teams demonstrated that the ripe and over-ripe fruit had come from three specific Guatemalan packing stations and with specific pack-dates. The rest of the Guatemalan cargo was in good condition, as was all of the Honduran cargo. When faced with such evidence, the cargo owner withdrew his claim and the matter was taken no further. This demonstrates that early collaboration leads to prompt resolution of claims.

Bibliography

Alders, A.W.C., 1995. Reefer Transport and Technology. Rotterdam Marine Chartering Agents.

Arpaia, M.L., Mitcham, E., Cantwell, M., Crisosto, C., Kader, A., Reid, M., et al., 2010. Fruit Ripening and Ethylene Management. Publication No. HS9. University of California, Davis, CA, 130 pp.

Badran, A.M., 1969. Controlled Atmosphere Storage of Green Bananas. Patent No. 3,450,548. United States Patent Office, 6 pp.

Burdon, J., Lallu, N., Yearsley, C., Osman, S., Billing, D., Boldingh, H., 2007. Postharvest conditioning of Satsuma mandarins for reduction of acidity and skin puffiness. Postharvest Biol. Technol. 43, 102–114.

Castelan, F.P., Saraiva, L.A., Cordenunsi, B.R., Chillet, M., 2013. Necrotic leaf removal: an effective method to limit the green life shortening effects of Sigatoka leaf spot disease in bananas. Acta Hortic. No. 986, 145–148.

CCQI, 2009. Cool Chain Quality Indicator Standard: The Concept of Cool Chain Quality, Version 2.2. Germanischer Lloyd and Cool Chain Association, Hamburg, 177 pp.

Civil Procedure Rules, 2013. Part 35: Experts and Assessors. Ministry of Justice, UK Government, London.

Crane, P., 2007a. Arbitration v. Litigation. Second Annual Seminar on Perishable Product Transportation. Lloyds Maritime Academy, London, 10 pp.

Crane, P., 2007b. Contracts of Carriage by Sea and Cargo Claims. Second Annual Seminar on Perishable Product Transportation. Lloyds Maritime Academy, London, 23 pp.

Cresswell, J., 1993. The "Ikarian Reefer". Lloyds Law Rep. 2, 81–82.

Cronje, P.J.R., Barry, G.H., Huysamer, M., 2011. Postharvest rind breakdown of "Nules Clementine" mandarin is influenced by ethylene application, storage temperature and storage duration. Postharvest Biol. Technol. 60, 192–201.

Delele, M.A., Ngcobo, M.E.K., Getahun, S.T., Chen, L., Mellman, J., Opara, U.L., 2013. Studying airflow and heat transfer characteristics of a horticultural produce packaging system using a 3-D CFD model. part II: effect of package design. Postharvest Biol. Technol. 86, 546–555.

Dodd, M.C., 2013. Managing airflow inside reefer containers benefits produce quality. Acta Hortic. No. 1012, 1159–1166.

Doyon, G., Lagimonière, M., 2006. Traceability and quality assurance systems in food supply chains. Stewart Postharvest Rev. 2 (3), 16.

Drewry, 2013. Reefer Shipping Market 2013/14, Annual Review and Forecast. Drewry Maritime Research, London UK, 90 pp.

East, A.R., Jabbar, A., Heyes, J.A., 2013. Approaches to prediction of storage out-turn for units of fresh produce. Acta Hortic. No. 1012, 1303–1309.

Erasmus, A., Lennox, C.L., Jordaan, H., Smilanick, J.L., Lesar, K., Fourie, P.H., 2011. Imazalil residue loading and green mould control in citrus packhouses. Postharvest Biol. Technol. 62, 193–203.

Federal Rules of Civil Procedure, 2010. Rule 26: Duty to Disclose; General Provisions Governing Discovery. US Government, Washington DC, pp. 34–42.

GS1, 2010. Traceability for Fresh Fruits and Vegetables Implementation Guide. GS1, UK, London, 57 pp.

de Haan, H., 2008. BMT de Beer's Consolidated Manual on Postharvest Handling, Cooling and Storage of Fruit and Vegetables. BMT de Beer, Rotterdam.

Heap, R., Marshall, R., 2003. Ventilation effects and requirements in containerised refrigerated transport. International Congress of Refrigeration. Washington DC, Paper ICR0472, 5 pp.

ISO, 2009. Flat pallets for intercontinental materials handling – principal dimensions and tolerances. ISO Standard 6780:2003. International Organisation for Standardisation, Geneva, Switzerland, 13 pp.

Jedermann, R., Geyer, M., Praeger, U., Lang, W., 2013. Sea transport of bananas in container – parameter identification for a temperature model. J. Food Eng. 115, 330–338.

Jedermann, R., Ruiz-Garcia, L., Lang, W., 2009. Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. Comput. Electron. Agric. 65, 145–154.

Johnson, P., Malik, A.U., Malik, O.H., Campbell, J., 2013. Issues and advances in commercializing sea-freight technology of mangoes. Acta Hortic. No. 992, 75–85.

Kader, A.A. (Ed.), 2002. Postharvest Technology of Fruits and Vegetables. third ed. University of California Agriculture and Natural Resources Publication No. 3311, Oakland, California.

Kader, A.A., 2013. Postharvest technology of horticultural crops – an overview from farm to fork. Ethiopian J. Appl. Sci. Technol.1–8, Special Issue No. 1.

Kelbie, J., 2008. ADR/Mediation for recoveries. Technical Paper of the Chartered Institute of Loss Adjusters, 9 pp.

Kuraoka, T., Iwasaki, K., Ishii, T., 1977. Effect of GA_3 on puffing and levels of GA-like substances and ABA in the peel of satsuma mandarin (*Citrus unshu* Marc.). J. Am. Soc. Hortic. Sci. 102, 651–654.

Lawton, R., 2007. Understanding Controlled Atmosphere storage. 2nd Annual Seminar on Perishable Product Transportation. Lloyds Maritime Academy, London, 14 pp.

LeBlanc, D.I., Hui, K.P.C., 2005. Land transportation of fresh fruits and vegetables; an update. Stewart Postharvest Rev. 1 (1), 13.

LeBlanc, D., Vigneault, C., 2006. Traceability of environmental conditions for maintaining horticultural produce quality. Stewart Postharvest Rev. 2 (3), 10.

Lesar, K.H., 2007. The potential role of GRAS (generally regarded as safe) chemicals, alone and in combination with post-harvest fungicides, in the control of the major post-harvest citrus pathogens, *Penicillium digitatum* (citrus green mould) and *Geotrichum candidum* (sour rot). In: Bertolini P. (Ed.), Novel Approaches for the Control of Postharvest Diseases and Disorders. Proceedings of the International Congress, Bologna, Italy, 3–5 May 2007, pp. 322–326.

Lukasse, L.J.S., Baerentz, M.B., Kramer-Cuppen, J.E. de, 2013. Quest II: reduction of CO2 emissions of reefer containers. Wageningen UR Food and Biobased Research, Report, Ref. 440747, 8 pp.

Lund, B.M., Snowdon, A.L., 2000. Fresh and processed fruits. In: Lund, B.M., Baird-Parker, T.C., Gould, G.W. (Eds.), The Microbiological Safety and Quality of Food. Aspen Publishers, Gaithersburg, Maryland, pp. 738–758.

Macnish, A.J., Padda, M.S., Pupin, F., Tsouvaltzis, P.I., Deltsidis, A.I., Sims, C.A., et al., 2012. Comparison of pallet cover systems to maintain strawberry fruit quality during transport. HortTechnology 22, 493–501.

Maheshwar, C., 2008. Container Refrigeration. Witherby Publishing Group, Edinburgh.

Maheshwar, C., Chanakwa, T.S., 2006. Postharvest losses due to gaps in cold chain in India: a solution. Acta Hortic. No. 712, 777–783.

Manganaris, G.A., Vicente, A.R., Crisosto, C.H., 2008. Effect of pre-harvest and post-harvest conditions and treatments on plum fruit quality. CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 3 (9), 10.

Michaelides, T.J., Manganaris, G.A., 2009. Harvesting and handling effects on postharvest decay. Stewart Postharvest Rev. 5 (2), 7.

Mitra, S.K., Chakraborty, I., Pathak, P.K., 2011. Postharvest technology of tropical export produce: recent developments and challenges of a future free-trade world market. Acta Hortic. No. 906, 115–123.

Oke, M.O., Sobratee, N., Workneh, T.S., 2013. Integrated pre- and post-harvest management processes affecting fruit and vegetable quality. Stewart Postharvest Rev. 9 (3), 8.

Paliyath, G., Murr, D., Handa, A.K., Lurie, S. (Eds.), 2009. Postharvest Biology and Technology of Fruits, Vegetables, and Flowers. Wiley-Blackwell, Ames, Iowa.

Pathare, P.B., Opara, U.L., Vigneault, C., Delele, M.A., Al-Said, F.A., 2012. Design of packaging vents for cooling fresh horticultural produce. Food Bioprocess. Technol. 5, 2031–2045.

Pelletier, W., 2010. Air Transport of Horticultural Produce: A Thermal Analysis. Ph.D. Dissertation No. 3436418. University of Florida, 248 pp.

Punt, H., Huysamer, M., 2005. Effect of the commercial dual temperature shipping regime on pulp temperature and fruit quality in Sapphire plums, shipped in integral reefer containers. Acta Hortic. No. 687, 289–296.

Rees, D., Farrell, G., Orchard, J. (Eds.), 2012. Crop Post-Harvest: Science and Technology, vol. 3, Perishables. Wiley-Blackwell, Oxford.

Reid, M.S., Serek, M., 1999. Guide to Food Transport: Controlled Atmosphere. Mercantila Publishers, Copenhagen.

Reynolds, F., 1992. The Hague Rules, the Hague-Visby Rules, and the Hamburg Rules. Aust. New Zeal. Marit. Law J. 7, 16–34.

Roche, J., 1998. The International Banana Trade. Woodhead Publishing Ltd, Cambridge UK.

Ruiz-Garcia, L., Barreiro, P., Rodriguez-Bermejo, J., Robla, J.I., 2007. Review. Monitoring the intermodal, refrigerated transport of fruit using sensor networks. Spanish J. Agr. Res. 5, 142–156.

Saeed, A., Thompson, A.K., Pervez, M.A., 2007. Effect of harvest maturity stage and position of hands on the ripening behavior and quality of banana fruit. Acta Hortic. No. 741, 117–123.

Serem, A., 2011. International trade opportunities for small scale horticultural production systems. Acta Hortic. No. 911, 53–60.

Siddiq, M., Ahmed, J., Lobo, M.G., Ozadali, F. (Eds.), 2012. Tropical and Subtropical Fruits: Postharvest Physiology, Processing and Packaging. Wiley-Blackwell, Ames, Iowa.

Sinclair, J., 1999. Refrigerated Transportation, second ed. Witherby & Co. Ltd, London.

Singh, Z., Singh, R.K., Sane, V.A., Nath, P., 2013. Mango – postharvest biology and biotechnology. CRC Crit. Rev. Plant. Sci. 32, 217–236.

Snowdon, A.L., 1990. A Colour Atlas of Post-Harvest Diseases and Disorders of Fruits and Vegetables, vol. 1, General Introduction and Fruits. Wolfe Scientific, London.

Snowdon, A.L., 1991. A Colour Atlas of Post-Harvest Diseases and Disorders of Fruits and Vegetables, vol. 2, Vegetables. Wolfe Scientific, London.

Snowdon, A.L., 1994. Diagnosing the causes of out-turn problems in imported tropical fruits. In: Champ, B.R., Highley, E., Johnson, G.I. (Eds.), Postharvest Handling of Tropical Fruits: Proceedings of an International Conference held at Chiang Mai, Thailand, 19–23 July 1993, ACIAR Proceedings No. 50, 94–101.

Snowdon, A.L., 2007. From Cargo Claims to Loss Prevention; Fresh Fruits and Vegetables in Transit. Second Annual Seminar on Perishable Product Transportation. Lloyds Maritime Academy, London, 6 pp.

Snowdon, A.L., 2010. Carriage of bananas (*Musa* spp.) in refrigerated ships and containers: pre-shipment and shipboard factors influencing cargo out-turn condition. Acta Hortic. No. 879, 375–383.

Streif, J., Kittemann, D., Neuwald, D.A., McCormick, R., Xuan, H., 2010. Pre- and post-harvest management of fruit quality, ripening and senescence. Acta Hortic. No. 877, 55–68.

Tanner, D.J., Amos, N.D., 2003. Temperature variability during shipment of fresh produce. Acta Hortic. No. 599, 193–203.

Tanner, D., Smale, N., 2005. Sea transportation of fruits and vegetables: an update. Stewart Postharvest Rev. 1 (1), 9.

Tchango, J.T., Achard, R., Ngalani, J.A., 1999. Study of harvesting stages for exportation to Europe, by ship, of three plantain cultivars grown in Cameroon. Fruits (Paris) 54, 215–224.

Thompson, A.K., 2010. Controlled Atmosphere Storage of Fruits and Vegetables, second ed. CAB International, Wallingford, UK.

Thompson, J.F., Bishop, C.F.H., Brecht, P.E., 2004. Air Transport of Perishable Products. University of California Agriculture and Natural Resources Publication No. 21618, Oakland, California, 22 pp.

Thompson, J.F., Brecht, P.E., Hinsch, T., 2002. Refrigerated Trailer Transport of Chilled Perishable Produce. University of California Agriculture and Natural Resources Publication No. 21614, Oakland, California, 28 pp.

Thompson, J.F., Brecht, P.E., Hinsch, T., Kader, A.A., 2000. Marine Container Transport of Chilled Perishable Produce. University of California Agriculture and Natural Resources Publication No. 21595, Oakland, California, 32 pp.

Thompson, J.F., Mitchell, F.G., Rumsey, T.R., Kasmire, R.F., Crisosto, C.H., 2008. Commercial Cooling of Fruits, Vegetables, and Flowers. University of California Agriculture and Natural Resources Publication No. 21567, Oakland, California, 61 pp.

Toussaint, V., Vigneault, C., 2006. Fresh horticultural produce quality and safety: the importance of traceability from the field to the consumer. Stewart Postharvest Rev. 2 (3), 6.

Valero, D., Serrano, M., 2010. Postharvest Biology and Technology for Preserving Fruit Quality. CRC Press, Boca Raton, Florida.

Varriano-Marston, E., 2010. Method for controlling banana and plantain quality by packaging. Patent No. EP 2197750/A1, European Patent Register, 38 pp.

Vicente, A.R., Civello, P.M., Martinez, G.A., Powell, A.L.T., Labavitch, J.M., Chaves, A.R., 2005. Control of postharvest spoilage in soft fruit. Stewart Postharvest Rev. 1 (4), 11.

Vigneault, C., Thompson, J., Wu, S., Hui, K.P.C., LeBlanc, D.I., 2009. Transportation of fresh horticultural produce. In: Benkeblia, N. (Ed.), Postharvest Technologies for Horticultural Crops, vol. 2. Research Signpost, Trivandrum, Kerala, India, pp. 1–24.

World Bank, 2009. Air Freight: A Market Study With Implications for Landlocked Countries. Transport Paper TP-26. International Trade Department, The World Bank, Washington DC, 95 pp.

Yahia, E.M. (Ed.), 2009. Modified and Controlled Atmospheres for the Storage, Transportation, and Packaging of Horticultural Commodities. CRC Press, Boca Raton, Florida.

Yahia, E.M., 2010. Cold chain development and challenges in the developing world. Acta Hortic. No. 877, 127–132.

Yahia, E.M. (Ed.), 2011. Postharvest Biology and Technology of Tropical and Subtropical Fruits, vols. 1–4. Woodhead Publishing Limited, Cambridge UK, Woodhead Publishing Series in Food Science, Technology and Nutrition, Nos. 206–209.

CHAPTER

19 Innovative and Integrated Approaches to Investigating Postharvest Stress Physiology and the Biological Basis of Fruit Quality During Storage

Pietro Tonutti[a] and Claudio Bonghi[b]

[a]Institute of Life Science, Scuola Superiore Sant'Anna, Pisa, Italy, [b]DAFNAE, University of Padova, Italy

I Introduction

The quality of horticultural products can be defined using a number of descriptors, and measured by several parameters related, in general, to physico-chemical properties and aimed at providing specific information on external or internal traits of the produce. For fruit in particular, besides shape, size and the absence of defects (mainly due to diseases and disorders), and without considering socioeconomic issues, the purchase decision is often dictated by external parameters such as color and, at least for some commodities, aroma (Kays and Paull, 2004). A further quality evaluation occurs during or following consumption, when properties such as flavor and texture are considered. In addition, there is today a growing emphasis on nutritional value and safety in terms of human health. Most of these quality attributes are the result of biochemical and structural modifications determined by a combination of gene expression, protein synthesis and metabolite concentrations, dynamically regulated by different factors, including development and environment.

In fruit, the transition from the immature to the mature stage is a crucial step involving the acquisition of edible traits and organoleptic quality (see also Chapters 2 and 4). The changes occurring during fruit ripening represent a wide spectrum of different biochemical processes (Seymour et al., 1993), and since the advent of molecular biology it has become clear that ripening is a highly complex, genetically controlled developmental phase (Seymour et al., 2013). Ripening is strongly influenced by environmental factors that are also of paramount importance after harvest from the mother plant. Throughout the postharvest chain (from grower to consumer) environmental parameters affect metabolism, and consequently, the shelf life and taste life of ripening fruit, as well as of other horticultural fresh produce represented by immature fruit, leaves, inflorescences, stems, tubers and roots.

The main goal of postharvest biologists is precisely that of elucidating the relationship existing between storage conditions and components of metabolism. Given that most postharvest phenotypes are genetic traits associated with one or more genes, understanding the genetic determinants that confer quality traits in fruit and other commodities is crucial for the development of new postharvest technologies. For years, researchers have studied one gene at a time, in isolation from the wider context of other genes. A number of investigations have been carried out on specific structural and regulatory genes involved in quality-related metabolic pathways in different horticultural produce.

As the molecular mechanisms of phenotypes and the biological basis of quality are complex, the methods of analyzing genes and their products *en masse* offer a wider view of biological events and allow the study of the network through which genes, proteins and metabolites are related and communicate. The development of high-throughput techniques and new biotechnological approaches covering a broad field of disciplines (chemistry, physics, biology, physiology, computer science) has also opened up the genomics era in horticultural produce research.

Genomics aims to study the organisms' genome and understand its structure and function. Functional genomics, in particular has the goal of studying the expression of genes and their functional characterization, and allows the detection of genes that are turned on or off at any given time depending on endogenous (e.g., developmental) or exogenous (e.g., environmental) factors (Eggen, 2003). Several technologies have emerged and are now available for measuring transcript abundance in parallel. The first important efforts at profiling plant transcriptomes started with the publication of an Arabidopsis Expressed Sequence Tags database (1152 ESTs isolated from different tissues and organs) compiled by Hofte et al. (1993). At present (October 2013), NCBI databases consist of more than 1,000,000 ESTs that are related to fruit and, among these, more than 70% have been isolated in nine fleshy fruit species (*Malus domestica*, 113,948; *Citrus sinensis*, 92,961; *Solanum lycopersicum*, 83,614; *Vitis vinifera*, 82,148; *Carica papaya*, 77,340; *Cucumis melo*, 62,704; *Citrus clementine*, 46,610; *Prunus persica*; 36,927; *Capsicum annuum*, 31,588).

Following the EST approach, another technique quickly became widely used for transcription profiling: the microarray. Microarrays (single color and dual color) are based on the hybridization between a set of probes, spotted on different materials (nylon and glass), and cDNAs obtained from RNAs extracted from studied tissues or organs. However, the efficacy of the microarray is limited by important drawbacks such as: (1) the profiling coverage is strictly limited by the probe sets available for specific hybridization in each species (this drawback has been overcome for some species by the development of genome-wide microarray platforms); (2) a limited sensitivity and specificity of this technology since detection is indirect, measured by fluorescent signal, and is thus subjected to a variety of confounding noise variables (Aharoni and Vorst, 2001; Wullschleger and Difazio, 2003; Ogundiwin et al., 2008).

In this context, the development of massive (high-throughput) sequencing techniques of transcriptome (RNA-Sequencing, RNA-seq) represents a more efficient approach. This advance is attributed to the RNA-seq not being restricted to detecting only those transcripts that are represented on microarrays, and also exhibiting more extreme upper and lower limits of detection, which allows more accurate quantification of differential transcript expression, as well as the identification of low-abundance transcripts (Martin et al., 2013). Applications of RNA-seq include generating genomic data for previously unsequenced species, thus expanding the boundaries of what had been considered "model organisms" (McGettigan, 2013). In plant science, the era of RNA-seq began in 2007 (Weber et al., 2007) and the transcriptome of different species bearing fleshy fruit has started to be investigated using this technique (Martin et al., 2013).

Genome-scale studies of gene expression patterns represent an appropriate strategy, particularly as a first step, given the cost-benefit ratio. However, reliance on this technique as the sole tool for describing the complexity of mechanisms responsible for the responses of perishable products to postharvest conditions has a number of limitations. Probably the most important of these is that changes in mRNA levels do not always correspond to changes in the translation of cognate proteins (Ideker et al., 2001). To study quantitative and qualitative characteristics of global protein expression, including polypeptide synthesis, degradation, post-translational modification, compartmentalization and interactions with other cell components, proteomics approaches, or the study of the protein complement of the genome, allow to span the gap between genomic DNA sequence and biological state (Rose et al., 2004; Rose and Saladié, 2005).

To reach this goal, new or improved techniques have been developed for high-resolution protein separation (gel-free or gel-based) and rapid, automated protein identification (soft ionization techniques such as matrix-assisted laser desorption ionization time of flight mass spectrometry MALDI-TOF MS, and electrospray ionization (ESI). MS techniques applied in plant proteomics studies have been described by Agrawal et al. (2013) and the proteomics and translational proteomics approaches in postharvest (and other field applications) have been reviewed by Agrawal et al. (2012) and Pedreschi et al. (2013). Since the ultimate goal of proteomics analysis is the identification (and quantification) of proteins, this result is largely dependent on the availability of an appropriate DNA sequence dataset (Heazlewood and Millar, 2003). The increase in the available genomic resources (Sonah et al., 2011) is indeed facilitating and improving the use of proteomics in horticultural crops.

A better understanding of the correlation between genes and the functional phenotype of an organism is the true goal of all functional genomic strategies, and metabolomics has emerged as a methodology that makes an important contribution to the understanding of complex molecular interactions in biological systems (Hall et al., 2002; Bino et al., 2004). As transcriptomics and proteomics aim to study the products of gene transcription and translation, the goal of metabolomics is that of quantifying and identifying all metabolites present within the cell under a given set of conditions (Withfield et al., 2004).

Metabolites in plants function in many resistance and stress responses and contribute to color, taste and aroma. It has been estimated that plants contain from 100,000 to 200,000 different chemical compounds, most the result of secondary metabolism (Pickersky and Gang, 2000; Dellapenna, 2001), and this makes the plant metabolome quite complex. Thanks to the development of high-throughput analyses, based on improvements in mass spectrometry (MS) methods and in computer hardware and software capable of interpreting large datasets (Last et al., 2007), the identification and quantification of these small molecules is becoming much easier.

Besides gas chromatography (GC) coupled with MS, metabolomic analytical platforms include high-resolution and high-throughput nuclear magnetic resonance (NMR) spectrometers, capillary electrophoresis (CE), ultra-high pressure liquid chromatography (UPLC and HPLC) systems for rapid compound separation, and MALDI TOF-MS (Villas-Boas et al., 2005; Glinski and Weckwerth, 2006; Shepherd et al., 2011).

Different approaches can be used for metabolomic studies: metabolic fingerprinting is used to complete metabolome comparison without knowledge of compound identification, while metabolite profiling involves the simultaneous measurement of a set of metabolites in a sample associated with specific pathways. The metabolite targeted analysis refers to the detection and precise quantification of a single or small set of target compounds (Fiehn, 2002; Oms-Oliu et al., 2013). Metabolomic analyses are increasingly used to assess quality (and safety) in the field of food production (Shepherd et al., 2011), including the effects of postharvest treatments (Nicolaï et al., 2010; Oms-Oliu et al., 2012) with promising applications in the field of early detection of storage-related disorders.

With the main goal of slowing down metabolism and prolonging shelf life, harvested horticultural crops are exposed to a number of stresses of different nature and intensity, often in combination (e.g., low temperature and altered atmosphere composition). The responses to the imposed stress involve changes in the flow of processes and information through transcription, translation and, ultimately, in the metabolic pool, with both primary and secondary metabolites playing a crucial role in the definition of the quality parameters of the produce.

In the last few years specific studies have been carried out using “omics” techniques, in some cases through an integrated (or Systems Biology) approach, to unravel the dynamic responses of horticultural produce to the imposed postharvest stress. These studies might also result in the identification of biochemical and molecular markers to be used for the optimization of the postharvest protocols to maintain quality and reduce the incidence and/or prevent the onset of storage-related disorders.

II "Omics" technologies and postharvest stress physiology

A Low temperature and chilling injuries

Lowering the temperature is the key factor for successful postharvest management of horticultural produce as a result of a general decrease of metabolic activity. However, the appearance of cold-related physiological disorders is often a major constraint in prolonged cold storage. Fruit of many species, in particular from subtropical and tropical areas, may undergo chilling injuries (CI) showing symptoms such as irregular ripening, pitting, discoloration, necrotic areas, wooly and dry flesh.

Customized microarrays have been developed to investigate the molecular mechanism responsible for this behavior. Pons et al. (2005), using a subset of the Spanish Citrus EST repertoire (Gonzalez−Candelas et al., 2005) printed a cDNA microarray to highlight changes in gene expression associated with CI of Fortune mandarin. They discovered that a group of fruit-specific genes is activated in response to cold and different storage pre-treatments, thus allowing the use of this gene set as a molecular tool for identifying the best storage practices, and helping in the selection of new cold-resistant cultivars.

The same approach has been used to investigate the molecular mechanism underlying tolerance to CI in peach (Granell et al., 2007). For this goal, a cDNA microarray, named CHILLPEACH™, has been developed selecting targets from a database (ChillpeachDB) containing 8,144 cDNA sequences obtained from the mesocarp of sensitive and tolerant peaches. Microarray slides containing 4,261 ChillPeach unigenes were printed and used in a pilot experiment to identify differentially expressed genes in cold-treated compared to control mesocarp tissues, and in vegetative compared to mesocarp tissues. The microarray and RT-PCR analyses indicated that ChillPeach is rich in putative fruit-specific and novel cold-induced genes and a website (http://bioinfo.ibmcp.upv.es/genomics/ChillPeachDB) was created to hold detailed information on the ChillPeach database (Ogundiwin et al., 2008).

A nylon macroarray containing 847 non-redundant ESTs from a ripe peach fruit cDNA library has been developed by Gonzalez-Aguero et al. (2008). Gene expression changes in peach fruit ripened for seven days at 21°C (juicy fruit) were compared with those stored for 15 days at 4°C and then ripened for seven days at 21°C (wooly fruit). A total of 106 genes were found to be differentially expressed between the juicy and wooly fruit. Data analysis indicated that the activity of most of these genes (>90%) was repressed in the wooly fruit.

Besides confirming the importance of cell wall genes, this transcriptomic study pointed out that changes in endomembrane trafficking might also play a role in the appearance of these postharvest physiological disorders in peaches and nectarines. In peach, cold-induced woolliness appears to be related to an up-regulation of genes linked to the oxidative stress response, suggesting changes in redox status (Pavez et al., 2013). In addition, the up-regulation of stress response genes in wooly fruit was accompanied by down-regulation of key components of metabolic pathways that are active during peach ripening, indicating the presence of an abnormal ripening process.

Other candidate genes for CI tolerance have been identified by Falara et al. (2011) using the μPEACH 1.0 platform, the first microarray developed for studying peach fruit ripening (Trainotti et al., 2006). In this case, the transcriptome profiles of peach fruit from “Morettini No2” and “Royal Glory”, two peach cultivars showing sensitivity and tolerance to CI, respectively, were compared. Genes encoding cell wall-modifying proteins (β-D-xylosidase and expansin) and stress proteins (HSPs, dehydrin, and PR-4B) were found highly expressed at ripening without storage and after storage in the CI-resistant cultivar.

The same genes were also identified when, using both the ChillPeach and μPEACH 1.0 platforms, the transcriptomes of a peach and its near-isogenic nectarine mutant showing high and low susceptibility to CI, respectively, were compared (Dagar et al., 2013). Interestingly, genes encoding a dehydrin, a HSP and cell wall enzymes appeared to be expressed at higher levels in the nectarine fruit already at harvest.

These genes (but also others showing differential expression) could be used as markers for an early (at harvest) prediction of the storage behavior. A set of 41 genes was thus selected since they showed differential expression levels depending on the sensitivity to developing storage disorders. Among these, *glutathione S-transferase GST22*, highly expressed in cold tolerant nectarine, has been suggested to play a key role in cold response adaptation. The hypothesis of a role played by *HSP* genes in modulating responses to cold storage is reinforced by the evidence that three cytosolic *HSP* genes are induced in banana fruit during storage at a temperature of 8°C but showing no visible CI due to the effect of a heat pretreatment (He et al., 2012).

Postharvest heat treatments (HT) were originally proposed to control fungal diseases and pest infestation of horticultural crops, but they can also be used to inhibit the ripening process, induce resistance to CI during storage and, as physical elicitors, to modify the content of phytochemical and antioxidant properties (Valero and Serrano, 2010). In general, heat is applied as pre-storage treatment before cold storage by using hot water, hot air or vapor heat: all these treatments may induce marked changes in the physiology of the produce. A transcriptomic approach, based on a differential display technique, was used to study the effect of a pre-storage HT on peach fruit aimed at reducing CI (Lauxmann et al., 2012).

This strategy allowed the identification of a set of heat-responsive genes mainly involved in protein modification, transcription and RNA metabolism. Based on a parallel expression analysis of a set of genes in low temperature- and heat-treated fruits, it is postulated that HT treatment may induce a stress response effective to acclimatize peaches to the subsequent cold storage. This hypothesis is also supported by analyses of the peach fruit proteome which show that the heat-induced CI tolerance may be acquired by the induction of related stress proteins such as HSPs, cysteine proteases, and dehydrin (Lara et al., 2009; Zhang et al., 2011).

Similar results have been obtained in postharvest heat-treated Satsuma mandarin fruits by means of a comparative proteomic and metabolomic profiling (Yun et al., 2013). Resistance associated proteins such as beta-1,3-glucanase, Class III chitinase, 17.7 kDa HSP and low molecular weight HSP were up-regulated in heat treated pericarp, whereas redox metabolism enzymes (including isoflavone reductase, oxidoreductase and superoxide dismutase) were down-regulated. Flavonoids were among the different metabolites that increased in heat treated pericarp, suggesting that reactive oxygen species (ROS) and lignin play important roles in inducing resistance to postharvest pathogens and physiological disorders in mandarin.

Peach and *Citrus* fruits are among the most widely studied in terms of responses to low temperature storage and development of CI using different “omics” techniques. In addition to the transcriptome profiling, a comparative proteomic approach with two dimensional difference gel electrophoresis (2-D DIGE) has been used to compare healthy and chill injured peaches allowed to identify 43 spots representing proteins that significantly change after cold storage and the subsequent ripening that leads to the development of chilling injury (Nilo et al., 2010). Among the 43 spots representing differently accumulating proteins, endoplygalacturonase, catalase, NADP-dependent isocirate dehydrogenase, pectin methylesterase and dehydrins were identified and, based on GO annotation, biological processes such as response to stress, cellular homeostasis and metabolism of carbohydrates and amino acids were the categories more affected during the cold storage period.

A role of thaumatin proteins in protecting low temperature stored peaches against CI has been reported by Dagar et al. (2010) based on the results of a cell wall proteomics approach. Coupling transcriptome with proteome studies based on digital gene expression (DGE) and 2-D electrophoresis, Yun et al. (2012) reported that, in Citrus (*C. grandis* × *C. paradisi*) fruit, lengthy low temperature storage up-regulates stress-responsive genes, arrests signal transduction and induces the accumulation of COR15 HSPs. Under these stress conditions, the fruit quality seems to be regulated by sugar-mediated auxin and abscisic acid signaling. A possible protective role played by small HSP and glycine-rich RNA-binding protein (GR-RBP) has been postulated in cold stored (4–5°C for about 20 days) tomato fruit. These conditions may induce the appearance of CI (rubbery texture, irregular ripening) and this is associated with a changes in the pool of proteins including HSP and GR-RBP (Page et al., 2010; Vega-Garcia et al., 2010).

As reported above, prolonged cold storage may induce the appearance of physiological disorders such as woolliness in peaches and superficial scald in apples and pears. Superficial scald, considered to be a type of CI induced by oxidative stress, develops during cold storage and intensifies after removal to market temperatures (Whitaker, 2013). Symptoms are brown or black patches on the fruit skin, but the biochemistry that leads to its development is not completely understood. Studies on scald etiology have focused almost exclusively on the involvement of α-farnesene and its oxidation, and little attention has been given to alternative options (reviewed by Lurie and Watkins, 2012). Several pieces of evidence associate conjugate triols (CTols), compounds related to α-farnesene metabolism, with scald development and a model based on CTol accumulation dynamics during early stages of storage (<50 days) has recently been proposed to predict scald occurrence in Granny Smith apples (Bordonaba et al., 2013).

Studies on the apple peel metabolome in fruit treated with chemicals (such as the ethylene antagonist 1-methylcyclopropene (1-MCP) and the antioxidant diphenylamine (DPA)) to reduce or control the incidence of superficial scald are providing novel information on metabolic changes occurring in pre-symptomatic and symptomatic fruit. Rudell et al. (2009) reported that, based on untargeted metabolic profiling approach, in cold stored Granny Smith apples, besides the α-farnesene oxidation products (conjugated trienols, 6-methyl-5-hepten-2-one and 6-methyl-5-hepten-2-ol), a large group of putative triterpenoids with mass spectral features similar to those of ursolic acid and β-sitosterol are associated with presymptomatic as well as scalded fruit. In addition to the isoprenoids (squalene, tocopherols), a strict association between scald development and individual metabolites from the phenylpropanoid, and a coregulation within the volatile synthesis pathways producing methyl, propyl, ethyl, acetyl and butyl alcohol and/or acid moieties for ester biosynthesis have also been observed in Granny Smith apples affected by superficial scald (Rudell et al., 2008; Rudell and Mattheis, 2009; Leisso et al., 2013).

B Low O_2/high CO_2

Changes in the atmospheric composition, in particular concerning oxygen (decreased) and carbon dioxide (increased) concentrations, are the fundamentals of the Controlled Atmosphere (CA) and Modified Atmosphere (MA) technologies used for the storage, transportation and packaging of several types of horticultural produce. These environmental conditions have a marked effect on product physiology, starting from altered primary metabolism and respiratory pathways, and involve changes in gene expression, protein accumulation and metabolite concentrations (Kanellis et al., 2009). Generally speaking, these conditions may result in beneficial effects (delayed ripening and senescence, prolonged commercial life, in some cases reduced susceptibility to CI), but can also have detrimental effects such as the development of internal browning in apples and pears, irregular ripening in commodities such as banana, mango, tomato, development of off flavors. It is evident that the effects on a specific genotype of changes in atmosphere compositions are mainly (although not exclusively) the result of the interaction of two parameters: duration of the treatment and O_2/CO_2 concentrations.

If we look at the evolution of the CA technology since its early practical applications for apple storage, one trend is evident: a steady decrease in oxygen and increase in CO_2 concentrations used in the storage rooms. The standard technology, based on an oxygen concentration of about 2−3 kPa, has, in the last 15 years, markedly changed and innovations are represented by CA-based methods characterized in particular by a reduction of O_2 levels. One example is represented by the ultra low oxygen (ULO) technology, where O_2 is maintained near 1 kPa, and ILOS (Initial Low O_2 Stress) in which O_2 levels are maintained as low as 0.25−0.7 kPa for short time periods after harvest. A further step, thanks to the advances in technology that allow sensing of fruit responses to stress hypoxic stress conditions, is represented by the dynamic CA (DCA). With this technology, fruit are kept at much lower O_2 concentrations than the "safe" − although not optimal − levels, but this concentration is promptly adjusted in relation to the fruit's metabolic responses.

The main parameters used to monitor the metabolic responses are based on the measurement of ethanol production by the fruit and/or the chlorophyll fluorescence (Schouten et al., 1997; Prange et al., 2002, 2003). If for apple (and a few other crops) storage, a constant decrease in oxygen concentration has been observed throughout the last recent decades, successful storage protocols for other fruit species are based on high (>10 kPa) CO_2 concentrations. This is the case for cherries, blueberries, raspberries and strawberries (Fadanelli, 2010). Omics approaches are now helping us to unravel the molecular basis of the responses to such conditions and stress experience, to better identify genotypes less susceptible to develop physiological disorders/off flavors and to optimize storage protocols.

High CO_2 effects were analyzed using microarrays in non-climacteric fruit such as strawberries (Ponce-Valadez et al., 2009) and grape berries (Becatti et al., 2010). For the strawberry analyses, the cDNA microarray TOM1 was used to evaluate the effect of 20 kPa CO_2 during storage of two cvs, Jewel that accumulates acetaldehyde and ethanol in response to elevated CO_2 during storage, and Cavendish that does not accumulate these compounds under the same storage conditions. This behavior is paralleled by a difference in terms of differentially expressed sequences, 168 in Jewel and only 51 in Cavendish, suggesting the presence of different regulatory molecular mechanisms activated in relation to the presence of this stressor.

For wine grape berries (cv. Trebbiano, white-skinned) maintained for three days at 30 kPa of CO_2 and then transferred to air for an additional nine days to partially dehydrate for vinification purposes, microarray analysis revealed that compared to flesh, skin cells undergo more pronounced changes in transcript profiling at the end of the incubation period. The functional categorization and gene enrichment analyses pointed out that in the skin, highly represented categories were fermentation, CHO metabolism, and redox regulation, while the categories related to protein, stress, transcript, RNA and hormone (ethylene, ABA) metabolism were highly represented in both skin and flesh tissues.

Despite the diffusion of CA technology in apple-producing areas, almost no information has been available up until now concerning transcriptome profiling under low oxygen conditions in fruit. Cortex tissues of Granny Smith apples stored for 28 days at 0.4 and 0.8 kPa oxygen concentrations have been analyzed using the RNA-seq technique (Tonutti, Ruperti, Velasco, unpublished observations). A preliminary analysis indicates that, when compared with fruit at harvest, more than 12,000 genes show some change in transcriptional activity: almost 7,000 are more or less affected under both conditions, but about 500 genes are apparently regulated only in the 0.4 kPa sample. If confirmed after robust statistical analyses, these data would indicate that the slight difference in terms of oxygen concentration is highly effective in modulating gene expression. This change is true when analyzing specific genes such as alcohol dehydrogenases (*ADH*), that show significant difference between samples in terms of transcript accumulation (compared to fruit at harvest, marked increase in 0.4 kPa, less pronounced increase in 0.8 kPa).

Other genes involved in the phenylpropanoid and isopreonoid pathways appear to be differentially expressed, thus representing potential candidates as molecular markers to monitor the metabolic responses of apples under low oxygen conditions. The different expression of specific Ethylene Responsive Factors (*ERF*), in particular those belonging to the group VII, that have been shown to be involved in low oxygen signaling in plants through the N-end rule pathway (Gibbs et al., 2011; Licausi et al., 2011) would indicate that in apple fruit the oxygen sensing mechanisms are similar to those detected in model species (*Arabidopsis*).

A contribution to the elucidation of metabolic changes occurring under complete deprivation of oxygen (anoxia) has been provided by Shi et al. (2008) who reported the changes in the proteome occurring in mandarins and grapefruit exposed to N_2 atmospheres for 24 h. In addition to the induction of anaerobic respiration and accumulation of the off flavor volatiles ethanol and acetaldehyde, exposure to these stress conditions significantly affected the abundances of 33 different proteins revealing tissue- and cultivar-specific differences in the anaerobic response of citrus fruit. Compared to grapefruit, mandarin juice vesicles appeared to be more sensitive, showing an induction of glycolytic enzymes and of ADH, and an increase in the abundance of stress proteins, such as HSPs and ascorbate peroxidase.

Among the possible negative effects of storing fruit under altered atmospheric compositions, the development of physiological disorders and/or the accumulation of off-odors and off-taste are of paramount importance. When pears are stored under low oxygen or elevated carbon dioxide conditions, they may develop the physiological disorder called core browning that is characterized by the development of brown spots and, eventually, cavities in the center of the fruit. The combination of different factors (including pre-cooling period and harvest time) plays a key role in core breakdown development during controlled atmosphere storage. Metabolic events leading to core browning in Conference pears were studied by means of proteomic and metabolomic approaches.

Changes in the accumulation of proteins related to respiration, ethylene biosynthesis, allergenic potential, defense mechanisms and oxidative system are highly dependent on the oxygen and carbon dioxide concentrations (Pedreschi et al., 2007, 2008, 2009a). Indeed, this disorder is supposed to be due to an imbalance between oxidative and reductive processes. Using GC-EI-TOF-MS, Pedreschi et al. (2009b) showed that brown pear tissue was characterized by a decrease in malic acid and an increase in fumaric acid and gamma aminobutyric acid (GABA), which would indicate altered Krebs cycle and GABA shunt pathway, and an increased gluconic acid concentration. According to these authors, GABA and gluconic acid can be considered as metabolic markers for core breakdown.

In addition, apples may develop internal browning during hypoxic cold storage in elevated levels of CO_2. Pre-storage treatment with the antioxidant DPA may reduce the incidence of this disorder in susceptible cultivars such as Braeburn (Braeburn browning disorder; BBD). An untargeted metabolic profiling (using GC-MS and LC-MS) revealed that flesh browning is associated with increases in the concentration of acetaldehyde, ethanol and ethyl esters that, together with several amino acids, results in reduced DPA-treated fruit (Lee et al., 2012a).

The level of metabolites in Braeburn apples were also studied by means of NMR, still at its infancy in postharvest study applications due to the high costs of the analyses (Vandendriessche et al., 2013). The different postharvest storage conditions (optimal CA and brown inducing CA) did result in significant changes in metabolite levels and differences in terms of pyruvate, citrate, fumarate, alanine, chlorogenate, methanol, ethanol, acetaldehyde and acetoine concentrations between brown and unaffected apples stored under the applied CA conditions were observed. Preliminary NMR analyses performed on Granny Smith apples (cortex tissue) revealed that, besides the difference in terms of ethanol accumulation, keeping fruits at 0.4 or 0.8 kPa for 28 days selectively affects metabolic pathways related to lactate, aspartate and alanine. Results showed different accumulations in the two samples, thus representing possible metabolic markers to properly handle DCA storage protocols (Tonutti, Scatizzi, Tenori, unpublished observations).

One of the metabolic changes affecting fruit maintained under hypoxic conditions concerns the volatile pattern and the impact of storage on particular aroma components. High-throughput methods are now starting to be used to study these effects. In particular, the volatile organic compound (VOC) fingerprint of Red Delicious apples has been analyzed by means of proton transfer reaction-mass spectrometry (PTR-MS), a MS-based metabolic fingerprinting technique. After storage in ULO, DCA-CF (dynamic controlled atmosphere monitored by chlorophyll fluorescence), RLOS (repeated low oxygen stress) and 1-MCP in ULO, apples were analyzed during the four weeks of shelf life and the four storage conditions were discriminated according to the PTR fingerprint mass spectra, considering in particular esters and terpenes (Ciesa et al., 2013).

C Ethylene and ethylene antagonists

1-MCP is an inhibitor of ethylene action that, at a very low concentration, is effective in prolonging the storage life of several climacteric fruit (Sisler and Serek, 1997). Its effects vary in relation to species, cv. and application time (Watkins, 2006, 2008); for instance bananas and apples are more sensitive to

1-MCP than fruits belonging to *Prunus* species such as peach and nectarine, where, in general, the ethylene inhibitor maintains its effects for only a short time after the end of the incubation period, when a quick recovery of ripening parameters occurs (Tonutti et al., 2007). Dal Cin et al. (2006) compared the responses of peaches and apples to 1-MCP at physiological and molecular levels, and concluded that the different behavior of the two species in response to the ethylene action inhibitor might be related to differences in terms of ethylene receptor ratio, expression and/or turn-over.

Large-scale analyses of transcripts have been performed on 1-MCP treated nectarines using μPEACH 1.0 (Ziliotto et al., 2008). The results clearly show that the presence of 1-MCP markedly changes the transcript profile, considering that only nine genes (instead of 90, in control samples) showed, in comparison to fruit at harvest, significant changes at the end of the 24 h incubation period, and 102 targets were differently affected when comparing fruit maintained for 24 h in air and in 1-MCP-enriched atmosphere. A number of these differentially expressed targets correspond to genes with a role in hormone (ethylene, but also auxin and ABA) metabolism and transcription regulation.

The fast recovery of ripening parameters (softening, in particular) observed in peach fruit 48 h after the end of the incubation period is the result of a change in the expression of about 50% of the 102 targets, including genes involved in ethylene perception (*ETR*2) and transcription regulation (*EIL*1-like) (Ziliotto et al., 2008). The hypothesis of the involvement of these hormone categories in the responses of peach fruit to 1-MCP treatment has been reinforced through a proteomic study (Zhang et al., 2012) showing that among the differentially accumulated proteins, ACC oxidase (ACO) and abscisic acid stress ripening-like protein (ASR) were depressed by the ethylene antagonist, while chaperonin 60 and HSPs were induced.

The severity of some physiological disorders can be modulated by ethylene and therefore by 1-MCP. In *Citrus*, non-chilling peel pitting is reduced by treatment with 10 μl/l ethylene during storage at 22°C and 90−95% RH; counter-wise peel damage is enhanced by 1-MCP. A transcriptome approach, based on a cDNA microarray containing 12,000 unigenes revealed that ethylene induced the metabolism of amino acid derivatives, including phenylpropanoids, and electron transport. Conversely, the severe peel damage in the 1-MCP-treated fruit was accompanied by marked changes in the expression of genes related to programmed cell death belonging to the ubiquitination and proteosome pathways, resembling the plant's defense response in an incompatible interaction (Establés-Ortiz et al., 2009).

The impact of 1-MCP on CI severity is different not only in relation to the species (and cultivar) considered (Manganaris et al., 2010), but is also strongly affected by harvest time. In different peach cv.s, the development of CI during storage was increased in early-harvested, but was reduced in late-harvested fruits following 1-MCP treatement (Jajo et al., 2012). A microarray analysis showed that 87 and 61 genes displayed differential expression following 1-MCP treatment in the early- and late-harvested fruits, respectively. Thirteen of these genes, mainly involved in membrane metabolism, cell wall synthesis and degradation and reaction to stress, were in common to fruits of both maturities. These results pointed out that the developmental stage reached at harvest heavily affects the 1-MCP efficacy in controlling ethylene action and the ethylene-related processes such as the susceptibility to specific physiological disorders.

Differences between cultivars have also been observed in terms of metabolic profiling in Empire and Granny Smith apples treated with 1-MCP (Rudell et al. 2009; Lee et al., 2012b). These approaches allowed the identification of specific metabolites putatively associated with the onset of physiological disorders such as flesh browning and superficial scald even at the pre-symptomatic stage.

Since the vast majority of fruit postharvest protocols are aimed at slowing down ripening and prolonging storage life, ethylene has to be removed, and/or inhibitors of its biosynthesis and action should be applied. Exogenous applications of ethylene can be performed at distribution facilities for specific (climacteric) crops such as banana, avocados, kiwifruit, mangoes, tomatoes and European pears in order to accelerate ripening and provide retail markets with fruit of appropriate ripeness; more or less ready to be eaten. Postharvest ethylene treatments have also been proposed and, in some cases, used practically to modulate specific quality-related parameters in non-climacteric fruit. These treatments are effective in de-greening citrus fruit and developing full color in pineapple, pepper and strawberry (Fox et al., 2005; John-Karuppiah and Burns, 2010; Villarreal et al., 2010; Zhou et al., 2010).

In the case of grape berries, it has been demonstrated that they respond to exogenous ethylene treatments performed in the field (at veraison stage, El-Kereamy et al., 2003; Chervin et al., 2008) or after harvest. Considering this latter case, Botondi et al. (2011) and Becatti et al. (2014) showed that, when this gas (at 1000 ppm for 36–48 h) was applied on harvested red-skinned wine grape berries, the activity of specific cell wall enzymes increased (with effects on the vinification process) and the concentration of different classes of polyphenols was affected. Microarray analysis of the effects of a prolonged (seven days) treatment with ethylene (500 ppm) showed that in grape berry skin, 139 genes were up-regulated by the gaseous hormone, whereas 16 appeared to be repressed. Considering the putative function of these genes differentially expressed following the hormone treatment, some of them appear to be involved in aromatic compound and secondary metabolism (e.g., phenylalanine ammonia lyase) (Rizzini et al., 2010).

D Other postharvest treatments/stressors

Dehydration

Besides direct financial loss due to reduced weight, water loss is responsible for large and significant changes in the composition and metabolism of detached fruit and other horticultural produce (Kays and Paull, 2004). Even in the absence of wilting, postharvest water loss affects quality parameters by inducing changes in color, palatability and loss of nutritional quality (Wills et al., 2007). From a physiological and metabolic point of view, the dehydration occurring in the postharvest phase is not identical to that of the organ still attached to the plant. This defect is due to: (i) the lack of water, mineral and energy supply provided through the vascular connections, and (ii) the environmental conditions that are present throughout the postharvest period and the effects of varying the level and source of stress.

If for most (if not all) fresh horticultural crops, postharvest water loss must be minimized, some strategies are based on the intentional postharvest dehydration of the raw biological material. For example, some wines (e.g., dessert and fortified) are obtained from grape berries undergoing a more or less intense postharvest dehydration process (Mencarelli and Tonutti, 2013).

Besides the physical process of transpiration leading to weight loss and solute concentration, postharvest dehydration induces marked and variable effects on grape berry metabolism. The molecular processes occurring during withering were analyzed by using different techniques, such as AFLP-transcriptional profiling (AFLP-TP) (Zamboni et al., 2008) and microarray approaches (Rizzini et al., 2009; Zamboni et al., 2010; Bonghi et al., 2012). These analyses pointed out that genes involved in transcriptional regulation, hormone, carbohydrate and secondary metabolism, transport and stress responses are particularly affected by dehydration, demonstrating that grape berries are metabolically reactive to water stress also after harvest. Among the different secondary metabolic processes, those concerning the phenylpropanoid pathway are of paramount importance in terms of quality properties, in particular for red wines.

Grape berry development has been studied through the integration of transcriptomic, proteomic and metabolomic data achieved using a hierarchical clustering strategy based on the multivariate bidirectional orthogonal projections to latent structures technique (Zamboni et al., 2010). This approach identified stage-specific functional networks of linked transcripts, proteins and metabolites. In the case of ripening and withering, the characteristic accumulation of secondary metabolites such as acylated anthocyanins was confirmed. The accumulation pattern of these compounds is strictly related to that of a BEACH transcript that encodes a protein with the role of facilitating the compartmentalization of anthocyanins through membrane trafficking. Based on this holistic approach, it has been demonstrated that withering involves the activation of specific osmotic and oxidative stress response genes and the production of stilbenes and taxifolin.

Wounding

Due to postharvest handling (sorting, storage, transportation, etc.), perishable fruits are at high risk of unintentional mechanical damage (Kays and Paull, 2004). Major (intentional) postharvest sources of wounds include injuries imposed during the preparation of the so-called minimally processed or fresh cut produce.

Compared to other plant organs/tissues, little information is available on the wound-induced molecular mechanisms and metabolic processes in fleshy fruits.

Using different *Prunus persica* genotypes characterized by different ripening behaviors (melting, non-melting, slow melting, stony hard), Tosetti et al. (2012, 2014) performed metabolics profiling and microarray analyses of mescoarp tissue following wounding in ripe fruits. Different concentrations of organic acids and other metabolites (dehydroascorbate, alanine) were observed in the wedges of the different genotypes, as well as marked changes in terms of transcript profiling when the melting and the slow melting cv.s were compared. A number of transcription factors (WRKY, AP2/ERF) and HSPs appeared to be involved in the responses to wounding, indicating the activation of regulatory and signaling mechanisms probably related to different hormone categories.

UV irradiation and ozone

Ultraviolet (UV) light , classified according to the wavelength as UV-A, UV-B, UV-C and far-UV, is mostly used for disinfecting purposes in the food industry and it has been demonstrated that low UV-C doses can induce resistance to pathogens and reduce decay in fruits (Ben-Yehoshua, 2003). Little information is currently available on the effects of such treatments on the metabolism of the produce. The effects of UV-C irradiation (4 kJ/m^2) on harvested tomato fruits were studied in terms of transcript profile changes via microarray analysis (Liu et al., 2011). A total of 274 and 403 genes were up- and down-regulated, respectively. The up-regulated genes were mainly involved in signal transduction, defence response and general metabolism.

Conversely, genes related to cell wall disassembly, photosynthesis and lipid metabolism were among those negatively affected by UV-C treatment. In apples (Granny Smith) a global metabolic profiling of the skin was employed for evaluating metabolomic alterations resulting from pre-storage UV-white light irradiation (Rudell et al., 2008). Fruit treated with fluorescent UV-white light for 0−48.5 h was stored for six months at 0°C and the analyses detected more than 200 components, 78 of which were identified. Metabolic pathways associated with ethylene synthesis, acid metabolism, flavonoid pigment synthesis and fruit texture were altered by pre-storage irradiation, and many of the alterations were detectable after six months of cold storage in air.

Ozone is a highly reactive molecule that is widely used to sterilize water, and ozone generators have found some applications for storage of fruit and vegetables aimed at inhibiting the onset of senescence symptoms through mechanims still to be elucidated. A proteomic approach in kiwifruit stored in the presence of ozone (0.3 μl/l) revealed that the inhibition of ethylene production, the delayed ripening and the stimulation of antioxidant and anti-radical activities of treated fruits were accompanied by changes in a total of 102 proteins, mainly involved in energy, protein metabolism, defense, and cell structure (Minas et al., 2012). Ripening-related protein carbonylation appeared to be depressed by ozone.

III Final remarks and future perspectives

The evolution of quality parameters in ripening fruit is the result of the modulation of gene expression, protein accumulation and enzyme activity, affecting physicochemical properties and metabolite concentration. These events are genetically programmed and the environmental conditions (on- and off- plant) have a profound effect on their evolution. Considering the postharvest phase, this results in a diversity of responses in relation to the application of specific storage protocols, where different treatments and environmental parameters are applied, and the genetic background of species and cultivar. Tailoring and optimizing the postharvest handling protocols to specific crops/genotypes is now facilitated by the number of datasets which incorporate genomic, proteomic and metabolomic information, which is often related to fruit physiological and biophysical parameters.

In this context, we can expect that the holistic approaches (also called Systems Biology), which represent the new frontier in plant biology, will be increasingly applied to advanced postharvest physiology studies (Hertog et al., 2011). Such approaches have already been used for studying tomato fruit development and ripening, where a combination of metabolite and transcriptomic data revealed that transcript abundance is less strictly coordinated by functional group than metabolite abundance, suggesting that posttranslational mechanisms dominate metabolic regulation (Carrari and Fernie, 2006). The correlation-based analysis of data obtained with this integrated approach is effective in revealing links between transcripts and metabolites and uncovering networks or clusters, eventually resulting in the identification of novel key genes and/or molecular and metabolic markers.

This is a main goal in postharvest science in order to better monitor the responses of the produce to postharvest stress. In particular, the development of untargeted metabolic analysis, used for the phenotyping of genetically mapped populations to reveal multiple metabolic QTLs (Dunemann et al., 2009), will be extremely useful in the discovery of metabolic quantitative trait loci related to components of fruit quality parameters such as specific flavor notes. Platforms such as Phenom-network (http://phnserver.phenome-networks.com) where omics data and phenotyping are integrated with the aim of studying the same trait in different populations represent additional tools to be exploited in postharvest science.

Bibliography

Agrawal, G.K., Pedreschi, R., Barkla, B.J., Bindschedler, L.V., Cramer, R., Sakar, A., et al., 2012. Translational plant proteomics: a perspective. J. Proteomics 75, 4588−4601.

Agrawal, G.K., Sarkar, A., Righetti, P.G., Pedreschi, R., Carpentier, S., Wang, T., et al., 2013. A decade of plant proteomics and mass spectrometry: translation of technical advancements to food security and safety issues. Mass. Spectrom. Rev. 32, 335−365.

Aharoni, A., Vorst, O., 2001. DNA microarray for functional plant genomics. Plant. Mol. Biol. 48, 99–118.

Becatti, E., Chkaiban, L., Tonutti, P., Forcato, C., Bonghi, C., Ranieri, A.M., 2010. Short-term postharvest carbon dioxide treatments induce selective molecular and metabolic changes in grape berries. J. Agric. Food. Chem. 58, 8012–8020.

Becatti, E., Genova, G., Ranieri, A., Tonutti, P., 2014. Postharvest treatments with ethylene on *V. vinifera* (cv Sangiovese) grapes affect berry metabolism and wine composition. Food Chem. submitted.

Ben-Yehoshua, S., 2003. Effects of postharvest heat and UV applications on decay, chilling injury and resistance against pathogens in citrus and other fruits and vegetables. Acta. Hortic. 599, 159–173.

Bino, R.J., Hall, R.D., Fiehn, O., Kopka, J., Saito, K., Draper, J., et al., 2004. Potential of metabolomics as a functional genomics tool. Trends Plant. Sci. 9, 418–425.

Bonghi, C., Rizzini, F.,M., Gambuti, A., Moio, L., Chkaiban, L., Tonutti, P., 2012. Phenol compound metabolism and genes expression in skin of wine grapes (*Vitis vinifera* L.) sujected to partial dehydration. Postharvest. Biol. Technol. 2012, 102–109.

Bordonaba, J.G., Matthieu-Hurtiger, V., Westercamp, P., Coureau, C., Dupille, E., Larrigaudière, C., 2013. Dynamic changes in conjugated trienols during storage may be employed to predict superficial scald in "Granny Smith" apples. LWT–Food Sci. Technol. 54, 535–541.

Botondi, R., Lodola, L., Mencarelli, F., 2011. Postharvest ethylene treatment affects berry dehydration, polyphenol and anthocyanin content by increasing the activity of cell wall enzymes in Aleatico wine grape. Eur. Food Res. Technol. 232 (4), 679–685.

Carrari, F., Fernie, A.R., 2006. Metabolic regulation underlying tomato fruit development. J. Exp. Bot. 57, 1883–1897.

Chervin, C., Tira-umphon, A., Terrier, N., Zouine, M., Severac, D., Roustan, J.-P., 2008. Stimulation of the grape berry expansion by ethylene and effects on related gene transcripts, over the ripening phase. Physiol. Plant. 134, 534–546.

Ciesa, F., Dalla Via, J., Wisthaler, A., Zanella, A., Guerra, W., Mikoviny, T., et al., 2013. Discrimination of four different postharvest treatments of "Red Delicious" apples based on their volatile organic compound (VOC) emissions during shelf-life measured by proton transfer reaction mass spectrometry (PTR-MS). Postharvest Biol. Technol. 86, 329–336.

Dagar, A., Friedman, H., Lurie, S., 2010. Thaumatin-like proteins and their possible role in protection against chilling injury in peach fruit. Postharvest. Biol. Technol. 57, 77–85.

Dagar, A., Pons Puig, C., Marti Ibanez, C., Ziliotto, F., Bonghi, C., Crisosto, C.H., et al., 2013. Comparative transcript profiling of a peach and its nectarine mutant at harvest reveals differences in gene expression related to storability. Tree Genet. Genomes 9, 223–235.

Dal Cin, V., Rizzini, F.M., Botton, A., Tonutti, P., 2006. The ethylene biosynthetic and signal transduction pathways are differently affected by 1-MCP in apple and peach fruit. Postharvest. Biol. Technol. 42, 125–133.

Dellapenna, D., 2001. Plant metabolic engineering. Plant Physiol. 125, 160–163.

Dunemann, F., Ulrich, D., Boudichevskaia, A., Grafe, C., Weber, W.E., 2009. QTL mapping of aroma compounds analysed by headspace solid-phase microextraction gas chromatography in the apple progeny 'Discovery' × 'Prima'. Mol. Breed. 23, 501–521.

Eggen, A., 2003. Basics and tools of genomics. Outlook Agric. 32, 215−217.
El-Kereamy, A., Chervin, C., Roustan, J.-P., Cheynier, V., Souquet, J.-M., Moutounet, M., et al., 2003. Exogenous ethylene stimulates the long-term expression of genes related to anthocyanin biosynthesis in grape berries. Physiol. Plant. 119, 175−182.
Establés-Ortiz, B., Lafuente, M.T., González-Candelas, L., Forment, J., Gadea, J., 2009. Transcriptomic analysis of ethylene-induced tolerance to non-chilling peel pitting in citrus fruit. Acta. Hortic. 839, 555−560.
Fadanelli, F., 2010. Stato attuale delle applicazioni dell'atmosfera controllata in Italia. Frutticoltura 11, 2−7.
Falara, V., Manganaris, G.A., Ziliotto, F., Manganaris, A., Bonghi, C., Ramina, A., et al., 2011. A ß-D-xylosidase and a PR-4B precursor identified as genes in accounting for differences in peach cold storage tolerance. Funct. Integr. Genomics 11, 357−368.
Fiehn, O., 2002. Metabolomics − the link between genotypes and phenotypes. Plant. Mol. Biol. 48, 155−171.
Fox, A.J., Del Pozo-Insfran, D., Lee, J.H., Sargent, S.A., Talcott, S.T., 2005. Ripening-induced chemical and antioxidant changes in bell peppers as affected by harvest maturity and postharvest ethylene exposure. HortScience 40, 732−736.
Gibbs, D.J., Lee, S.C., Isa, N.M., Gramuglia, S., Fukao, T., 2011. Homeostatic response to hypoxia is regulated by the N-end rule pathway in plants. Nature 479, 415−418.
Glinski, M., Weckwerth, W., 2006. The role of mass spectrometry in plant systems biology. Mass. Spectrom. Rev. 25, 173−214.
Gonzalez-Aguero, M., Pavez, L., Ibáñez, F., Pacheco, I., Campos-Vargas, R., Meisel, L.A., et al., 2008. Identification of woolliness response genes in peach fruit after post-harvest treatments. J. Exp. Bot. 59, 1973−1986.
Gonzalez−Candelas, L., Sànchez-Torres, S., Alamar, B., Establés, A.R., Ballester, M.T., Sànchez-Ballesta, Y.L., et al., 2005. Genomics approaches to postharvest biotic and biotic stresses of Citrus fruit. Acta. Hortic. 682, 247−254.
Granell, A., Pons, C., Marti, C., Forment, J., Royo, C., Gradziel, T.M., et al., 2007. Genomic approaches − innovative tools to improve quality of fresh cut produce. Acta. Hortic. 746, 203−211.
Hall, R., Beale, M., Fiehn, O., Hardy, N., Sumner, L., Bino, R., 2002. Plant metabolomics: the missing link in functional genomics strategies. Plant Cell 14, 1437−1440.
He, L.H., Chen, J.Y., Kuang, J.F., Lu, W.J., 2012. Expression of three sHSP genes involved in heat pretreatment-induced chilling tolerance in banana fruit. J. Sci. Food. Agric. 92, 1924−1930.
Heazlewood, J.L., Millar, A.H., 2003. Integrated plant proteomics − putting the green genomes to work. Funct. Plant Biol. 30, 471−482.
Hertog, M.L.A.T.M, Rudell, D.R., Pedreschi, R., Schaffer, R., Geeraerd, A.H., Nicolaï, B. M., et al., 2011. Where systems biology meets postharvest. Postharvest. Biol. Technol. 62, 223−237.
Hofte, H., Desprez, T., Amselem, J., Chiapello, H., Caboche, M., Moisan, A., et al., 1993. An inventory of 1152 expressed sequence tags obtained by partial sequencing of cDNAs from arabidopsis thaliana. Plant J. 4, 1051−1061.
Ideker, T., Galitski, T., Hood, L., 2001. A new approach to decoding life: systems biology. Annu. Rev. Genome Hum. Genet. 2, 343−372.
Jajo, A.N., McGlasson, W.B., Holford, P., Jones, M.R., Golding, J.B., Bonghi, C., et al., 2012. Transcriptome analysis of the differential effects of 1-MCP on the development

of chilling injury in peaches harvested at early and late maturities. Acta. Hortic. 934, 1003–1010.

John-Karuppiah, K.-J., Burns, J.K., 2010. Degreening behavior in 'Fallglo' and 'Lee × Orlando' is correlated with differential expression of ethylene signaling and biosynthesis genes. Postharvest. Biol. Technol. 58, 185–193.

Kanellis, A., Tonutti, P., Perata, P., 2009. Biochemical and molecular aspects of modified and controlled atmospheres. In: Yahia, E.M. (Ed.), Modified and Controlled Atmopsheres for the Storage, Transportation, and Packaging of Horticultural Commodities. CRC Press, Boca Raton, FL, USA, pp. 553–567.

Kays, S.J., Paull, R.E., 2004. Postharvest Biology. Exon Press, Athens, GA, USA.

Lara, M.V., Borsani, J., Budde, C.O., Lauxmann, M.A., Lombardo, V.A., Murray, R., et al., 2009. Biochemical and proteomic analysis of 'Dixiland' peach fruit (*Prunus persica*) upon heat treatment. J. Exp. Bot. 60, 4315–4333.

Last, R.L., Jones, A.D., Shachar-Hill, Y., 2007. Towards the plant metabolome and beyond. Nat. Rev., 167–174.

Lauxmann, M.A., Brun, B., Borsani, J., Bustamante, C.A., Budde, C.O., Lara, M.V., et al., 2012. Transcriptomic profiling during the post-harvest of heat-treated dixiland prunus persica fruits: common and distinct response to heat and cold. PLoS ONE 7, e51052.

Lee, J., Mattheis, J.P., Rudell, D.R., 2012a. Antioxidant treatment alters metabolism associated with internal browning in 'Braeburn' apples during controlled atmosphere storage. Postharvest. Biol. Technol. 68, 32–42.

Lee, J., Rudell, D.R., Davies, P.J., Watkins, C.B., 2012b. Metabolic changes in 1-methylcyclopropene (1-MCP)-treated 'Empire' apple fruit during storage. Metabolomics 8, 742–753.

Leisso, R., Buchanan, D., Lee, J., Mattheis, J., Rudell, D., 2013. Cell wall, cell membrane, and volatile metabolism are altered by antioxidant treatment, temperature shifts, and peel necrosis during apple fruit storage. J. Agric. Food. Chem. 61, 1373–1387.

Licausi, F., Kosmacz, M., Weits, D.A., Giuntoli, B., Giorgi, F.M., Voesenek, L.A.C.J., et al., 2011. Oxygen sensing in plants is mediated by an N-end rule pathway for protein destabilization. Nature 479, 419–422.

Liu, C., Cai, L., Han, X., Ying Tiejin, T., 2011. Temporary effect of postharvest UV-C irradiation on gene expression profile in tomato fruit. Gene 486, 56–64.

Lurie, S., Watkins, C.B., 2012. Superficial scald, its etiology and control. Postharvest. Biol. Technol. 65, 44–60.

Manganaris, G.A., Jajo, A., Holford, P., Jones, M.R., McGlasson, B., Ziosi, V., et al., 2010. Comparative transcriptomic analysis of plum fruit treated with 1-MCP. Acta. Hortic. 877, 1105–1109.

Martin, L.B.B., Fei, Z., Giovannoni, J.J., Rose, J.K.C., 2013. Catalyzing plant science research with RNA-seq. Front. Plant Sci 4, 66.

McGettigan, P.A., 2013. Transcriptomics in the RNA-seq era. Curr. Opin. Chem. Biol. 17, 4–11.

Mencarelli, F., Tonutti, P., 2013. Sweet, Reinforced and Fortified Wines. Wiley–Blackwell, West Sussex, UK, pages 357.

Minas, I.S., Tanou, G., Belghazi, M., Job, D., Manganaris, G.A., Molassiotis, A., et al., 2012. Physiological and proteomic approaches to address the active role of ozone in kiwifruit post-harvest ripening. J. Exp. Bot. 63, 2449–2464.

Nicolaï, B.M., Pedreschi, R., Geeraerd, A., Vandendriessche, T., Hertog, M.L.A.T.M., 2010. Postharvest metabolomics. Acta. Hortic. 880, 369–376.
Nilo, R., Saffie, C., Lilley, K., Baeza-Yates, R., Cambiazo, V., Campos-Vargas, R., et al., 2010. Proteomic analysis of peach fruit mesocarp softening and chilling injury using difference gel electrophoresis (DIGE). BMC Genomics 11, 43.
Ogundiwin, E.A., Marti, C., Forment, J., Pons, C., Granell, A., Gradziel, T.M., et al., 2008. Development of chillpeah genomic tools and identification of cold-responsive genes in peach fruits. Plant. Mol. Biol. 68, 379–397.
Oms-Oliu, G., Odriozola-Serrano, I., Martin-Belloso, O., 2012. Using metabolomics to improve the quality of harvested fruit (Review). CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 7, A45.
Oms-Oliu, G., Odriozola-Serrano, I., Martín-Belloso, O., 2013. Metabolomics for assessing safety and quality of plant-derived food. Food Res. Int. 54, 1172–1183.
Page, D., Gouble, B., Valot, B., Bouichet, J.P., Callot, C., Kretzschmar, A., et al., 2010. Protective proteins are differentially expressed in tomato genotypes differeing for their tolerance to low-temperature storage. Planta 232, 483–500.
Pavez, L., Hödar, C., Olivares, F., González, M., Cambiazo, V., 2013. Effects of postharvest treatments on gene expression in *Prunus persica* fruit: normal and altered ripening. Postharvest Biol. Technol. 75, 125–134.
Pedreschi, R., Vanstreels, E., Carpentier, S., Hertog, M., Lammertyn, J., Robben, J., et al., 2007. Proteomic analysis of core breakdown disorder in Conference pears (*Pyrus communis* L.). Proteomics 7, 2083–2099.
Pedreschi, R., Hertog, M., Robben, J., Noben, J.-P., Nicolaï, B., 2008. Physiological implications of controlled atmosphere storage of 'Conference' pears (*Pyrus communis* L.): a proteomic approach. Postharvest. Biol. Technol. 50, 110–116.
Pedreschi, R., Franck, C., Lammertyn, J., Erban, A., Kopka, J., Hertog, M., et al., 2009a. Metabolic profiling of 'Conference' pears under low oxygen stress. Postharvest. Biol. Technol. 51, 123–130.
Pedreschi, R., Hertog, M., Robben, J., Lilley, K.S., Karp, N.A., Baggerman, G., et al., 2009b. Gel-based proteomics approach to the study of metabolic changes in pear tissue during storage. J. Agric. Food. Chem. 57, 6997–7004.
Pedreschi, R., Lurie, S., Hertog, M., Nicolai, B., Mes, J., Woltering, E., 2013. Post-harvest proteomics and food security. Proteomics 13, 1772–1783.
Pickersky, E., Gang, D., 2000. Genetics and biochemistry of secondary metabolites: an evolutionary perspective. Trends Plant Sci. 5, 439–445.
Ponce-Valadez, M., Moore Fellman, S., Giovannoni, J., Gan, S.-S., Watkins, C.B., 2009. Differential fruit gene expression in two strawberry cultivars in response to elevated CO2 during storage revealed by a heterologous fruit microarray approach. Postharvest. Biol. Technol. 51, 131–140.
Pons, C., Royo, C., Forment, J., Gadea, J., Lluch, Y., Granell, A., et al., 2005. A customized citrus cDNA microarray and its use in postharvest. Acta. Hortic. 682, 225–232.
Prange, R., DeLong, J., Leyte, J., Harrison, P., 2002. Oxygen concentration affects chlorophyll fluorescence in chlorophyll-containing fruit. Postharvest. Biol. Technol. 24, 201–205.
Prange, R., DeLong, J., Harrison, P., Leyte, J., McLean, S.D., 2003. Oxygen concentration affects chlorophyll fluorescence in chlorophyll-containing fruit and vegetables. J. Am. Soc. Hortic. Sci. 128, 603–607.

Rizzini, F.M., Bonghi, C., Tonutti, P., 2009. Postharvest water loss induces marked changes in transcript profiling in skins of wine grape berries. Postharvest. Biol. Technol. 52, 247–253.

Rizzini, F.M., Bonghi, C., Chkaiban, L., Martinelli, F., Tonutti, P., 2010. Effects of post-harvest partial dehydration and prolonged treatments with ethylene on transcript profiling in skins of wine grape berries. Acta. Hortic. 877, 1099–1104.

Rose, J.K.C., Saladié, M., 2005. Proteomic analysis and fruit ripening. Acta. Hortic. 682, 211–224.

Rose, J.K.C., Bashir, S., Giovannoni, J.J., Jahn, M.M., Saravanan, R.S., 2004. Tackling the plant proteome: practical approaches, hurdles and experimental tools. Plant J. 39, 715–733.

Rudell, D.R., Mattheis, J.P., 2009. Superficial scald development and related metabolism is modified by postharvest light irradiation. Postharvest Biol. Technol. 51, 174–182.

Rudell, D.R., Mattheis, J.P., Curry, E.A., 2008. Prestorage ultraviolet–white light irradiation alters apple peel metabolome. J. Agric. Food. Chem. 56, 1138–1147.

Rudell, D.R., Mattheis, J.P., Hertog, M.L.A.T.M., 2009. Metabolomic change precedes apple superficial scald symptoms. J. Agric. Food. Chem. 57, 8459–8466.

Schouten, S.P., Prange, R., Verschoor, J.A., Lammers, T.R., Oosterhaven, J., 1997. Improvement of quality of "Elstar" apples by dynamic control of ULO conditions. In: Proceedings of the Seventh International Controlled Atmosphere Research Conference, Davis, Calif. 2: 71–78.

Seymour, G.B., Taylor, J.E., Tucker, G.A., 1993. Biochemistry of Fruit Ripening. Chapman & Hall, London, UK.

Seymour, G.B., Giovannoni, J.J., Tucker, G., 2013. The Molecular Biology and Biochemistry of Fruit Ripening. Wiley–Blackwell, Ames, Iowa, USA.

Shepherd, L.V.T., Fraser, P., Stewart, D., 2011. Metabolomics: a second-generation platform for crop and food analysis. Bioanalysis 3, 1143–1159.

Shi, J.X., Chen, S., Gollop, N., Goren, R., Goldschmidt, E.E., Porat, R., 2008. Effects of anaerobic stress on the proteome of citrus fruit. Plant Sci. 175, 478–486.

Sisler, E.C., Serek, M., 1997. Inhibitors of ethylene responses in plants at the receptor level, recent developments. Physiol. Plant. 100, 577–582.

Sonah, H., Deshmukh, R., Singh, V., Gupta, D., Singh, N.K., Sharma, T.R., 2011. Genomic resources in horticultural crops: status, utility and challenges. Biotechnol. Adv. 29, 199–209.

Tonutti, P., Bonghi, C., Ramina, A., 2007. Modulating effects of ethylene and ethylene inhibitors in the control of fruit ripening. In: Ramina, A., Chang, C., Giovannoni, J., Klee, H., Perata, P., Woltering, E. (Eds.), Advances in Plant Ethylene Research. Springer, The Netherlands, pp. 407–416.

Tosetti, R., Martinelli, F., Tonutti, P., Barupal, D.K., 2012. Metabolomics approach to studying minimally processed peach (*Prunus persica*) fruit. Acta. Hortic. 934, 1017–1021.

Tosetti, R., Tardelli, F., Tadiello, A., Zaffalon, V., Giorgi, F.M., Guidi, L., et al., 2014. Molecular and biochemical responses to wounding in mesocarp of peach (*Prunus persica* L. Batsch) ripe fruits. Postharvest Biol. Technol. 90, 40–51.

Trainotti, L., Bonghi, C., Ziliotto, F., Zanin, D., Rasori, A., Casadoro, G., et al., 2006. The use of microarray mPEACH1.0 to investigate transcriptome changes during transition from pre-climacteric to climacteric phase in peach fruit. Plant Sci. 170, 606–613.

Valero, D., Serrano, M., 2010. Heat treatments. In: Valero, D., Serrano, M. (Eds.), Postharvest Biology and Technology for Preserving Fruit Quality. CRC Press, Boca Raton, FL, pp. 91–108.

Vandendriessche, T., Schäfer, H., Verlinden, B.E., Humpfer, E., Hertog, M.L.A.T.M., Nicolaï, B.M., 2013. High-throughput NMR based metabolic profiling of braeburn apple in relation to internal browning. Postharvest. Biol. Technol. 80, 18–24.

Vega-Garcia, M.O., Lopez-Espinosa, G., Ontiversos, J.C., Caro-Corrales, J.J., Vargas, F.D., Lòpez-Valenzuela, J.A., 2010. Changes in protein expression associated with chilling injury in tomato fruit. J. Am. Soc. Hortic. Sci. 135, 83–89.

Villarreal, N.M., Bustamante, C.A., Civello, P.M., Martínez, G.A., 2010. Effect of ethylene and 1-MCP treatments on strawberry fruit ripening. J. Sci. Food. Agric. 90, 683–689.

Villas-Boas, S.G., Mas, S., Akesson, M., Smedsgaard, J., Nielsen, J., 2005. Mass spectrometry in metabolome analysis. Mass. Spectrom. Rev. 24, 613–646.

Watkins, B.C., 2006. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnol. Adv. 24, 389–409.

Watkins, B.C., 2008. Overview of 1-methylcyclopropene trials and uses for edible horticultural crops. HortScience 43, 86–94.

Weber, A., Weber, K., Carr, K., Wilkerson, C., Ohlrogge, J., Weber, K., et al., 2007. Sampling the Arabidopsis transcriptome with massively parallel pyrosequencing. Plant. Physiol. 144, 32–42.

Whitaker, B.D., 2013. Genetic and biochemical bases of superficial scald storage disorder in apple and pear fruits. Acta. Hortic. 989, 47–60.

Wills, R., McGlasson, B., Graham, D., Joyce, D. (Eds.), 2007. Postharvest. fifth ed. CABI, Wallingford, UK.

Withfield, P.D., German, A.J., Noble, P.J., 2004. Metabolomics: an emerging post-genomic tool for nutrition. Br. J. Nutr. 92, 549–556.

Wullschleger, M., Difazio, T.D., 2003. Emerging use of gene expression microarrays in plant physiology. Comp. Funct. Genomics 4, 216–224.

Yun, Z., Jin, S., Ding, Y., Wang, Z., Gao, H., Pan, Z., et al., 2012. Comparative transcriptomics and proteomics analysis of citrus fruit, to improve understanding of the effect of low temperature on maintaining fruit quality during lengthy post-harvest storage. J. Exp. Bot. 63, 2873–2893.

Yun, Z., Gao, H., Liu, P., Liu, S., Luo, T., Jin, S., et al., 2013. Comparative proteomic and metabolomic profiling of citrus fruit with enhancement of disease resistance by postharvest heat treatment.. BMC Plant Biol. 13, 44.

Zamboni, A., Minoia, L., Ferrarini, A., Tornielli, G.B., Zago, E., Delledonne, M., et al., 2008. Molecular analysis of post-harvest withering in grape by AFLP transcriptional profiling. J. Exp. Bot. 59, 4145–4159.

Zamboni, A., Di Carli, M., Guzzo, F., Stocchero, M., Zenoni, S., Ferrarini, A., et al., 2010. Identification of putative stage-specific grapevine berry biomarkers and omics data integration into networks. Plant. Physiol. 154, 1439–1459.

Zhang, L., Yu, Z., Jiang, L., Jiang, J., Luo, H., Fu, L., 2011. Effect of post-harvest heat treatment on proteome change of peach fruit during ripening. J. Proteomics. 74, 1135–1149.

Zhang, L., Jiang, L., Shi, Y., Luo, H., Kang, R., Yu, Z., 2012. Post-harvest 1-methylcyclopropene and ethephon treatments differently modify protein profiles of peach fruit during ripening. Food Res. Int. 48, 609–619.

Zhou, J.Y., Sun, C.D., Zhang, L.L., Dai, X., Xu, C.J., Chen, K.S., 2010. Preferential accumulation of orange-colored carotenoids in Ponkan (*Citrus reticulata*) fruit peel following postharvest application of ethylene or ethephon. Sci. Hortic. 126, 229–235.

Ziliotto, F., Begheldo, M., Rasori, A., Bonghi, C., Tonutti, P., 2008. Transcriptome profiling of ripening nectarine (*Prunus persica* L. Batsch) fruit treated with 1-MCP. J. Exp. Bot. 59, 2781–2791.

This page intentionally left blank

CHAPTER

Challenges in Postharvest Handling

20

Wojciech J. Florkowski[a], Robert L. Shewfelt[a], Bernhard Brueckner[b] and Stanley E. Prussia[a]

[a]*University of Georgia,* [b]*Institut fuer Gemuse- und Zierpflanzenbau, Germany*

The first edition of *Postharvest Handling: A Systems Approach* introduced a somewhat radical concept of treating individual operations in the handling of fresh fruits and vegetables in the context of broader systems (Shewfelt and Prussia, 1993). The book was primarily aimed at academic research in the area and discussed how research could become more relevant to the commercial distribution of fresh fruits and vegetables. It identified the major challenges as the need for a consistent definition of quality and the opportunities for working at the interfaces of postharvest systems and preharvest operations on one end and the consumer on the other end. Much has changed in the two decades since the first edition was published and even in the few years since the second edition (Florkowski et al., 2009) as described in Chapter 1. Although the challenges associated with academic research on fruit and vegetable handling addressed in the first edition are still relevant, the importance of understanding the commercial aspects of the system are receiving much more attention in this edition (Chapters 1, 6, 7, 12, 16). We see many important trends for the next decade in postharvest handling of fruits and vegetables.

Health professionals around the world will continue to encourage consumers to incorporate more fruit and vegetables into their diets in an effort to combat the obesity epidemic and diseases of civilization preventable through improved nutritional input (Chapter 5). Unfortunately, per capita consumption of fresh vegetables and fruits remains below the World Health Organisation (WHO) daily recommended amount in many countries; both in high-income and low-income countries (Chapter 7). It appears that income is not a constraint in such countries to fresh vegetable and fruit consumption, but the low intake results from other factors. Even countries endowed with natural resources that are exceptionally suitable for fruit and vegetable production also report fresh consumption well below the daily recommended volume. Changes in family and household size, role in preparing regular dishes and snacking contribute to altered food selection (Chapter 3). Innovation is necessary to provide successfully competing fresh produce. Convenient and safe ready-to-eat preparations of vegetables and fruit benefit from these developments, explaining the tremendous success of fresh-cut products (Chapter 9).

Postharvest Handling.

Fruit marketers are receiving a clear message to focus on markets frequented by consumers whose disposable incomes are growing. Currently, such markets are outside North America and Europe. Disposable incomes grow in nearly all countries because income distribution varies. The foreseeable future will witness an unprecedented world trade in fresh fruit across regions with an increasing number of origination points and destinations. Although per capita fruit consumption in the United States appears to have stagnated (see Chapter 3), the nutritional advantages will probably lead to greater consumption in the future (Chapter 5).

As disposable incomes grow, the fraction of additional income spent on fresh vegetables increases less and less. This trend is not a surprise because vegetables tend to be consumed in larger volumes than fruit by consumers with low income. Vegetables have been a mainstay in many diets and are consumed in larger volumes if a low-income household experiences income growth. In many countries or households, the consumption of fresh vegetables declines much too early and does not reach the daily WHO-recommended volume. Fresh vegetable markets pose a much more challenging environment than fresh fruit, require a different approach, have diverse postharvest handling practices, and need varied storage and logistic practices. The exploration of flavor preferences is one of the fast developing areas with implications for vegetable consumption and possibly postharvest handling (see Chapter 4).

The dichotomy of the observed fresh fruit and vegetable consumption trends in terms of income effect across countries poses a challenge to postharvest handling. The multiplicity of causes of highly variable consumption levels requires a systems approach if the goal is for fresh produce businesses to remain profitable and for public health policies to increase and sustain a high level of fresh produce consumption. The systems approach recognizes the need for market-led coordination or, at least, participation of all players in the supply and distribution of fresh produce. The national programs aiming at increasing fresh fruit and vegetable consumption (see Chapters 3 and 7) coincide with the profit-seeking behavior of numerous businesses ready to supply quality produce that meets retailer and consumer expectations (see Chapters 1, 5, 6 and 8). Fresh produce businesses have been expanding rapidly in recent years and have been supported by the novel postharvest research that dynamically alters the ability to raise, store, pack and deliver fresh produce year-round to any destination in the world (see also Chapters 13, 16 and 18). Mathematical modeling of quality attributes has reached a stage where it can assist distribution logistics (Chapter 15). Smaller growers who supply local markets will seek to expand production to lands marginally suited to growing fruits and vegetables, but the most popular fruits are bananas, apples, oranges and grapes. These popular fruits reflect the achievement of combined production, postharvest and logistic efforts, while the emerging trends will reflect primarily the progress in postharvest handling and genetics (see also Chapter 19). It is unclear how local production will be able to meet consumer demand. Vegetable crops are more likely to be supplied locally in season. Consumers in colder climates are more dependent on long-term storage, long-distance shipments, glasshouse production and further processing of fresh vegetables out of season. It is against this background that the newest efforts in fresh fruit marketing focus on widening the variety by making other fruits accessible to consumers.

Postharvest handling has become increasingly sophisticated because of the growing international fresh produce trade, consumer preference for variety, increasing awareness of beneficial nutritional properties of fruits and vegetables and price premiums for supplying out-of-season high-quality fresh produce. Advances in marketing and distribution of tropical fruits provide consumers with a wider range of choices in the retail market (Chapter 10). The conceptual framework of a systems approach matches the expansion of corporate retailing as the systems approach stems from the management science (see Chapters 1, 2 and 6). The growth of supermarket and hypermarket chains on an international scale has characterized the last two decades. We are in the golden age of postharvest science and technology, but to apply research results effectively and at acceptable costs requires broad, informed thinking. From the cost-accounting standpoint, postharvest systems continually search to reduce costs of the most expensive operations.

Not all who want to or should increase their fresh produce consumption can afford to pay the supermarket price. For example, in many developing countries, the customer segment frequenting supermarkets consists of well-off households, leaving the majority of consumers to satisfy their preferences for fruits and vegetables at different outlets or in different ways altogether (see also Chapter 7). To meet their needs, suppliers and distributors need to apply a modified set of postharvest practices. These practices must ensure quality, but at a cost that permits pricing that matches ability to purchase. The challenge is to select the appropriate practices given the climatic conditions and infrastructure, but that meet quality expectations and safety levels comparable to that associated with the system of corporate fresh produce procurement and imposed by regulations (see Chapter 8). Consumers with lower resources have been underserved, but if growth opportunities elsewhere become limited, they could attract the attention of entrepreneurs.

Increasing incomes and rapid information flow induces the demand for variety, stimulating the international trade in fresh fruit and vegetables. As the concerns about pest transfer through international shipments subside because of the new postharvest handling practices that eliminate or reduce the potential threat, domestic fruit or vegetable sectors, which enjoyed protection through phytosanitary regulations, can no longer expect exclusive access to the domestic fresh produce market.

For example, apple growers now compete across the globe with identical or different varieties with the fruit having attributes preferred by consumers. The apple market has become fragmented to increase margins. New varieties are licensed, limiting the supply, while genetically modified (GM) apples that are patented have become available on a commercial scale. These developments fragment the once fairly homogenous domestic or regional apple market. Then there is a growing presence of other fruits competing with apples, some domestic, but more often exotic fruit that is novel to consumers. The expansion of the mix of fruits offered is facilitated by the safety and traceability of new offerings and the world-wide use of Good Agricultural Practices (GAP) (see also Chapter 8).

Nothing can dampen consumer interest in fresh fruits and vegetables as much as a food-poisoning outbreak associated with a specific fruit or vegetable (Chapter 11). Unlike their processed counterparts, fresh items are not preserved and treatments can only slow spoilage or limit the growth of harmful microbes. Food-borne outbreaks associated with fresh fruit and vegetables will be publicized and the responsible parties are more likely to be condemned and sanctioned. Fortunately, consumers associate the outbreak with that specific item and do not tend to generalize to all fresh produce. Such an outbreak can have devastating consequences on growers and distributors of the specific fruit or vegetable implicated. Food safety practices are being adopted throughout post-harvest systems to minimize the chances of an outbreak, but with the volume of product flowing through major operations, a minor error can be magnified into a major problem.

World population will continue to grow exponentially, forcing all aspects of fresh produce chains to look at the sustainability of its operations (Chapter 1). Life-cycle assessment (Gunady et al., 2012) will become essential for any item shipped in major distribution channels. Water and energy use, contribution to global warming and eutrophication are concerns in the preharvest system. Conservation of water and energy will become increasingly critical during handling, sorting, transport and storage within postharvest systems. Minimizing waste of associated packaging along with the loss of fruits and vegetables themselves will demand more attention, particularly items which travel further in the chain, as all inputs accumulate between field and consumer. In developed countries, much of the food waste occurs at the consumer level (Chapter 2). Part of this waste could be avoided with improved acceptance of the food item, when directed to responsive consumer preference segments (Chapters 3 and 4).

The interface between preharvest operations and postharvest systems are becoming blurred and in some cases are likely to merge into a single entity with many parts. If the desires of health professionals to increase fruit and vegetable consumption by consumers at all income levels are to be realized, the needs of consumers must be carefully studied and better understood.

With all of these opportunities, the future looks bright for handlers of fresh produce. A systems approach will become even more critical to meet the new challenges during postharvest handling. The conceptual frameworks for systems thinking developed recently for a wide range of businesses will be increasingly applied to fresh produce businesses (Jackson, 2003; see also Chapters 1, 2 and 6). Researchers, business leaders, government agencies, associations, consumer groups and others will apply methodologies from systems thinking to continually improve the delivery of fresh produce that satisfies changing consumer expectations of quality, safety, nutrition and costs.

Bibliography

Florkowski, W.J., Prussia, S.E., Shewfelt, R.L., Brueckner, B., 2009. Postharvest Handling: A Systems Approach, second ed. Academic Press, San Diego.

Gunady, M.G.A., Biswas, W., Solah, V.A., James, A.P., 2012. Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (*Lactuca sativa*), and button mushrooms (*Agaricus bisporus*) in Western Australia using life cycle assessment (LCA). J. Cleaner Prod. 28, 81–87.

Jackson, M.C., 2003. Systems Thinking, Creative Holism for Managers. John Wiley & Sons, Chichester, England.

Shewfelt, R.L., Prussia, S.E., 1993. Postharvest Handling: A Systems Approach. Academic Press, San Diego.

This page intentionally left blank

Index

Note: Page numbers followed by "*f*", "*t*" and "*b*" refer to figures, tables and boxes, respectively.

D

G

H

I

J

Q

R

S

U

V

W

X

Y

Z