1 Introduction

Importance of fruit and vegetables as food

Fresh fruit and vegetables have been part of human diets since the dawn of history, although most societies have tended to value foods from animal sources more highly. Societies with largely or totally vegetarian diets, for religious or economic reasons, have had a greater dependence on fruit and vegetables. With the assistance of modern nutritional science, the profile of fruit and vegetables has risen considerably and health professionals, particularly in developed countries, are actively recommending increased consumption of fruit and vegetables and restricted consumption of animal foods.

The nutritional value of some fruits and vegetables was recognised in the early 17th century in England. One example is the ability of citrus fruit to cure scurvy, a disease widespread among naval personnel. While individual captains took advantage of this knowledge to maintain the health of their crews on long voyages, it was not until the late 18th century that the British Royal Navy issued a regular ration of lime juice to all sailors, leading to their nickname, 'limeys'.

Ascorbic acid (vitamin C) was not discovered as the ingredient responsible for preventing scurvy until the 1930s. It has since been shown to have a range of beneficial effects related to wound healing and as an antioxidant. There is now also considerable speculation about its possible action as an anti-viral and anti-cancer agent. Dietary sources of vitamin

C are essential, since humans lack the ability for its synthesis. All fruit and vegetables contain vitamin C; as a group, they are the major dietary source of the vitamin, supplying about 90 per cent of bodily requirements in virtually all countries.

Specific fruits and vegetables are also excellent sources of the provitamin A carotenoids, which are essential for maintenance of ocular health; and folic acid, which prevents certain anaemias. FAO and WHO have been actively promoting the use of home vegetable gardens for many years, as an inexpensive, readily available way to combat vitamin deficiency diseases in less developed regions.

The recent rise in nutritional importance of fruit and vegetables has been stimulated by a range of degenerative diseases prevalent in sedentary affluent societies, particularly in Western countries. Epidemiological evidence shows that communities who consume higher amounts of fruit and vegetables have lower incidences of such diseases. Fruit and vegetables is one of the five food groups used by nutritionists to promote a healthy diet; a common recommendation is for at least seven servings of fruit and vegetables to be consumed every day.

Concerns over obesity and coronary heart disease have led to the promotion of reduced levels of fat in the diet, while dietary fibre is considered to be beneficial in reducing or preventing a raft of medical conditions including colonic and rectal cancers, diabetes, diverticulitis, gallstones, haemorrhoids, hiatus hernia and varicose veins. Fruit and vegetables are generally low in fat and reasonably high in dietary fibre and are thus promoted as a substitute for animal-based foods and highly refined plant-based foods. There is now also considerable interest in determining the potential of fruit and vegetables to protect against various cancers, due to the antioxidant properties of a range of their constituents, including phenolic compounds and carotenoids such as ß-carotene and lycopene. However, clinical trials to date have not generated conclusive support for the anti-carcinogenic activity of any carotenoid.

The status of fresh fruit and vegetables has also benefited from an international trend towards fresh, natural foods; these are perceived to be superior to processed foods and to contain less chemical additives. This community perception has, however, placed additional pressure on the horticultural industry to retain its fresh, natural image by minimising the use of synthetic chemicals during production and postharvest handling.

Notwithstanding their nutritional status and their appeal as fresh and natural foods, the attraction of fruit and vegetables for many consumers is the sensory stimulation they impart. Fruit and vegetables provide variety in the diet through differences in colour, shape, taste, aroma and texture that distinguish them from the other major food groups of grains, meats and dairy products. The sensory appeal of fruit and vegetables is not confined to consumption but also has market value. Their colour and shape diversity is used to great effect by traders in arranging product displays to attract potential purchasers (Plate 1), and chefs have traditionally used fruit and vegetables to enhance the attractiveness of prepared dishes or table presentations. The use of parsley and similar herbs to adorn meat displays is widespread throughout the Western world, while fruit and vegetable carvings have become an art form in countries such as Thailand, where they are used as table ornaments.

While the nutritional composition of ornamental horticultural crops is inconsequential to consumers, flowers are increasingly being included in prepared mixed salads and therefore can make a limited contribution to the diet. However, the principal contribution of ornamentals is their provision of sensory pleasure and serenity, derived from the colour, shape and aroma of individual species. Apart from the more traditional home uses of garden plants and cut flowers, foliage and flowering plants are increasingly being used in the interiorscapes of commercial premises, including offices, hotels and restaurants. The importance of ornamentals in a society's cultural life should not be underestimated. Considerable commercial opportunities arise from their role in ceremonies such as weddings and funerals, in conveying messages on special occasions such as Mother's Day and Valentine's Day, as decorations in parades and rallies, and in art and creative pastimes, as reflected in the growth of ikebana schools. Ornamentals are given official national status too, since most countries have a flower as one of the symbols of state.

Horticultural production statistics

Fruit and vegetables

Worldwide production of fruit and vegetables has been increasing over many years, partly in response to population growth but also due to rising living standards in most countries and active encouragement by government health agencies of fruit and vegetable consumption. Table 1.1 shows that total world production of fruit and vegetables has doubled in the 23-year period of 1980–2003. The bulk of this increase was due to China, which has shown a 7-fold increase in production and in 2003 accounted for about one-third of world production. The second greatest producer is India, which now accounts for about 10 per cent of world production. While fruit and vegetable production in India doubled over the 23-year period, this was in proportion with the world increase. The increases in China and India are understandable given their large populations and rapid rates of economic growth. Most of the production growth from other countries has also been in developing countries, with only relatively small increases in traditional producers such as USA and Spain. France and Japan are no longer in the top 10 producers, with production declining from 21 million tonnes to 18 and 16 million tonnes, respectively, over the 23 years.

Table 1.1 Major national producers of fruit and vegetables

Country	Production (millions of tonnes)				Percentage of 2003 world production
	1980	1990	2000	2003	
China	67	150	388	483	37
India	56	76	119	128	10
USA	52	56	68	66	5
Brazil	23	36	43	42	3
Turkey	21	27	35	37	3
Italy	34	32	34	31	2
Spain	21	24	28	29	2
Iran	8	15	24	24	2
Mexico	12	16	23	24	2
Egypt	10	13	21	22	2

SOURCE FAO Statistical Yearbook 2004. FAO, Rome, 2005.

The international trade in fruit and vegetables grew rapidly until about 1990, to around US$50 billion, but little growth has occurred since that time. The recent lack of growth is probably due to the saturation of markets in developed countries, particularly within the European Union (EU), the major importing region for fruit and vegetables. Statistics on imports and exports of fruit and vegetables are distorted, because certain countries act as transit centres for imports, which are then re-exported to other countries in their region. An example is Belgium, which does not produce bananas but exports them to the value of $660 million – a value greater than that of Costa Rica (about $500 million), a major world producer. Table 1.2 lists the major countries involved in import and export. The 15 EU countries (as at 2000) were the major importers of fruit and vegetables, followed by USA and Japan. The EU and USA are also major exporters. Of the developing countries, China, Mexico and Turkey are important exporters. Many developing countries have targeted fruit and vegetables as a national export specialty. This strategy has been aided by the more relaxed trade barriers to fresh fruit and vegetables in developed countries compared to many other agricultural commodities.

Table 1.2 Major international traders in fruit and vegetables in 2000

Imports		Exports	
Country	**% of total world value**	**Country**	**% of total world value**
EU	25	USA	17
USA	20	EU	11
Japan	12	China	8
Canada	6	Mexico	7
		Turkey	4
		Canada	4

SOURCE E. Leguen de LaCroix, The Horticulture Sector in the European Union. European Commission, Directorate General for Agriculture, 2003.

Ornamentals

Reliable statistics on the production and trade in ornamentals are difficult to obtain. Nonetheless, it is well established that ornamentals comprise a very important sector of horticulture. Ornamental crops include cut flowers and foliage, flowering and foliage pot plants, bedding plants, and containerised shrubs and trees. These crops constitute part of the lifestyle horticulture industry, which also includes turf.

Worldwide consumption of floral crops was around US$25 billion per annum in 1990. In 1995 the total world markets for cut flowers and potted plants were suggested to be US$31 billion and US$19 billion, respectively. Total floriculture product exports in 2001 were considered to be US$7.3 billion, comprised of US$0.5 billion for bulbs, US$2.7 billion for plants, US$3.6 billion for cut flowers, and US$0.5 billion for cut foliage.

The world trade in ornamentals is dominated by Europe and most notably by the Netherlands. Rose and kalanchoe head the top 10 cut flower and pot plant lists, respectively, of lines supplied in 2005 through the Dutch auction system (Table 1.3). In 2001, exports of cut flowers were dominated by the Netherlands (US$3.7 billion) with the next major exporters being Colombia, Canada, Belgium and Italy, each at US$0.3–0.4 billion.

Table 1.3 Top 10 cut flowers and pot plants in the Dutch 'Bloemenveiling Aalsmeer' (VBA) auction system in 2005

Cut flower	Volume (millions of stems)	Pot plant	Volume (millions of units)
Rose	1979	Kalanchoe	31
Tulip	668	Hyacinth	15
Spray chrysanthemum	545	Phalaenopsis (orchid)	15
Gerbera	272	Dracaena (dragon tree)	14
Lily	141	Ficus	13
Freesia	126	Pot rose	13
Alstroemeria (Peruvian lily)	124	Pot chrysanthemum	12
Gypsophila (baby's breath)	73	Saintpaulia (African violet)	12
Hypericum	63	Daffodil	10
Carnation	57	Spathiphyllum (peace lily)	10

SOURCE Key Figures 2005, Bloemenveiling Aalsmeer: www.aalsmeer.com, accessed 23/6/2006.

Due to allied secondary industries (e.g. florists and plant hire businesses) that rely on fresh ornamentals of high quality, postharvest (postproduction) handling is a critical issue. Compared with fruit and vegetables, ornamentals have higher multiplier value in terms of their use by secondary industries. Relative added value multipliers of around 0.5, 0.4 and 8.0 have been proposed for the fruit, vegetable and ornamental industries, respectively.

Need for postharvest technology

Fruit, vegetables and ornamentals are ideally harvested at optimum eating or visual quality. However, since they are living biological systems they will deteriorate after harvest. The rate of deterioration varies greatly between individual products depending on their overall rate of metabolism, but for many it can be rapid. For simple marketing chains where produce is transferred from farm to end user within a short time period, the rate of postharvest deterioration is of little consequence. However, with the increasing remoteness of production areas from population centres in both developing and developed countries, the proliferation of large urban centres with complex marketing systems and the growth in international trading, the time from farm to market can be considerable. The deliberate storage of certain produce to capture a better return adds to this time delay between farm and end user, by extending the marketing period into times of shorter supply. Thus the modern marketing chain puts increasing demands on produce and creates the need for postharvest techniques that allow retention of quality over an increasingly longer period.

Extending the postharvest life of horticultural produce requires knowledge of all the factors that can lead to loss of quality or generation of unsaleable material. The field of study that adds to and uses this knowledge in order to develop affordable and effective technologies that minimise the rate of deterioration is known as postharvest. The increased attention afforded postharvest horticulture in recent years has come through the realisation that faulty handling practices after harvest can cause large losses of produce that required substantial inputs of labour, materials and capital to grow. Informed opinion now suggests that increased emphasis should be placed on conservation after harvest, rather than endeavouring to further boost crop production – as this would appear to offer a better return for the available resources of labour, energy and capital.

The actual causes of postharvest loss are many, but they can be classified into two main categories. The first of these is physical loss. Physical loss can arise from mechanical damage or pest and disease damage resulting in produce tissue being disrupted to a stage where it is not acceptable for presentation, fresh consumption or processing. Physical loss can also arise from evaporation of intercellular water, which leads to a direct loss in weight. The resulting economic loss is primarily due to the reduced mass of produce that remains available for marketing but can also be due to a whole batch of a commodity being rejected because of a small proportion of wasted items in the batch.

Loss of quality is the second cause of postharvest loss, and this can be due to physiological and compositional changes that alter the appearance, taste or texture and make produce less aesthetically desirable to end users.

The changes may arise from normal metabolism of produce (e.g. senescence) or abnormal events (e.g. chilling injury) arising from the postharvest environment. Economic loss is incurred because such produce will fetch a lower price. In many markets there is no demand for second class produce, even at a reduced price, which leads to a total economic loss even though the goods may still be edible.

In tropical regions, which include a large proportion of the developing countries, these losses can assume considerable economic and social importance. In developed regions, such as North America, Europe and Australia/New Zealand, postharvest deterioration of fresh produce is often just as serious, although often for different reasons. As the value of fresh produce may increase many times on its journey from the farm to the retailer, the economic consequences of deterioration at any point along the chain are serious. When farms are located near towns and cities, faulty handling practices are often less of a problem, because the produce is usually consumed before serious wastage can occur. Even in the tropical regions, production of some staple commodities is seasonal, and there is a need to store produce to meet requirements during the off-season. In industrialised countries and in countries that encompass a wide range of climatic regions, fresh fruit and vegetables are frequently grown at locations remote from the major centres of population. Thousands of tonnes of produce are now transported daily over long distances, both within countries and internationally. Fresh fruit and vegetables are important items of commerce, and there is a huge investment of resources in transport, storage and marketing facilities designed to maintain a continuous supply of these perishable commodities. Postharvest technology aims to protect that investment.

While the magnitude of losses of horticultural produce during postharvest and marketing operations are widely acknowledged to be considerable, few studies have accurately quantified these losses. Part of the difficulty in quantifying postharvest losses is identifying the actual steps in the postharvest chain where the loss was induced. It is not uncommon for a physical or metabolic stress to be imposed on produce but not visually evident until later in the marketing chain. For example, exposure to excess field heat after harvest can advance general senescence, but visible symptoms such as loss of green colour may not occur for days or weeks. Also, the visible cause of loss may not be the actual cause; for example, chilling injury of tomatoes is induced by prolonged storage at sub-optimal temperatures, but visual symptoms are usually mould growth on the damaged tissues and not the chilling injury itself.

The Inter-American Institute for Cooperation on Agriculture (IICA) has worked for many years to develop thorough assessments of postharvest systems that minimise the need for large scale quantitative measurements. Their work has resulted in the generation of a practical manual (the Commodity Systems Assessment Methodology tool, Postharvest Institute for Perishables, www.uidaho.edu/uipip/index.html) that can guide the systematic identification of postharvest problems within any horticultural situation. Application of the methodology, however, requires an interdisciplinary team approach, as knowledge of all the pre-production, production, harvest, postharvest and marketing operations that comprise any commodity handling system is required.

Postharvest technology

The ultimate role of postharvest technology is to devise methods by which deterioration of produce is restricted as much as possible during the period between harvest and end use, and to ensure that maximum market value for the produce is achieved. This requires a thorough understanding of the structure, composition, biochemistry and physiology of horticultural produce, as postharvest technologies will be mainly concerned with slowing down the rate of produce metabolism without inducing abnormal events. While there is a common underlying structure and metabolism, different types of produce vary in their response to specific postharvest situations. Appropriate postharvest technologies must be developed to cope with these differences. The variation in response can also be important between cultivars of the same produce and also often between different maturities, growing areas or seasons.

The principal weapon in the postharvest armoury relates to controlling the storage environment and handling conditions. Control over temperature is the most important environmental factor, as it affects the rate of postharvest deterioration from all causes. Fresh horticultural produce must be kept within a certain temperature range. The lower limit is the freezing point of plant tissues (about –2°C to 0°C) and the upper limit is the point at which plant tissues start to collapse (around 40°C). The effects of temperature are not uniform over the range. Moreover, there are time/temperature relationships, such that produce can withstand abnormally high or low temperatures for a short period. Thus, detailed knowledge of the responses of particular produce across the temperature range is essential in determining optimal storage temperature conditions. In general, the ideal postharvest temperature is just above the freezing point, where metabolism is slowest; but other factors, such as the onset of abnormal metabolism at reduced temperatures, can limit the use of low temperatures. The suppression of microbial growth at reduced temperatures is also a major consideration in many postharvest systems.

Other important environmental conditions are the concentration of certain gases and water vapour in the atmosphere around produce. Maintenance of a high relative humidity atmosphere is necessary to minimise water loss – a key quality factor, since wilted or shrivelled produce has a greatly reduced market value. The use of modified and controlled atmospheres, utilising elevated carbon dioxide and reduced oxygen levels from the normal atmosphere concentrations of around 0.033 per cent and 21 per cent, respectively, has been known for many years to beneficially affect produce metabolism; but the difficulties in adequately containing gas levels within the beneficial range has restricted the use of this technology to a few commodities. The recent development of plastic films with variable gas permeability and other atmosphere-control features has re-ignited interest in modified atmosphere storage. The presence of ethylene in the atmosphere has been of concern in the postharvest handling of ornamentals and unripe climacteric fruit for many years, because it promotes abscission, ripening and senescence, but its presence around non-climacteric fruit and vegetables is also important.

The major abnormal postharvest events are physiological disorders, arising from adverse postharvest and preharvest environmental conditions or mineral imbalances arising during growth; and microbial decay arising from a range of bacteria and moulds that can infect produce before and/or after harvest. Apart from ensuring that produce is not exposed to the causative factors, control measures in the past have tended to focus on synthetic chemicals. However, with current consumer concerns, there is a trend towards the use of natural compounds or physical treatments. Postharvest insect infestation tends not to be a serious problem, except where the insect is subject to quarantine restrictions (e.g. fruit flies) – then it becomes a major technical and international and regional trade issue.

Apart from generating information on the effects of environmental conditions on particular produce, postharvest research must develop technology that is user-friendly and cost effective, to enable the scientific knowledge to have commercial value. Technical information can be used to either adapt existing technology, such as the refrigerated container, which created a mobile cool storage chamber; or to design new technology, such as vapour-heat treatments for insect disinfestation. Packaging design is one facet of technology development, since packages are required to protect their contents from physical damage and contamination, while at the same time meeting other marketing criteria.

Once loss of quality and wastage in the postharvest chain are under control, the next goal is responsiveness to market needs in terms of consumer expectations about quality, safety and presentation. This has forced marked changes in quality assessment, which was originally limited to grading operations in the packing house for size or weight, the removal of defects, and ensuring the correct labelling of containers. It has now become a total quality management (TQM) operation, to ensure that all market specifications are met and that the enterprise operates in the most efficient manner. Quality is thus linked with profitability, and the successful implementation of TQM requires a complete understanding of all factors that affect produce and the market environment in which produce is traded. Thus, quality management starts in the field and continues until produce reaches the end user. Staff training is now an integral part of quality management, as individuals or work teams are empowered to take responsibility for ensuring predetermined quality criteria are met.

Fresh fruit and vegetable produce that is cut or lightly processed, making the original commodity more convenient for consumers, has become an important and expanding presence on supermarket shelves. However, such processing invariably increases metabolism and renders produce more susceptible to microbial attack and adverse environmental conditions. It is often a challenge to develop the technology that retains quality in such products for the desired market period at a reasonable cost.

Applications of molecular biology are of increasing interest to researchers in overcoming specific postharvest problems. While a number of genetically modified (GM) products have been developed, such as tomatoes that remain firm over an extended period through inhibition of the polygalacturonase enzyme system, commercialisation has been almost non-existent as consumers remain resistant to accepting GM foods. There is likely to be less resistance to the development of GM ornamentals, since these are not consumed. Carnations with an extended shelf life through diminished production of ethylene have been developed, but again commercialisation is limited. There needs to be a marked demonstrable benefit to growers, traders and consumers before GM produce can have a reasonable chance of commercial success.