CHAPTER

2

Postharvest Losses and Waste

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2.1 INTRODUCTION

Horticultural products are important to the human diet and health. They constitute a good source of energy, carbohydrates, calcium, phosphorus, iron, magnesium, dietary fiber, and vitamins (e.g., A, B6, B12, and C), essential amino acids (e.g., thiamine, riboflavin, and niacin), in addition to other hundreds of phytochemicals essential for human nutrition and health. Fruits and vegetables provide >90% of vitamin C in human food. Horticultural food products are essential for maintaining the gut microbiome, which in turn has a profound positive impact on overall human health. In addition, fruits and vegetables provide bioactive compounds, such as phenolic compounds (i.e., phenolic acids, stilbenes, flavonoids, lignans, coumarins, and tannins), phytotestorols and organosulfur compounds, many of which have activity as antioxidants and in controlling enteropathogens growth. All of the above are available within the vast variety of options in the horticultural realm that assures the possibility for healthy diets while providing satisfying taste. Fruit and vegetables in the 21st century are increasingly recognized as key to achieving the end of hunger and contributing to enhanced food security and nutrition, and ultimately contributing to the overall improvement of human health and well-being.

While a lot of efforts have been invested in raising awareness of the importance of fruits and vegetables in providing a diversified and nutritious diet that contribute to human well-being in the long term, the consumption of fruits and vegetables in the last several decades has not necessarily increased as much as has other food products. For example, animal products providing dietary fats and proteins and processed sugars have shown steady increases in almost all countries. Based on the estimation of product availability (production data, combined with import/export), only a few countries appear to have enough fruit and

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vegetables to fulfill the per capita recommendation of the World Health Organization of 400 g per capita per day. An estimation for the per capita consumption of fruits and vegetables is often limited, given the lack of an accurate estimation of postharvest losses. In fact, it is expected that taking into account postharvest losses, only a negligible portion of the global population would achieve the recommended intake.

Postharvest losses and waste (PHLW) of horticultural commodities are very significant all over the world, but they vary greatly among commodities, cultivars/varieties, seasons, production areas and handling systems. Both losses and waste may occur during all phases of the supply and handling chain, including at harvest, during transport to packing houses or markets, sorting, grading, classification, storage, marketing, processing, and at home before or after preparation. More specifically, postharvest losses occur throughout the supply chain from harvest throughout all postharvest stages before consumption. They are an unintended result of the way production and produce supply chain systems function in their technical, institutional, and legal frameworks. Waste, on the other hand, is produce that is fit for consumption but is not consumed and instead discarded; it is usually associated with the consumer's or retailer's behavior. Although losses may be considered distinct from waste, notably because each has its own particular causes and solutions, they are nonetheless interrelated and sometimes difficult to distinguish. For example, fresh produce spoiled at the retail level could be considered either loss or waste depending on whether the main cause was the lack of logistics coordination/mishandling (in this case, it would be "loss") or discards due to consumer preference for perfect visual appearance (in this case would be "waste"). Therefore, both terms (loss and waste) will often be referred to in conjunction as PHLW throughout this chapter.

PHLW are both quantitative and qualitative. Quantitative losses refer to mass or volume, where losses reduce the amount of produce available for consumption. Quantitative losses are commonly expressed in units of weight, monetary value (currency), and energy value (calories). The selection of the way to report losses and waste has often been associated to priorities of the informant. Clearly, all the modes of reporting show pros and cons, as discussed later in the chapter. Briefly, the monetary value often does not allow to compare the level of impact across diverse places, given that prices are scenario specific and often fluctuate greatly. The energy value is used to determine impact on caloric availability, given the importance for monitoring levels of hunger or food insecurity, but fruits and vegetables are in general low in calories and show great variability among them (e.g., avocado has substantially more calories per weight than oranges or spinach). Measuring weight normally does not capture the entire dimension of the loss, given the rapid loss of water of fresh horticultural commodities. The easy loss of water would mean that a report of losses in the market, for instance, could have a weight substantially lower than when the product was harvested. On the other hand, while most fresh produce show clear visual symptoms of excessive transpiration above 3%–5% of water loss (e.g., shriveling, oxidative injury commonly shown as changes in color), there are products that may lose more than that without consumers noticing it at first sight.

Qualitative losses relate to decreases in edibility, nutrition, caloric value, safety issues, consumer acceptability, and subsequently economic value, which occur before the produce item has been discarded, consumed, or utilized in another way. Qualitative losses and waste are

very difficult to assess and quantify. Qualitative losses are mostly perceived in the supply chain as economic losses. However, the latter is highly dependent on supply and demand in the market, as well as on the existence of institutional frameworks that impact quality standards to different levels. For example, in many countries the presence of supermarket chains has shaped the expectation of consumers for certain visual attributes in products, such as size, color, or shape. However, under conditions of high demand and low supply the regulation of those standards are clearly not as stringent.

Qualitative losses are a major challenge in postharvest systems and economic development, especially in the developing world, particularly because they can affect poor value chain actors including producers, handlers, and consumers because of the shortage of postharvest techniques for proper handling. Qualitative losses are often associated with a lack of basic supplies and conditions to properly handle fresh produce, something that is less of an issue for those that can afford means to improve logistic systems (e.g., information, containers, cooling, storage, transportation, and marketing). The produce with decreased quality is then channeled (when not quantitatively lost) through systems that further increase the risk of quality deterioration and even food safety. Moreover, the concept of qualitative losses is further evolving to include the so-called credence values, or parameters. The recognition of those quality aspects in relation to postharvest losses are not well studied, despite the evidence for a growing population that is purchasing food on the basis of those factors that often are a mix of freshness, local production, small scale sustainable production, and social and environmental integrity, which are often not so easy to prove to the consumer.

The proper handling of fresh horticultural commodities and subsequent reduction of PHLW require the understanding of the biological and environmental factors involved in postharvest deterioration. Moreover, it implies the proper use of available postharvest technologies and procedures that can slow down deterioration and maintain quality and safety of the produce. Finally, it requires the understanding of the social context in which the product is handled, as proper handling is in the end often reduced to quick decisions of people, who often lack the capacity to adapt knowledge due to educational or cultural issues.

While zero losses or waste of food is conceived as one of the challenges to overcome in order to achieve the United Nations vision for zero hunger, a certain level of losses and waste under the current circumstances of the planet should be acceptable, as the cost to completely avoid losses and waste may not be realistic and/or affordable. Sometimes losses are even desirable. For example, by sorting out damaged or decayed produce early in the postharvest chain (e.g., at harvest or during initial packing), these discards or culls can be prevented from causing more postharvest losses and waste later on in the value chain, when the economic and environmental cost will be higher. Leaving damaged/decayed produce in clusters of produce during postharvest handling activities can result in cross contamination that can increase the possibility of a proliferance of opportunistic microorganisms in other fruits or vegetables. Proper management of losses is even a way to prevent more losses in the future. For instance, in the field, fruit that is discarded at harvest should be removed from the field because damaged and infested fruit left to decay in the field will increase the possibility for latent pathogens to eventually proliferate in the next harvest season, therefore causing potential losses of the next crop.

2.2 IMPORTANCE AND MAGNITUDE

PHLW of horticultural commodities are high in developing countries as well as in developed countries but varies at different points of the handling chain. It is common that losses are higher in developing countries due to a lack of proper handling techniques from farm to market, while waste at the retail and consumer levels are higher in developed countries or regions, especially where visually based quality standards are utilized to market produce. Kader (2005) estimated that approximately 1/3 of all fruits and vegetables produced worldwide are lost during the postharvest period (excluding waste after reaching the consumer) and do not reach the consumer. A tentative estimate of postharvest losses (harvest to retailer) in the United Kingdom are suggested to be 9%, not including produce left in the field that fail to meet cosmetic and quality criteria. The total value of fruit and vegetable losses at the retail and consumer levels in the United States was estimated at $42.8 billion in 2008 or roughly $141 per capita (Buzby et al., 2011).

It has been estimated by the FAO led Global Initiative on Food Loss and Waste Reduction (known as SAVE FOOD) that at least 1/3 of the food produced in the world (an equivalent to at least 1300 million metric tons) are lost and wasted every year (FAO, 2011). In addition to the loss of food that could be part of a healthy diet, food loss and waste reflects a tremendous misuse of resources, such as land, forests, water, fertilizers, chemicals, energy, labor, and results in tremendous economic losses. The vast amounts of wasted food also contribute to immense environmental problems as they decompose in landfills and emit harmful greenhouse gases. Food waste management is one of the most critical problems local governments deal with whenever local landfills reach capacity. Moreover, food is often handled in plastic containers and packages, which are not often recycled in many countries, subsequently resulting in additional serious waste and pollution to the environment.

Perishable horticulture commodities are the category of food that represents the most losses and waste when measured by weight. It is estimated that global losses and waste of perishable horticultural commodities reach up to 60% depending on the type of commodity, season and location (FAO, 2011). While there is some uncertainty on the exact numbers due to a wide variety of measurement methods in use, there is sufficient evidence suggesting that tropical fruits and leafy green vegetables may suffer losses as high as 80%, especially during rainy seasons, before reaching a formal market.

Perishable products present serious difficulties in handling as well as a wide propensity for losses and waste. Much of the information describing PHLW of horticultural food commodities are estimates because accurate data are very scarce. Losses during harvest are not available for many crops in developed countries, as it is considered proprietary (belonging to the food companies that produce or purchase the crop for processing or marketing). In addition, most of the estimates in developing countries are related to postharvest losses and hardly include any data related to postharvest waste. Therefore it is possible that the losses and waste exceed the estimates frequently presented in different forum and publications.

Postharvest losses in developing countries were such a serious concern that the United Nations General Assembly adopted a resolution in its 7th Special Section on September 19, 1975, which established that the reduction in postharvest food losses in developing countries should be considered as a priority issue and should be reduced by 50% by 1985. All countries

and international organizations must cooperate financially and technically in the effort to achieve this goal." The adoption of this resolution has attracted the attention of a number of governments and aid agencies around the world, focusing attention on the serious problem of postharvest food losses in general and the consequence of initiating various actions. However, the deadline has passed, and we are still a long way from reaching the targets set in 1975. A decade later (1985) the value of postharvest losses of perishable products (and fish) was estimated to be approximately $4 trillion. In 2009 the estimation of total food losses was $11 trillion. The continued persistence of high levels of food losses prompted the UN country members to persuade more action. The UN/FAO, in collaboration with the private sector, initiated the "Global Initiative on Food Losses and Waste" (Save Food Initiative) in 2011 to address this problem. In 2015 the United Nations led the new initiative on developing a set of "Sustainable Development Goals" (SDGs) wherein SDG 12 on responsible production and consumption, sets a new target (12.3) for reducing food losses and waste by 50% by 2030.

As mentioned the PHLW of fresh fruit and vegetables vary substantially depending on the type of product, region, postharvest handling, packaging, market, and methods used for estimation, etc. (Table 2.1). Around the world, there is a high concern with fruits and vegetables produced and handled by small/poor holders. They normally lack the capacity to undertake processes that contribute to a longer shelf life of produce, such as having access to knowledge, to infrastructure, and means to transport produce in appropriate containers

TABLE 2.1 Estimates of Global Postharvest Losses in Some Fruits and Vegetables

Commodity	% Losses	References
Avocado	Up to 43	Coursey and Booth (1971)
Banana	20–80	NAS (1978)
Cabbage	Up to 37	NAS (1978)
Carrots	Up to 44	Coursey and Booth (1971)
Grapes, raisins	20–95	Steppe (1976)
Grapes, table	Up to 27	Steppe (1976)
Cauliflower	Up to 49	Coursey and Booth (1971)
Lettuce	Up to 62	Coursey and Booth (1971)
Onions	16–35	Coursey and Booth (1971), Steppe (1976)
Papaya	40–100	NAS (1978)
Plantain	35–100	NAS (1978)
Potatoes	5–40	FAO (1977)
Stone fruits	Up to 28	Steppe (1976)
Sweet potatoes	35–95	Coursey and Booth (1971)
Tomato	20–50	Coursey and Booth (1971), Steppe (1976)
Yams	10–60	FAO (1977)

and vehicles. Small farmers are still today producing a significant share of the fresh produce around the world, and in the least developed countries, it is likely that the majority of the fresh produce comes from small holder production and logistics. Following general principles for achieving adequate postharvest handling can be a struggle for them. The most basic general principles or rule of thumbs are to harvest in cool weather or early in the morning and handle produce quickly and gently. However, the conditions are often just the opposite: the harvest is conducted during hot weather and produce is handled roughly or is exposed to the rain or sun, resulting in losses that can be very high. In some cases the produce may be lost completely. It is therefore important to take into account that the available information on the losses of these products is relative to specific situations of different products and regions. On the other hand, studies to estimate postharvest losses often use ad hoc methodologies that can produce different results. However the basic information generated (regarding the types, amounts, causes, and sources of losses) are useful in establishing appropriate management programs for reducing losses for these perishable foods. Very variable results (5%–95%) on PHLW of fruits and vegetables have been reported during the last decades based on different methodologies (Table 2.1). The losses reported were observed:

1. In the field, especially during harvest, mostly due to the lack of experience of the collectors, type and perishability of the product, degree of maturity, handling methods, and/or harvesting tools.
2. During packing in the field or in the collection center or packing house, especially during sorting and classification of products, due to mechanical damage and when some of these products are sorted out because they do not meet the standards established by the market, such as size, weight, shape, color, etc.
3. During transportation, depending on the mode, the distance and time required for travel, type of product, type of containers, conditions of roads, temperature management, etc.
4. During storage, whether in traditional facilities or modern cold storage, use of inadequate temperatures, relative humidity, and other storage components.
5. During marketing, depending on the state in which the products arrive to markets, type of markets (open markets, outdoors or covered, indoor markets, with or without refrigerated displays), handling during marketing, temporary storage, temperature management, etc.
6. At home during handling, preparation, and consumption.

2.3 CAUSES OF PHLW

Fresh horticultural commodities are living organisms whose quality and postharvest life are affected by various factors, such as temperature; humidity; composition of the surrounding atmosphere; the level of damage that can be caused before, during, and after harvest; and the type and degree of infection with microorganisms, attacks by insects, etc. These products are easily affected by less-than-optimal handling conditions and can be lost or wasted during the postharvest period due to many possible causes, such as the following:

- Loss of moisture
- Loss of reserve materials such as carbohydrates

- Loss of other nutrients such as vitamins
- Physical loss due to different types of mechanical damage
- Losses and waste by pests and diseases
- Losses of quality due to physiological disorders
- Fiber development (toughness)
- Greening of some products (e.g., potatoes) when exposed to light
- Growth as in the case of carrots, potatoes, and onions
- Germination of seeds

The causes of PHLW are very diverse and can be generally divided into primary and secondary causes.

2.3.1 Primary Causes

The following five primary causes result in major postharvest losses and waste, which may vary from one region to another:

1. *Biological or microbiological*: These are caused by an attack of insects, bacteria, fungicides, animals, etc., and may result in considerable losses. Typically, postharvest pathogens do not attack fresh produce if it is healthy and in good condition, but wounds, bruises, or other deterioration will increase its susceptibility to an attack.
2. *Chemical or biochemical*: These are losses caused by the chemical or biochemical changes that occur in the commodity and are manifested by the different reactions, among which oxidation (which causes browning among other symptoms), for example, stands out. Biochemical reactions are often triggered by mechanical and physical factors and are part of the physiological process described later. On the other hand, there are also negative effects produced by the different chemicals applied, such as pesticides and insecticides.
3. *Mechanical*: Mechanical damage is a major cause of losses and waste. This problem can be very severe during harvesting, but it also occurs frequently during handling of the product after harvest, especially during packing, with the use of poor quality containers, and during transport (Fig. 2.1A–D).
4. *Physical*: Improper environmental or climate conditions can be a physical cause of losses, as is the case of high and low temperatures, low relative humidity, sunburn, wind, or hail.
5. *Physiological*: These are losses that occur during the natural process of development of the produce (i.e., ripening and senescence), as well as changes due to the processes of respiration and transpiration and anatomical and morphological changes such as the germination of some types of produce such as potato, onion, and carrot.

2.3.2 Secondary Causes

Development agencies in search of facilitating policy makers have also come up with underlying or secondary causes, which derive from the question: "Why are those losses (biological, chemical, physical, physiological) occurring in the first place, and what can be done to avoid them?" These underlying or secondary causes include:

FIG. 2.1 (A–D) Mechanical injury in fresh fruits and vegetables due to different causes, such as inadequate packages, is a major cause of losses and waste.

1. *Inadequate storage systems*: such as lack of or inadequate precooling, temperature management, relative humidity, and atmospheric composition control.
2. *Inadequate transport systems*: including the use of inadequate transport units, inadequate handling during transport, inadequate loading practices, etc. (Fig. 2.2A–E).
3. *Inadequate marketing systems*: such as lack of adequate infrastructure in the market, poor handling, inadequate inventory control systems, delays in marketing, etc.
4. *Lack of knowledge regarding the proper handling of perishable products*: lack of access to postharvest extension or postharvest education on appropriate handling practices by producers, harvesters, packers, traders, processors, and marketers.

Each of these primary and secondary causes of PHLW can be categorized as either biological, environmental, or socioeconomic in nature.

2.3.2.1 Biological Causes

Biological (internal) causes of deterioration include respiration rate; ethylene production and action; rates of compositional changes associated with color, texture, flavor, and nutritive

FIG. 2.2 (A–E) Inadequate transport systems, especially in developing countries, are a major source of losses and waste.

value; water stress; sprouting; physiological disorders; and pathological breakdowns. Biological deterioration of fresh produce will occur more rapidly as temperature increases.

2.3.2.2 *Environmental Causes*

The rate of biological deterioration also depends on several other environmental (external) factors besides temperature, including relative humidity, air velocity, and atmospheric composition (concentrations of oxygen, carbon dioxide, and ethylene) (Fig. 2.3A–C).

2.3.2.3 *Socioeconomic Causes*

Although the biological and environmental factors that contribute to PHLW are relatively well understood and many technologies have been developed based on this knowledge to avoid or reduce these causes, they sometimes have not been implemented in certain regions due to one or more of the following socioeconomic factors.

2.3.2.4 *Inadequate Marketing Systems*

Growers can produce large quantities of good-quality produce, but if they do not have a dependable, fast, and equitable means of getting such commodities to the consumer, losses and waste will be extensive (Figs. 2.4A–C and 2.5A–C). This problem exists in many locations, especially within developing countries, and it is accentuated by a lack of communication between producers and receivers and a lack of market infrastructure and market information. Marketing associations and cooperatives should be encouraged among producers of major commodities in important production areas. Such organizations are especially needed in developing countries because of the relatively small farm size. Advantages of marketing cooperatives include: providing central accumulation points for the harvested commodity, purchasing harvesting and packing supplies and materials, providing for proper preparation for market and storage when needed, facilitating transportation to the markets, and acting as a common selling unit for the members, coordinating the marketing program, sharing risks and distributing profits equitably. Alternative distribution systems, such as direct selling to the consumer (e.g., roadside stands, produce markets in cities, local farmers' market in the countryside, etc.) can be very helpful. Production should be maintained as close to the major population centers as possible to minimize transportation costs. Many wholesale markets in most of the developing countries are in desperate need for improvement in terms of facilities

FIG. 2.3 (A–C) Exposure of fresh horticultural commodities to inadequate environmental conditions, especially high temperatures and low relative humidity, is a major cause of losses and waste.

FIG. 2.4 (A–C) Horticultural commodities are sometimes left to be wasted in the field because of lack of markets or other factors such as lack of resources, lack of capacity to pack, to transport, among others.

FIG. 2.5 (A–C) Local open markets, especially in developing countries, are major sites for losses and waste due to lack of proper infrastructures and proper handling.

and sanitation. These are commonly overcrowded, unsanitary, and lack adequate facilities for loading, unloading, ripening, consumer packaging, and temporary cooling and cold storage.

2.3.2.5 Inadequate Transportation Facilities

In many developing countries, roads are not adequate for the proper transport of perishable food commodities, and transport vehicles and other modes, especially those suited for fresh horticultural perishables, are in short supply. This is usually true for local marketing and for export. Many producers have small holdings and cannot afford to own their own transport vehicles. A more cumbersome problem is that in some countries, transportation is monopolized by a single or a few national associations that block the emergence of small third-party logistics/transportation service providers. Refrigerated vehicles are in short supply and can be very expensive because they have to be imported. In a few cases, marketing organizations and cooperatives have been able to acquire refrigerated transport vehicles, but they cannot do much about poor road conditions and other public infrastructure, which is where the public sector needs to invest and implement public works projects.

2.3.2.6 Government Regulations and Legislations

The degree of governmental controls, especially on wholesale and retail prices of fresh fruits and vegetables, varies from one country to another. In many cases, price controls are counterproductive. Although intended for consumer protection, such regulations can encourage fraud and provide no incentive for producing high-quality produce or for postharvest quality maintenance. Price transparency in key points of the supply chain, as it is the case for public wholesale markets, are measures that have improved conditions for growers to liaise with their brokers. Moreover, regulations covering proper handling procedures and public health aspects (food safety issues) during marketing are, if enforced properly, very important to the consumer. One interesting example has been the enforcement of standard packages and materials (e.g., plastic crates of certain dimensions) that is directed at sustainable postharvest systems, though there is always the challenge of breaking paradigms based on traditional practices for decades.

2.3.2.7 Unavailability of Needed Tools and Equipment

In many cases, especially in developing countries, even if growers and handlers of fresh horticultural crops were convinced of the merits of using some special tools and/or equipment in harvesting and postharvest handling, they most likely will not be available in the domestic market. This is true for harvesting aids, containers, equipment for cleaning, waxing, packing, and cooling facilities. Most of the tools and supplies are not commonly manufactured locally and are usually imported in insufficient quantity to meet demand. Various governmental regulations in some countries do not permit the direct importation of packaging or equipment by producers, regardless of their needs. It is imperative that the tools that will enable produce handlers to use recommended technology for a given situation be available for purchase and use. In many cases, such tools can be manufactured locally at a much lower cost than those that are imported.

2.3.2.8 Lack of Information

Many handlers involved directly in harvesting, packaging, transporting, and marketing of horticultural commodities, especially in developing countries, have limited awareness or no appreciation for the need to cool fresh produce and to handle it gently in order to maintain quality. If they are aware, they may lack the knowledge and skills to choose among the possible options for reducing postharvest damage and losses. Effective and far-reaching educational (i.e., extension/advisory services or outreach) programs on these aspects are very much needed. The availability of needed information on the Internet is an important source. This issue of lack of information may also be present in mid- and large-size organizations, especially in areas where the turnover of employees is high and where there is emphasis on good job induction or on-the-job training processes.

2.3.2.9 Poor Maintenance

In many cases, some very good postharvest facilities are built or purchased, but the lack of maintenance and unavailability of spare parts, especially in developing countries and in the public sector, are very common and are a source of major losses and waste. It is strongly recommended that any project planning to establish a postharvest facility (e.g., packinghouse, precooling unit, cold storage) should include in its plan adequate funds for repairs and maintenance to ensure its success and extended usefulness and sustainability.

2.4 THE UNDEREXPLORED LINKAGES BETWEEN SELECTED FOOD SYSTEM FACTORS AND PHLW

Another way to classify causes of losses is by determining how immediate or direct the impact of the failure in the food supply chain is on the PHLW. In this regard, the losses occurring at one point of the supply chain can be due to: (i) an immediate specific issue (micro causes); (ii) a loss due to a failure in the previous handling stage of the supply chain, or the accumulation of different failures along the supply chain showing the lack of a vertically integrated quality supply system (*meso* causes); or (iii) a dysfunctional structure that impacts in a systemic way the coordination of actors, secure investments, and the adoption of efficient practices in the food system and other related coexisting systems, such as transport (macro causes).

As indicated above the evidence for connecting different factors with PHLW is prominent. However, there is still uncertainty about the weight of certain factors that have started to be mentioned in recent research. Here, we refer more specifically to what could be associated with meso causes and macro causes and the intersecting biological, environmental and socio-economic factors. What follows is a noncomprehensive list that suggests some questions that warrant further research in the near future.

2.4.1 Preharvest Factors

While in general terms sufficient water for the healthy growth of plants is required, the role of water content in the harvested produce on PHLW is not very clear. In fact, it is already

known that preharvest water excess may result in a reduced postharvest shelf life of some leafy vegetables and some fruits, and may decrease sensory attributes (qualitative loss) in vegetable fruits such as tomatoes. Moreover, it is known that regulated (limited) water during the growth of a fruit will tend to produce sweeter fruits associated with higher quality. Water stress is also thought to affect the development of some secondary metabolites in fruits and vegetables. Regulation of water before harvesting is an issue that requires better understanding in the context of PHLW and sustainable food systems. Research is also needed to determine the effect of several other preharvest factors, as those discussed in another chapters of this book.

2.4.2 Logistics for Small Producers and Shippers

Efficiency, with regard to time, to move products immediately after harvest is key to maximizing economic feasibility, improving competitiveness in the market, and reducing overall PHLW. The question is how inclusive can an efficient logistic system be? More specifically, can small producers and handlers develop a logistical system that is as efficient as those that have several or all steps of the supply system in a vertically integrated scheme, or that move large volumes to allow them to benefit from the economy of scale? Some recent research is being developed showing that a combination of good cooperation of small producers with third-party logistics agents can develop a well-performing system that allows them to compete. This, however, is not the norm, and better understanding of the factors that are required for establishing an efficient system is needed. Furthermore, development agencies are exploring and promoting schemes that build on social capital for ensuring a more reliable logistics relationship between growers and transporter or brokers.

2.4.3 Transmission of Knowledge to Newcomers in the Supply Chain

PHLW, in some cases, appear to increase rather than decrease for a series of factors that are mentioned in this chapter. The problem is that the increased PHLW are due to issues that were thought to be resolved in the past. This situation could be due to technology not being adapted to the changing environmental conditions, but in other cases even under similar conditions the PHLW increase in certain supply chains. The fact that handling is done by people suggest issues such as the high turnaround of employees and poor investment in work related trainings, which are important factors contributing to the persistent losses and waste. This analysis has only been done internally in private enterprises. For the general practitioner, the concern to resolve is how to effectively implement knowledge management and particularly the transmission of knowledge from one generation of workers to the next.

2.4.4 Ugly Fruits and Vegetables

"Ugly" produce is a term that has been used lately for produce that does not meet certain standards for mostly superficial cosmetic characteristics such as size, shape, color, blemishes, and uniformity, and so end up most of the time been rejected and wasted. The PHLW due to rejection for cosmetic defects are particularly high in scenarios where formal corporate retail

is well established or is growing at a fast pace. Regardless of where the rejection is done in the supply chain, the food never gets to the consumer. While the link of reduction of PHLW with improved food security is not so tight in all cases, there is no doubt that rejecting and throwing away product for cosmetic reasons is of increased concern. The only justification for nonconsumption of the "ugly" produce would be a food safety risk. More research is needed to determine when blemishes (a term used commonly in quality standards) do pose a food safety risk, given a majority of blemishes would not even involve any rupture of skin. A crooked carrot or a tomato that is too large to fit in the carton packed by count is entirely edible and nutritious foods. In fact a number of species and cultivars of horticultural crops are naturally prone to high incidence of russeting (showing as color oddities on the peel) without affecting other quality attributes (e.g., nutrition, flavor, safety). Commonly, this fact is not clarified in the mandatory or voluntary quality standards, with some exceptions where a certain subsector has been successful in raising awareness of the issue. One clear example was the case of apples cv. Yellow Newtown, for which up to 20% (as supposed to 10% that is for the rest of the varieties) is accepted of smooth russeting in USDA quality standards. More scientific work is needed to develop a good basis to vindicate the benefits of marketing and consuming of ugly fruits, while noting that some chains in Europe and the United States have already started this process.

2.4.5 Indigenous Species and Cultivars

The diversity of diets depends greatly on how much postharvest technology is developed because it has permitted the extension of postharvest and shelf life of produce, thus allowing it to be transported and reach places at the far sides of the globe. However, the development of postharvest technology for only a few selected crops and cultivars has impacted the food industry and decreased consumer options, which have already been increasingly narrowed to only a few. Examples of one to two cultivars of pineapples, avocados, and bananas crossing continents are due to the lack of development of postharvest technologies and systems suitable for many local varieties or alternative fruit and vegetables species. This situation suggests that improved postharvest research is still very much needed to develop postharvest handling systems for local species and cultivars, as well as to determine potential for reducing overall losses of indigenous and little known produce.

2.5 EVALUATION AND ESTIMATION OF PHLW

There is no standard methodology for the evaluation of PHLW, and it is difficult to establish one due to the great diversity of horticultural commodities, their high perishability, the great diversity in handling requirements and value chains, and above all the lack of an objective system to determine the types of losses, especially the qualitative losses.

However, any evaluation or assessment method should consider a definition of terms, classification/categorization of losses, and standardization of data collection, analysis, and reporting methods. The unification of terms allows to standardize the criteria in the use of

concepts, and the categorization of causes allows PHLW evaluators to know the impact of each of the causes and sources within the total losses and waste.

PHLW are generally translated into the disappearance of food from the supply chain and can be calculated in quantitative, qualitative, economic, or nutritional losses and waste, if the fruit or vegetable is discarded.

Quantitative losses and waste occur when horticultural products are totally discarded. These can be estimated based on well-defined quality standards. Perishable crops tend to lose weight due to losses of water or organic matter.

Qualitative losses can be due to physical damage, decay, or visual issues (colors, sizes, or shapes of produce that are deemed less than optimum for the market).

Nutritional losses and waste are the combination of quantitative and qualitative losses and result in the losses and waste of certain nutritional components, such as vitamins. Nutritional losses can be invisible, but they tend to increase due to inadequate handling conditions such as high temperatures, low relative humidity, and very prolonged storage durations.

Economic losses and waste (decreases in market value) increase as the produce deteriorates, especially in visual quality. Economic losses depend on the amount invested in a postharvest process for a particular type of product in a specific region and which measures in financial terms the contained labor, inputs, investment in machinery, etc. For a certain amount of product (measured in tons), economic losses can be determined by comparing what was invested for its production and handling and what was expected to be obtained through marketing, depending on the price determined by the market at the time of sale.

Three general approaches or methodologies or estimations exist for the assessment of PHLW. The first refers to the global/regional estimations, the second is the single scenario-base analysis, and the third is the experiment-based estimation. Many of the studies on PHLW were performed using one of these methods.

Global and regional estimation. This method identifies the stages where the greatest losses and waste occur. In general terms a loss/waste profile is obtained for the product under investigation. The critical analysis of the stages involved and the number of operations and intermediaries involved in each one allows the expert to judge with a degree of reliability not only where losses are occurring, but also where the postharvest system and handling processes require more attention. Based on this assessment, proposals for loss and waste reduction are made and programs are formulated. Examples of these types of reports are the "Global food losses and food waste" (FAO, 2011) and the "Reducing food losses and waste: Creating a sustainable food future" (Lipinski et al., 2013). In this category the model developed by the Natural Resource Institute under the African Postharvest Losses Information Systems (APHLIS) would also fit. Even though APHLIS is meant only for grains, there is intention in the future to include horticultural commodities. In fact the second generation of the system, namely APHLIS+ will expand crops to include root and tubers (in particular cassava, yam, and sweet potato), as well as plantains and bananas. The combined information from published studies and expert consultation is fed through an algorithm that produces percentages of loss at each link of the value chain (e.g., at harvest, during threshing or storage) and is modified according to the factors for localized estimates. APHLIS+, in addition to looking for an improved model for estimation, will also include value and nutritional losses.

The SDG target 12.3 "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest

losses" will be monitored with a tier III indicator: Global Food Loss Index (GFLI) that measures the total losses of agricultural commodities from the production to the retail level. UN/FAO is the custodian for the target, and while in principle GFLI has been developed, it is currently being tested. The limitations in developing GFLI are essentially the problem of collecting data (e.g., waste, as losses in generally are only reported by a few countries). The GFLI has been suggested to be based on a volume basis by commodity, by country, on an annual frequency. The lack of data is being approached in two ways: (i) developing model-base estimates as an interim for global monitoring, being fed with case studies, empirical data, and review by national and international experts; and (ii) developing cost-effective methods for collecting postharvest losses data and provide capacity development to countries to improve food loss measurement. The Index has been suggested to be measured by two separate indicators, given waste loss requires different approaches. A proposal for measuring food waste, which in this case involves retail and consumption, is under development.

2.5.1 Single Scenario-Base Analysis

It begins with the loss and waste profile and makes a detailed analysis of the points or stages that are most likely to present losses and waste. For this purpose a data collection methodology is elaborated upon, including procedures that led to the choice of localities to be evaluated (e.g., plots, orchards, farms) and of the parts of the postharvest system to be analyzed, the data collection protocols, the statistical procedure for the selection of the units, the sampling method, and the sample size. Many existing published field studies on PHLW have been done using ad hoc methods or indirect methods (surveys and questionnaires), and so the reports on losses measured in the field can lack one or more of these key parameters. Field research studies are typically published as project reports or in-house studies. Examples include a field case studies report on postharvest losses of mangoes in India (FAO, 2017), and a commodity systems assessment of tomato postharvest losses in Rwanda.

The UN FAO SAVE FOOD initiative has been using a methodology for assessing PHLW through a modified version of case study research that generally includes four steps: (1) screening (literature reviews and key informant interviews); (2) surveys (specific interviews, estimates, and observations); (3) load tracking (measurements); and (4) synthesis (holistic analysis and recommendations). This methodology is known as field case studies for food loss analysis. The initial case study for the FAO was on postharvest losses in fish, but case studies on horticultural crops have also been done in India (mangoes), Kenya (bananas), and some others. The synthesis step of the FAO methodology includes identifying the symptoms and causes of postharvest losses along the food supply chain (FSC), critical loss points, and potential solutions. While it is clear that a case study represents only a specific scenario and not the reality of an entire country, there has been criticism to the field case studies methodology for assessing PHLW. This is related to the lack of guidance for the user on implementing a standardized way to conduct surveys or collect samples, which in turn makes it difficult to determine if the analysis is conducted with a sample that truly represents the universe of the specific case scenario. Thus the agreement internally across technical units in FAO has been to use this case study methodology for the identification of hot spots (the critical loss points in a specific food supply chain), but to avoid using the methodology for reporting on the national or subsector dimensions of PHLW.

2.5.2 Experiment-Based Estimation

It refers to the quantification of the losses of various selected samples and the estimation of the total loss due to a specific postharvest practice or technology or treatment in comparison to a control (typically the traditional practice or no treatment). It is recommended to distinguish between the data obtained in the different stages of the postharvest system and to specify whether they were obtained from the same batch, and therefore whether the losses are cumulative or whether they were obtained from different batches, and if they are a mixture of both. A strong study design, for example, would utilize produce harvested at the same time from the same farm to prepare the desired number of randomly selected and assigned samples. One advantage of this approach compared with the previous approaches is that the assessment is done with the same product throughout the postharvest shelf life of the product. The drawback is that the number of samples taken is normally very limited, and the simulations of the conditions normally do not fully reflect what takes place in reality. PHLW estimations via experimental studies are typically published in agriculture, food, horticulture, and economic journals and/or presented at professional meetings and technical reports.

2.5.3 Lessons Learned So Far From Current General Approaches

The analysis or quantification of the PHLW occurs at specific stages during the movement of the commodity through the food supply chain (FSC). It is a detailed analysis of the points or stages of product management, identifying at which stage the food product is most susceptible to damage. Therefore there is a need for the following:

- Development of high quality, standardized methodologies and protocols depending on the product, the handling system used, and the region, among other factors.
- Development of defined terms and FSC stages.
- Use of established standards as control, especially for the subjective measures.
- Development of standardized data analysis and reporting protocols.

When recent reviews were done on existing PHLW study measurement methods, it was found that the data on PHLW generally had been collected either via surveys/interviews or via sampling/direct measurements and reported as physical and/or economic losses (Kitinoja and Kader, 2015; Xue et al., 2017). Only occasionally data were provided on qualitative losses, and almost no data on postharvest waste have been estimated or reported for perishable horticultural commodities in developing countries.

Written surveys and interviews are generally considered to be less accurate than making direct measurements, but the latter may not be highly reliable. Often when measurements are made in the field, little or no information is provided regarding important variables, such as how much time has passed from harvest, the temperature of the produce and the ambient air, the relative humidity, or the type of packaging. The time of harvest, for example, could be hours, days, or weeks before the sampling is done, and the exact time may even be unknown to the data collector, while both qualitative and quantitative losses continue to occur in the period following harvest.

Surveys and interviews do not always result in gathering accurate information on PHLW. Many times the survey questions are developed by people with little or no experience in

measuring PHLW. They ask someone to recall their practices, weight losses, and quality problems in specific terms (e.g., the amount of produce lost during harvesting) when the activities may have occurred long time ago.

The basis for measurement of economic losses can be monetary or unit losses. Monetary losses depend upon market prices, and unit loss can be measured as changes in numbers of items, volume, or weight loss percentages. One advantage of monetary loss measurement is the characterization of the accumulated costs of a commodity. Losses expressed in monetary terms should increase at each and every step in the postharvest handling chain, up until the commodity is consumed. It is reasonable to assume that the economic value of a commodity, as represented by price per unit weight, would probably be a true measure of costs as averaged over a period of time. Prices at any given time and place, however, will vary with supply and demand, competition from similar food products, different governmental support programs, and other market factors.

Monetary losses are one of the key factors that can lead people to seek advice and make investments in postharvest technologies that can help to reduce PHLW. Often, losses are counted after the unit of commodity is considered unfit for human consumption and is being discarded. Some problems with unit loss measurements include the following:

(1) The point at which a commodity becomes inedible often depends upon the social, cultural, and economic level of the consumers and/or on local cultural preferences. Tolerance levels vary in different markets of the world, in relation to the levels of classification for a fruit or vegetable to merit a rejection. In some markets in developed countries the product may be rejected and considered be lost when it shows even slight surface damage. However, in markets in developing countries, the product may be marketed and consumed even with severe damages.

(2) The reduction of quality, condition, or appearance might involve serious monetary losses but would not be reflected in the data as long as the produce was consumed.

(3) The diversion of produce to a secondary or salvage market might represent a real loss in monetary terms, but would not be considered a loss by this method because it would be consumed.

(4) Moisture loss is an important factor in quality and consumer acceptability of fresh horticultural commodities. Such a loss of acceptability would be measured as a unit loss only if dehydration was so severe as to render the commodity unfit for human consumption.

Many past measurements have targeted PHLW occurring within the farm (at harvest), in the packinghouse, during and after storage, during transport, and at the wholesale and retail markets. Differences in pack-out commodity weight and the weight upon entering the packinghouse are commonly considered as the loss due to cullage. Likely included as culls are small, immature, overmature or overripe produce, and variously damaged or defective (e.g., deformed, hail, or frost damaged) units. Culls are a postharvest loss unless there was an available alternate use (such as processing) or secondary market (such as animal feed). For example, if culled fruits were processed to jams or candies, further measurements would be required to determine the extent to which losses/waste in the processed products occurred. If long-term storage is part of the value chain, PHLW sampling may occur as packed produce is removed from storage to be loaded into transit vehicles. Measurements of weight

are commonly made before and after transportation, so weight loss can usually be determined in distribution centers or upon arrival at the retail stores.

It can be safely concluded in this section that there are very sophisticated methods for estimating grain losses, but the determination of losses in fresh perishable products is very complicated for several reasons, such as:

A. The high moisture content of perishable horticultural commodities, where the loss/waste estimation is based on their dry weight or on their fresh weight, is very difficult to define, which is not the case for grains with very low water content.
B. Compared with grains, perishable products do not have uniformity in weight or shape.
C. Perishable horticultural commodities can have partial losses; for example, only one part of lettuce can be lost. On the other hand, in grains, everything can be lost.
D. Perishable horticultural commodities deteriorate much faster and easier than grains.

It is of great importance to know when and where PHLW occur during the postharvest chain. The losses will be more serious if the damage occurs at the beginning of the chain, because not only would these losses be aggravated along the chain, but they may also cause the losses and waste of others, particularly if the causes are pathological and spread to the neighboring produce. On the other hand the damage would be very expensive if it occurs during the final stages of the chain, because of all the cost invested on this product all along the chain (e.g., grading, packaging, cooling, storage, transport, etc.). To make the issue even more complex, in reality often the reason for discarding or rejecting a product is not due to one single cause (being direct or indirect) but to the accumulation of failures along the food production and supply chain. An example is provided with pineapples produced in Ecuador that were being shipped to Europe (Table 2.2). In real transit simulation studies, quality defects symptoms produced were of different types and of different degree/severity depending on where the failure was and how many failures had taken place before. For example, failure to adjust the concentration of the wax show quality defects in 4%–12% of the fruits. When the fruits were not only exposed to a low concentration of wax, but also were subjected to a delay of >6 h between harvest and cooling and were not treated with a proper sanitizing treatment prior to refrigeration, the quality defects were present in as much as 27% of the fruits.

2.5.4 Other Initiatives to Standardize Measurements/Assessments of PHLW

The Inter-American Institute for Cooperation in Agriculture (IICA) has published a food loss assessment method known as Commodity Systems Assessment Methodology (CSAM), based on the early work of LaGra (1990) and recent modifications. CSAM includes standardized interviews, observational checklists, and field level measurements of postharvest losses at key stages of the FSC: on the farm, in the packing house, in storage, and at wholesale and retail markets, followed by cost/benefit analyses of potential solutions and the development of recommendations for research needs, training needs, and advocacy issues. An updated manual on the use of the method has been published by IICA (LaGra et al., 2016).

The German Society for International Cooperation (GIZ) has developed and implemented a rapid loss appraisal tool (RLAT) which consists of three main phases: (1) preparation (screening of information, desktop analysis of current data); (2) field research

TABLE 2.2 Quality Defects and Nonacceptable Pineapple Fruits (%) Reaching a Destination Market After a Single Failure or Cumulative Failures Across the Handling Chain

	Type of Failure				
	Over Delay (> 6 h) Between Harvest and Cold Storage	**Lack of Monitoring Sanitizer Level in the Flume Tank**	**Low Concentration of Wax**	**Low Relative Humidity in Cold Room**	**Broken Cold Chain at Destination Port (2–4 days at >25°C)**
	A	***B***	***C***	***D***	***E***
Without additional failure in the handling chain	Skin dryness in some fruits. High risk of pitting in high temperatures	Risk of mold in stem scar and crown leaves. High risk in rainy season	Risk of chilling injury. Moderate risk of skin water loss	High risk of "pitting" due to excessive water loss	Excess fading of green color. Risk of anaerobium/ fermentation/ darkening of flesh
	6%–10%	3%–22%	−12%	4%–15%	9%–29%
		$+A$	$+A+B$	$+A+B+C$	$+A+B+C+D$
With additional failures in the handling chain		High risk of mold developing even in the skin of fruit	Mold and pitting risk in skin (darkening and dry)	Mold, development of "old" appearance due to excessive water loss	Dark/brown fruits (inside and outside), with severe water loss symptoms and mold
		−25%	7%–28%	9%–35%	19%–56%

(multistake holder and experts provide qualitative data through different mechanisms, including focus group meetings); and (3) follow-up (triangulation of results, outline of aggregated results, results and recommendations).

The World Resources Institute (WRI) has developed a global reporting protocol (WRI, 2016) that aims at becoming a highly used tool, given it provides a versatile framework for collecting and reporting data on food losses and waste in a standardized way such that results can be shared across stakeholders.

2.6 CONTROL OF PHLW

General strategies for reducing PHLW should include: (1) Application of current available knowledge to improve the handling systems, especially the cold chain and proper packaging, and assurance of quality and safety; (2) Overcoming socioeconomic constraints, such as inadequacies of infrastructure, poor marketing systems, and weak research and innovation capacity; and (3) Encouraging consolidation and vertical integration among producers and marketers.

TABLE 2.3 Categories of Solutions to Reduce Postharvest Losses and Waste of Fresh Produce by Levels: Micro, Meso, and Macro

Categories	Levels		
	Micro	**Meso**	**Macro**
Investments	Private investments in production, postharvest, businesses and logistics	– Financial mechanism – Collective private investments in production, postharvest, business and logistics – Public investments	– Support to financial mechanisms – Infrastructure – Enabling environment – Proper incentive
Good practices	Good practices in production and postharvest according to changing environmental conditions	– Capacity building – Training	– Support to capacity building – Multistakeholder initiatives
Behavioral change	Behavioral change in business and consumers	– Corporate social responsibility – Community and local engagement	– State led awareness raising campaigns – Multistakeholder initiatives
Coordination inside food supply chains	Individual research prior planting	Integrated quality supply chain approach	– Enabling environment (contractual rules and incentives – Policies
Revalorization of product		Revalorization of product due to noncompliance with cosmetic quality	– Support and incentives for implementation
Coordination of policies and actions			– Policies – Multistakeholder initiatives

Adapted from HLPE, 2014. Food losses and waste in the context of sustainable food systems. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Just as causes may be classified as micro, *meso*, and macro, the respective solutions could be placed in those levels. Several categories have been suggested to summarize the entire set of solutions for losses and waste of fresh produce, which are embedded in one or more cause levels. Table 2.3 provides typical solutions at the three different levels using selected categories including: investment, good practices, behavioral change, coordination in the supply chain, revalorization of product, and coordination of policies. Fig. 2.6 provides a scheme of what could happen in certain points of the supply chain when different failures at micro/meso/macro levels occur.

PHLW in many countries are of different natures and correspond to causes that, as mentioned before, could go from a single failure in the supply chain to the common scenario of

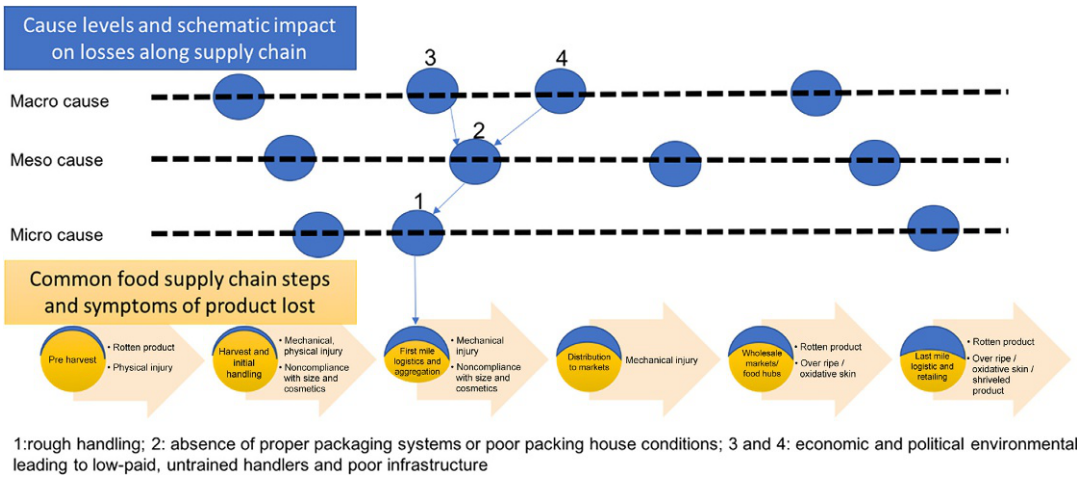

FIG. 2.6 Schematic representation of the relationship between cause levels (micro, meso, macro) and the symptom of losses at different points of the supply chain. The example with arrows represent a scenario in which the impact of different failures (1, 2, 3, 4) in the three cause levels result in high losses, showing particular symptoms during the first mile logistics and the aggregation of product. Points in the supply chains are indicated as examples.

several failures impacting the symptoms and dimensions of the losses and waste. Consequently the control of losses and waste depend on the nature of the causes, but they also will depend on the measures taken to implement the solution(s). In this regard and adhering to sustainability principles the solutions should be environmentally friendly. However, while reducing losses and waste per se is beneficial for the environment, there are solutions that even when affordable would not be recommended. One example is the chemicals of low cost that are already targeted to be banned given their levels of toxicity in the field. Moreover the solutions should have a low economic cost (this is considered desirable by those involved in the supply chain) or a high economic return, but also a low social cost.

In summary a systematic analysis of the production and handling system of each commodity in each particular region or site is the logical first step in identifying an appropriate specific strategy for reducing postharvest losses and waste. In addition a cost-benefit analysis to determine the return on investment for the recommended postharvest techniques and technologies to be used is essential. Socioeconomic constraints may include issues with access to tools and supplies, the affordability of improved postharvest technologies or handling practices, and cultural or gender related barriers to their adoption or utilization.

Fresh fruits and vegetables are highly perishable and suffer high losses and waste directly or indirectly between the field and the final consumer. Direct losses and waste include the elimination of the produce by factors such as microbial deterioration or deterioration by agents such as insects or rodents. Indirect losses refer to the reduction of produce quality to a point where it cannot be sold or consumed. Several factors can contribute to these losses and waste, such as physiological changes of the product, mechanical damage, heat damage, insect attack, and diseases, among others.

FIG. 2.7 (A–C) Major quantities of fresh horticultural commodities are lost and wasted at different stages of handling, such as at packing houses and minimal processing plants.

PHLW require an adequate control over the product and a constant observation throughout the process. For this the following points should be considered:

1. Proper knowledge of the characteristics and requirements of perishable products, especially for people who handle these products in the markets and in homes.
2. Harvest according to proper maturity indexes (i.e., adequate maturity and ripening for fruits).
3. Reduction of improper handling such as mechanical damages during harvest and in all the stages of the postharvest handling system.
4. Fast precooling and proper maintenance of the cold chain.
5. An adequate sanitation program, especially during packaging in the packing plant.
6. Proper use of adequate packaging systems.
7. The use of appropriate storage systems and their proper maintenance.
8. Use of proper transport systems.
9. The use of proper techniques for the management of modified and controlled atmospheres, when needed.
10. Efficient management of food lost and wasted in different forms (Fig. 2.7A–C) such as for processing, compost, animal feed, energy, etc.

The points of control of losses and waste of fresh produce depend on what is the shelf life needed. For example, if the fruit, vegetable, root, or tuber is harvested today and will reach the consumer within 48 h (common situation in many cases) clearly the key principles are to move product fast, avoid rough contact of the product with surfaces that can cause mechanical injury or contamination of product, and avoid exposure to sun light, hot temperature, and low relative humidity conditions.

The following chapters in this book describe the proper means and technologies to reduce PHLW.

2.7 CONCLUSIONS

PHLW of perishable horticultural commodities are high all over the world, but especially in developing countries and are globally estimated at up to 60% depending on the

commodity, the season, and the production region. Minimizing PHLW could be an effective way of reducing food insecurity by increasing food availability, optimizing the use of natural resources such as land, water, chemicals, energy, and reducing environmental contamination. However the reduction of PHLW requires adequate plans, cooperation, and effective communication among all stakeholders including research, extension, and industry personnel involved. In particular, postharvest horticulturists need to coordinate their efforts with those of production horticulturists, agricultural marketing economists, engineers, food technologists, and others who may be involved in various aspects of the production, handling, and marketing systems. In most cases, solutions to existing problems in the postharvest handling system require the use of available information and the application of available technologies at the appropriate scale. For those postharvest problems for which there is no existing solution or for which links (factors/facts impacting overall losses) are underexplored, there is a need to conduct innovative research and to develop new technologies. Overcoming the socioeconomic constraints for the adoption of improved postharvest practices and technologies is essential to achieve the goal of reducing PHLW. Paying attention to the costs of externalities (e.g., social, environmental, etc.) in formulating solutions is crucial for adhering to the sustainability sought for future generations.

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