Chapter 13
Postharvest Care and the Treatment of Fruits and Vegetables

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Abstract This chapter describes existing postharvest care of fruits and vegetables in both the developing and developed economies of the world. Food waste is the metric which reveals the success or failure of the existing postharvest care. Figures vary depending on the source and the assumptions made to arrive at the estimated waste values but all agree that fruit and vegetable waste is at least 30 % of the production. Reasons for losses in the developing economies of the world relate to lack of basic postharvest technologies and access to adequate and reliable cooling. However, there are many societal issues that also impact on successful distribution of fruits and vegetables in developing economies. In developed economies, waste is associated at the distribution/retail/consumer levels and the underlying reasons for these losses are not so much the lack of or access to technology, rather to structure and function of the marketing chain. Capability to store product longer or transport it further does not necessarily lead to lower losses, however it does lead to greater distribution of availability over time or over distance. Consumer behavior and psychology play a significant role in waste at both the retail and home levels. While there continues to be numerous challenges for postharvest care of fruits and vegetables, the chapter provides some insight to the directions that must be followed to reduce wastage and enhance the availability of good quality, nutritious fruits and vegetable to all in developing and developed economies.

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Introduction

Postharvest handling encompasses operations at harvest, transport to a packing facility, storage and transport technologies to preserve horticultural products until delivery to a customer whether they be local, national or international. The best possible outcome that can be achieved in postharvest operations is the preservation of the quality of the fruit or vegetable in its original condition at harvest. While that is the optimal goal, it can rarely be achieved in reality.

The final consequence for inadequate postharvest care is the loss or waste of that fruit or vegetable. Extent of postharvest loss varies depending on the industry context, i.e. whether we are discussing practices in developing or developed economies and whether we are discussing local/regional or international distribution/marketing chains. It is interesting to note that total losses of fruits and vegetables are generally 40–50 % in both developed and developing economy countries, with the exception of industrialized Asia where losses are estimated at less than 40 % (Gustavsson et al. 2011). It is instructive to analyze where the losses occur in the postharvest continuum. Generally, losses in postharvest handling, processing and distribution are greater in the developing world, where much greater proportional losses are found at the marketing/distribution/consumer level in developed economies, including industrialized Asia (Gustavsson et al. 2011). This observation leads to the conclusion that the postharvest care challenges and issues facing the developing world economies versus the developed world are quite different in nature and more importantly are produce and even cultivar specific.

A number of technologies have developed over the last century which has enabled remarkable quality retention for most products. The greatest impact has been due to implementation of refrigeration technologies. The widespread use of modern mechanical refrigeration systems has allowed for longer term storage and transport of most commodities from local to international scales. Refrigeration still continues to be a challenge to successful postharvest care of fruits and vegetables in developing economies where lack of infrastructure is a constraint on access to refrigeration (Anon 2011). This issue will be discussed further later in this chapter.

Other technologies have been employed to augment refrigeration in modern postharvest handling chains. These technologies include ethylene control (either treatment with or methods to remove), ethylene action inhibition (1-methylcyclopropene), modified atmosphere packaging, controlled atmosphere storages, controlled atmosphere transport trailers, coatings and waxes, and postharvest disease and insect control (Yahia 2009). Such technologies have been important largely for long term storage and/or long distance shipping in national and in international marketing chains. In fact, without the development of these other technologies, a large component of international trade in fruits and vegetables would not be possible.

Whether these developments have always reduced total losses for specific fresh produce types is debatable as often technologies which have extended storage have not ultimately reduced waste but increased availability and the prospect of sourcing from different origins.

Implementation of storage technologies has been a consequence of need to extend the duration for availability of fruits and vegetables (Yahia 2009). The most successful example of postharvest technology is that of controlled atmosphere storage of apples (Yahia 2009). As international transport and postharvest transport technologies have evolved, the goal was transformed to enabling orderly, profitable marketing of fruits and vegetables to whatever market demands the product (Yahia 2009). Despite the driving force of optimizing profit, there are layers of marketing chains that attempt to continue to serve the original purpose, that of preserving product to local and regional consumers such that the season for availability is extended as much as possible and yet this does not always translate to minimization of losses.

Clearly, postharvest care for fresh fruits and vegetables is a complex issue, impacted by the location of the producer (developed or developing economies), the intended market (local, regional, national or international) and the sophistication of the distribution chain and ultimately the changing factors and drivers which influence consumer demand. The intent of this chapter is to gain an appreciation for issues surrounding postharvest care in developing economies, sustaining horticulture in developed economies and in reducing losses and ensuring optimal quality and nutrition for consumers.

Role of Postharvest Technology in Developing and Emerging Economies

Postharvest losses in the developing world can be substantial. Losses range from 30 to 80%, depending on the commodity (Kitinoja et al. 2011). For example, leafy greens which are subject to physical damage and high rates of water loss can suffer 80% loss after harvest. In addition, in the developing world, losses tend to occur between the grower and the market, rather than at the consumer level; opposite to the developed world (Kader 2005, 2010). With the world population expected to exceed 9 billion by 2050, there are urgent calls to greatly increase food availability. Reduction in postharvest losses is a key factor in increasing food availability in a sustainable manner.

Postharvest losses are very high in the developing world due to a number of factors, including harvesting at improper maturity, rough handling and poor packaging leading to physical damage, lack of protection from water loss leading to wilting, shrivel and loss of saleable weight, inadequate transportation to market, and lack of cooling or cold storage capabilities (largely due to unreliable electrical power supplies).

Challenges to Adapting Postharvest Technologies to a Developing World Scale

Why is postharvest handling so poorly managed in these regions? A number of factors clearly play a role, including a lack of incentives to improve practices in anticipation of a higher market price, lack of awareness of improved practices that might be used, lack of resources to invest in supplies or technologies, particularly for smallholder farmers, lack of availability or high tariffs on imported supplies, and policies that provide a disincentive to changing practices (Kader 2005, 2010). Also, poor access to developing markets and poor distribution channels and the lack of vertical integration in the supply chain contribute to the challenge (Kader 2005, 2010).

For farmers and traders to be encouraged to adopt improved postharvest practices, there must be a benefit gained from the sale of higher quality produce. Grade standards or specifications are often non-existent in many parts of the world and there is a lack of trust between buyers and sellers. Also, products often change hands many times between the farm and the market, reducing the vertical integration between care in product handling and potential for better prices.

Lack of knowledge is another challenge. Many who grow and handle produce have no experience with or knowledge of improved handling practices. Training and demonstrations can illuminate the benefits of simple practices like harvesting early in the day, protecting product from the sun, or using plastic bags to reduce water loss.

Farmers and handlers in developing countries often lack the resources to invest in postharvest technologies. Access to capital through microfinance or savings programs is possible, but farmers must be convinced of the return on their investment. This requires linkage to a reliable market that will provide a fair price for the product's quality. More expensive technologies, such as small scale cold rooms, would generally require that an association of farmers or a village pool their resources for such an investment.

In many countries, supplies taken for granted in the developed world, such as thermometers, packaging materials, clippers, and sanitizers are not manufactured locally and are either unavailable for purchase or are only available at a much higher price due to shipping costs and tariffs.

There are a number of examples of policies that create disincentives to improved postharvest practices. For example, in some cases, transportation costs are based on the number of packages, not the size or weight of the package. This has led to use of extremely large crates for transport of bulk produce, leading to crushing of fruit on the bottom as well as challenges in careful handling of these products. In other cases, extra tall sacks are used for produce packaging so that they fill the width of the truck bed for maximum space utilization during transit. In India, a law related to produce marketing required that all produce be sold through wholesale markets (Kitinoja et al. 2011). This had precluded farmers from developing relationships for direct marketing to supermarkets or export markets. This law has recently changed in some parts of India and it has only just been

Fig. 13.1 Scientists at the United States Department of Agriculture, Agricultural Research Service developed a process (going from front to back in the photo) by which chicken feathers are shredded, powdered, converted to pellets, and then transformed into biodegradable plastics. Photograph is used with the kind permission of the USDA-ARS

abolished throughout the country. It is likely that this change will open up markets to multiple retailers thereby resulting in greater efficiencies as seen in other parts of the globe.

Needs for Research and Implementation of Logistics and Supply Chain Management.

There are three critical research needs for improving postharvest handling in the developing world: development of inexpensive, sustainable packaging, food safety strategies that work when water supply is scarce, and affordable strategies for cold storage and cool transport. Regarding packaging, there is a need for inexpensive but sturdy crates or boxes (Kitinoja et al. 2012). Returnable Plastic Containers (RPCs) are a possible option, but are expensive, subject to theft, and generally not produced locally. The benefits of a reusable packaging system may outweigh however, the challenges to its effective implementation (Manalili et al. 2011). Perhaps a package could be developed from locally available, natural materials. Chicken feathers have been suggested as one possible material that might be feasible (Fig. 13.1). Plastic bags are very useful to reduce moisture loss of harvested produce, but their use for many purposes (mostly not related to produce) have resulted in extreme pollution due to ineffective waste disposal systems. The problem is so bad that many countries are considering banning their use and Rwanda has already banned the use of plastic bags. An alternative technology should be developed that is inexpensive and sustainable, and serves the purpose of maintaining high relative humidity around the product.

Food safety is the most important topic for marketing of fresh produce. Unsafe use of pesticides during production of fruits and vegetables is a frequent issue, including use of unregistered materials, application at higher than approved dosage, lack of protective clothing and training of operators, and applications close to harvest and consumption. Microbial safety of fresh produce is also a significant problem. Consumption of raw fruits and vegetables increases the chances that microbial contamination can sicken consumers. Many of the recommended strategies for reducing the risk of contamination with human pathogens are particularly challenging to implement in the developing world. For example, the recommendation to wash one's hands after using sanitary facilities is a luxury in many locations. Water for hand washing is often not available in adequate amounts, and clean water is often unavailable. Soap for washing is also not readily available. Research is needed to develop convenient and affordable strategies to overcome these obstacles to human hygiene to make significant progress in microbial safety of fresh produce.

Finally, a lack of cooling, cool transport, and cold storage facilities is a major challenge to reducing postharvest losses in developing countries. Cooling technology is generally expensive and requires electricity that is often unavailable. A number of small-scale, inexpensive coolers have been developed (Kitinoja and Thompson 2010), but many are based on evaporative cooling which has limited cooling capacity, especially in humid environments. Innovative engineers must be incentivized to develop strategies to address this need in a cost-effective and scale appropriate manner. Technologies have been developed for keeping life-saving medicines and blood cool. These technologies can potentially be adapted for use on a larger scale for produce transport. Improved insulation can be used to maintain products at lower temperatures after harvest and can be effective when combined with harvesting at the coolest time of the day.

Successes

There have been a few modest successes in adoption of technologies for postharvest handling in developing countries. A small-scale, lower cost cold room technology, the Cool-Bot, is beginning to be adopted in several parts of the world (Anon 2012a). The Cool-Bot uses a special controller developed by Keep It Cool, Inc. based in New York, USA (http://keepitcoolinc.com) together with a window air conditioner. The two are installed in an insulated room that can be made of a variety of materials, including locally sourced natural materials. The cost of this unit is considerably less than a traditional cold room, and the unit can be run using solar power in remote areas. Research is underway to adapt this technology this for cool transportation. These small-scale cold rooms have been adopted by a number of small-scale farmers in the U.S. as well.

The concept of a Postharvest Training and Services Center was developed by Dr. Lisa Kitinoja, founder of the Postharvest Education Foundation. Two such centers have been created, one in Tanzania and one in India. The centers have facilities for training of trainers and farmers in postharvest practices, including demonstrations of the effects of improved practices. In addition, the Centres have a supply of materials needed for improved postharvest handling, such as packaging, harvest umbrellas, clippers and thermometers that are available for sale. It is hoped that this type of center will be replicated in many parts of the developing world. The Postharvest Education Foundation and the Horticulture Innovation Lab (formerly Horticulture CRSP) have funded the training of several individuals in Africa and Asia who can provide training in postharvest practices to farmers, handlers and technicians who work with farmers and handlers (Anon 2012b).

Future Outlook

There is tremendous room for improvement in postharvest handling of harvested horticultural products. By increasing awareness of simple practices, we can reduce losses and improve the quantity and quality of food available to consumers. Hopefully, improved practices will allow fruits and vegetables to eventually be sold at lower prices to increase consumption and result in improved health. Development of innovative, adapted technologies will assist resource poor farmers in adoption of improved practices.

Role of Postharvest Technology in Sustaining Horticulture in Developed Economies

Importance of Quality Management in Advanced Supply Chains

Supply chains in developed economies and even those within some emerging economies, which service their burgeoning populations, have over recent decades become ever more globalized and more interconnected. This situation together with the increased use of just-in-time logistics and lean manufacturing has undoubtedly led to greater efficiencies, but perhaps to more risk in terms of resilience.

Food prices in recent times have generally been increasing across the world, notably with spikes in 2008, 2010 and 2012 (Fig.13.2) (Anon 2013). This trend is causing concern amongst governments, consumers and industry. In many parts of the developed world profits within the fresh produce sector are being forever squeezed

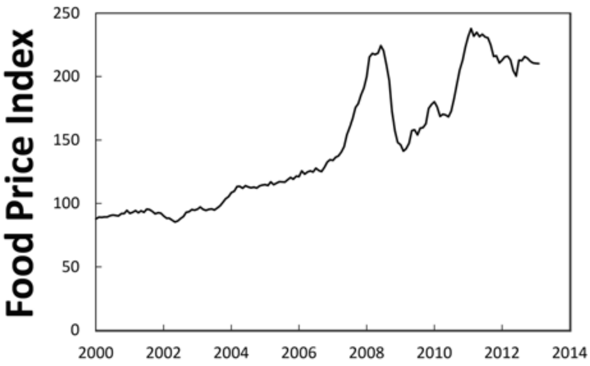

Fig. 13.2 World nominal food price index for the new millennium. The FAO Food Price Index is a measure of the monthly change in international prices of a basket of food commodities. Data for January 2000 to March 2013 extracted from FAO database (Anon 2013)

in the present economic environment, whilst inflation for fruits and vegetables remains stubbornly high. Demand is also relatively static, with some standard lines for many fresh produce types falling out of favor to products of lower specification. The problem is compounded by consumer purchasing power and confidence being at an extended low ebb. Yet a dichotomy exists whereby quality demands for horticultural products keep increasing or at least are at an unsustainable level, such that something has to change or break in order for the industry and growers to remain competitive and continue to invest in new postharvest technologies. The incentives for doing so seem to be centered on gaining market share in a period of austerity and reducing waste through implementing stricter key performance indicators with the view that things will eventually turn and become more favorable. The scope for introducing new postharvest technologies in a stagnant market is therefore limited.

Quality remains the mainstay of many supermarket offerings as it can markedly influence footfall, market share and the incidence of customer defections. Quality is intimately linked with postharvest technology and biology, yet the drivers of demand are increasing centered on price and promotions (e.g. buy one get one free and multi-buys). Since 2008, promotions are being used more widely by retailers in the developed world to increase the affordability of fruit and vegetables as well as attract new customers (and stop customer defecting to other stores). In this sense they are part of the discussion about price/value and can increase footfall.

The effectiveness of fruit and vegetable promotions on demand is difficult to analyze. For example, promotions are usually time-limited and are traditionally used to celebrate the season and clear ‘gluts’. Where flushes or gluts are predictable (e.g. release from end of storage apples) then they can perform a valuable role in promoting greater product utilization and decreased waste, but even so may not increase demand overall. Another possible impact is that consumers’ simply switch away from a product that is not being promoted to one that is. If both are fruits, for example, there is no overall increase in fruit purchases—a process known as product ‘cannibalization’. Promotions can have other unforeseen consequences that may not be accounted for in forecasting. For instance, where a promotion works too well, it may lead to the necessity to supply product from a lesser standard or different quality tier so as not to fall short (e.g. not satisfactory conditioning potatoes before packing which can increase waste or using premium potato variety in a lower tier). When customers over-purchase as a result of being tempted by promotions then complaints can increase not only because of the pressure to deliver in full, but also because consumers may store more product at home. Often this product is kept under sub-optimal storage conditions, and the consumer becomes disappointed when they attempt to consume the product beyond its inherent home-life. This then may lead to increased waste in the home and/or depression of future sales due to customer dissatisfaction.

Promotions are being overused in the current climate such that consumers are suffering from 'promotion fatigue' and are confused over the basis of some such offers. The overuse of promotions (e.g. up to 50–80% for some categories now sold) is destroying the price structure of the whole fresh produce category and actually making promotions less effective (Terry et al. 2013). It was highlighted by Terry et al. (2011) that the impact and mechanics of promotions should be better understood from both an industry and consumer perspective and this recommendation still holds. Although the vast majority of promotions are collectively agreed between retailers and suppliers, there are some which are imposed with little thought on availability and how postharvest technology might be better utilized. The frequency and timing of some promotions is often governed more by retailer positioning rather than by being aligned to the biology of the product, to oversupply/availability or even recognized seasonal demand. Multi-buy promotions and changing pack sizes across a range of categories may be confusing consumers. It is now unclear whether consumers understand promotions and indeed the true price of different fruit and vegetable lines as they have little to compare prices with (Terry et al. 2013).

Even though the choice of fruit types available to the consumer in developed economies is now vast there is contraction in that varietal choice within many fruit species can be limited. For example, out of the hundreds of mango cultivars grown worldwide barely 10 are available through the global market (Table 13.1) (Araújo and Garcia 2012; Anon 2012c). Most of these preferred cultivars have been selected for their inherently long postharvest life so that they can withstand global trade. They have rarely been selected for flavor or taste and this problem stands for many other fruit and vegetables such as avocado [Hass and Fuerte], and banana [Cavendish]. Thus, despite postharvest technologies being available to extend storage there is often a trade-off between taste and postharvest life. The industry often selects cultivars which have longer postharvest life rather than investing in technologies which might be used to increase the postharvest life of better tasting types. Concomitant to this, many fruits are still harvested at premature horticultural stages to ensure extended storage or shelf life even though postharvest technologies might be available to allow fresh produce to be harvested later and thus ensure greater consumer appeal. Implementing postharvest technologies is costly so that a reasonable return must be realized on that investment and financial outlay. If there

Table 13.1 Major cultivars of mango marketed in the European Union and the United States. Cultivars in italics are the most important in terms of sales volume for each market

European Union	US
Haden	*Ataulfo*
Kent	*Francis*
Keitt	*Keitt*
Tommy Atkins	*Kent*
Alfonso	*Tommy Atkins*
Julie	*Alphonse (Alphonso)*
Zill	*Edward*
Osteen	*Kesar*
Maya	*Manila*
Shelly	
Palmer	

is declining propensity from consumers in developed economies to pay more for fruits and vegetables then the slow decline in fresh produce diversity and increase in commoditization will continue amongst middle income social economic groupings.

There is no uniform approach to quality in the retail market. Instead, each of the multiple retailers has developed a 'quality position' in terms of the products they sell as well as the shopping experience they provide (Terry et al. 2013). Retailers will use their 'quality position' to differentiate themselves from each other, to attract particular types of customer to their stores and to develop specifications for their suppliers. These specifications are particularly important for the retailers 'own label' ranges including the majority of fruit and vegetables.

In many developed economies the major multiple retailers have developed three quality tiers for their fruit and vegetables (Terry et al. 2013). These have various names depending on the retailer but can be broadly categorized as follows: Premium, Standard and Basic/Value. These three tiers provide a basis for understanding fruit and vegetable quality across large parts of the retail market but cannot be applied in every case. Even in the retailers that recognize three quality tiers it does not follow that all fruit and vegetables are offered at every quality level, for example typically bananas are just offered as a standard or value range whereas apples are commonly sold at all three levels. Indeed, some products may be offered in the premium tier for only certain periods because they depend on a particular cultivar being available in the season.

Some fruit and vegetables have additional branding like Organic or Fair Trade or carry a carbon label or some other differentiator for example 'Red Tractor'. These types of branding are not generally used as a quality attribute, that is the presence or absence of one or another mark does not lead the retailer to automatically assign that product to a particular quality tier. In other words these attributes have only a secondary influence on the retailers' quality positioning for fruit and vegetables.

In the fresh produce industry in developed economies, there are few truly dedicated supply chains; instead the major growers/suppliers tend to have multiple customers (Terry et al. 2013). The advantage of this approach is that it ensures the crop is better utilized. Typically the way this works is that suppliers have multiple primary customers among the major retailers (and in some cases foodservice operators). Specific crops and cultivars will be grown for a specific primary customer according to pre-determined planting programs which are, where possible, agreed upon ahead of the season and are informed by historic data on consumption and other market intelligence. For products where demand is predictable and is less affected by weather or where extended storage can better ensure extended availability (e.g. apples, onions and potatoes) these procurement programs tend to work well. For products where demand is more volatile then there is an increase risk that procurement programs fail. Growers will usually over produce to ensure that product can always be supplied in full and this may have an influence on crop utilization and waste (Terry et al. 2011). It could be argued that excess volume is in commercial interest and that growers must fulfill orders or risk losing business. There is recognition that over-programming can result in increased waste, but it is also understood that some degree of buffering against unforeseen problems in supply is essential.

Procurement programs are influenced by planned promotional activity. For example for strawberries, retailers determine promotional campaigns and these plans are discussed with suppliers, yet they are based on key dates, e.g. events in the social calendar viz. Wimbledon Lawn Tennis Tournament and predictable crop flushes and are aimed to maximize crop utilization.

As a season progresses and crops near maturity allocations can be made between quality tiers and customers (Terry et al. 2013). For example, if a crop grown for the premium tier fails to meet the desired specification then it may be switched to the standard or even value tier. This practice can undermine however, the differentiation between the quality tier offerings if noticed or understood by consumers. When a crop does not meet a specification and where there are limited alternatives for downgrading or alternative sourcing then specifications can be relaxed. Often the difference between tiers is largely subjective and will vary from time to time and according to variety, sizes and pack formats. The flexibility of the fresh produce industry in many developed economies enables the shifting of crop between quality tiers depending on shortage/surplus position such that specifications will differ by tier but can be fairly flexible depending on volumes available. Fruit 'tiering' is more resilient as it is more based on cultivar whereas vegetables and salads are more difficult to tier.

Although specifications are regarded by all retailers as key to defining and differentiating apparent product quality and are stringently adhered to, there is still some degree of plasticity when availability is stretched (i.e. as seen in 2012/2013 as a result of the poor weather conditions in Northern Europe during 2012). The advantage of the three tier system allows for some degree of product differentiation. If the crop does not meet the specification of any primary customer then it is usually switched to processing or wholesale markets (though increasingly both these 'secondary' markets also require products grown to a specification) (Terry et al. 2013).

It is inevitable that there will be product that does not meet any market specification. The amounts will vary product by product and season by season (Terry et al. 2011). These products will suffer quality defects including disease that may make them unsuitable for human consumption. These products will be variously used for animal feed, as feedstock for anaerobic digester (AD) plants and as soil amendments applied to land. It is clear that no successful grower intentionally grows lower grade products as the returns are less and they will endeavor to utilize crop where there is an economic gain in doing so.

Underpinning each of the quality tiers is a specification which is usually much more detailed than the EU or other international marketing standards. These specifications are usually commercially sensitive. Inevitably, however, there is often some degree of commonality between specifications used by many retailers, especially when considering a specific product in a single quality tier. Indeed, many suppliers supply more than one retailer and the differentiation between specifications is less than might be assumed. In developed economies, specifications are fundamentally based on visual appearance (e.g. size, shape and color uniformity) and freedom from defects (e.g. disease, blemish, bruising or even susceptibility to bruising physiological disorder); however cultivar and other attributes such as taste and flavor which are also related to consumer preference (for some products) are also important e.g. apples attaining threshold firmness and total soluble solids content. Specifications are enforced by internal quality control inspections by suppliers and retail customers. This said, the statistical validity of these inspections is questionable. There is typically little tolerance for severe aesthetic defects even for basic/value tiers. Specifications determine the assignment of products to each quality tier, yet it is true that some specifications for certain product types are solely based on physical attributes such as appearance. This does not mean that these specifications are not useful as the importance of appearance should not be underestimated (Terry et al. 2013).

It is easy to criticize specifications, but it should be acknowledged that non-adherence to most specifications can markedly influence consumer preference and purchasing decisions (Terry et al. 2013). Customer complaints and increasingly other feedback mechanisms are used to judge whether specifications reflect consumer purchasing behavior. Yet, the accuracy of customer complaints is questionable.

Research Needs and Impact on Sustainability

There is a misconception that extending postharvest life always will reduce waste and loss. The relationship is more complex and is related to appreciation of the influence that management practices have on postharvest biology. For example, where demand is predictable then waste and loss levels will be minimized even if a product has a short shelf life (e.g. post climacteric bananas). On the other hand, where demand is unpredictable because of weather influencing consumption (e.g. unforeseen cold weather reducing strawberries and salad consumption even when hot weather has been forecast) then there may be a propensity to oversupply such that the residence time of product in store (often at sub optimum conditions) is increased leading to greater risk of waste (Terry et al. 2011). Thus, although the use of innovative postharvest technologies is often needed it is their implementation that also needs to be taken into account in the context of supply chain management. Despite this, numerous technological advances have been shown to reduce waste and extend availability; yet it is questionable whether all technologies are sustainable in the long-term. The ubiquity of low temperature storage in recent decades has helped to significantly reduce postharvest waste of fruit and vegetables. Most in the postharvest community believe that maintaining the cool chain is a pre-requisite before any other technologies are considered. It is true that cold storage can vastly increase postharvest life. But the overreliance on cooling systems in developed supply chains and allied just-in-time logistics may not be sustainable or resilient in the long term.

Alternative or supplementary technologies which might allow for extended postharvest life without the over-reliance of cool storage may become more common place. For instance, the targeted use of next generation controlled atmosphere storage (e.g. ultra low oxygen and dynamic controlled atmosphere systems (Watkins 2008a), ethylene control, genetic modification, and novel packaging innovations may allow for products to be stored at slightly higher temperatures.

The removal of ethylene and/or inhibition of its action in stored environments are fundamental to maintaining the postharvest quality of most climacteric produce. In recent years, however, there has been a paucity of research on developing new and more efficacious ethylene scrubbing materials. In contrast, there has been an exponential increase in research using the ethylene binding inhibitor 1-MCP (Lu et al. 2008). Despite availability of various ethylene scrubbing technologies (e.g. high temperature catalytic degradation, activated carbon) most commercial ethylene control systems rely on both adequate ventilation (often periodic) and oxidation of ethylene using potassium permanganate. Ventilation, however, is not appropriate in sealed environments (e.g. controlled atmosphere or some packaging formats) or where precise ethylene control is required. Ethylene supplementation has been shown to extend storage life of onions and potatoes even though they are low ethylene producers Cools et al. (2011). Ethylene inhibition using substances like 1-methylcyclopropene (1-MCP) (Blankenship and Dole 2003; Watkins 2006; Watkins 2008b; Lu et al. 2008) and ethylene scrubbers (Terry et al. 2007; Smith et al. 2009; Meyer and Terry 2010; Elmi et al. 2012) have been shown to improve postharvest storage.

Future Outlook

The disparity in quality of fresh produce between developed and developing economies is unsustainable. Yet, despite this realization and much talk, little in the way of a global consensus and viable action planning has been forthcoming. Developed economies have had an unparalleled period of relative and sustained growth until 2008 and this has inevitably affected fresh produce supply chains. The large multinational retailers continue to dominate at the expense of less efficient outlets that do not possess the market intelligence, buyer power, convenience offerings and mass market appeal. The future dominance of emerging markets is becoming more likely, such that it is unclear whether all socio-economic groupings within developed economies will continue to have access to the quality and choice of produce which they might have expected or have become accustomed to. Better and more targeted implementation of innovative postharvest technologies is required to ensure the sustainable supply of a diverse range of fruit and vegetables in the future.

Role of Postharvest Technology in Reducing Losses and Ensuring Optimal Quality and Nutrition for Consumers

Challenge of Postharvest Losses in Existing Marketing and Distribution

Most losses at the retail and consumer levels are incurred in the developed economies of the world (Parfitt et al. 2010) and therefore the discussion in this section will pertain to issues in developed economies. Produce retailers have many options that have been developed over the decades to help in reducing losses and shrinkage. One of the most beneficial at the retail and consumer level has been packaging, since it can provide physical protection for the product, help to control weight loss, provide produce in portions suitable for consumers, and provide increased levels of protection from microbial and/or chemical contamination during the handling of the product on the shelf and to the consumers table (Anon 2011). However, there are many societal and environmental issues that are yet unresolved with the lifecycle for package use, such as ubiquity of recycling programs for used packaging (Anon 2011). Despite these issues, it has been estimated that use of packaging results in significant reductions in terminal food waste (disposal to landfill) and as such has a much lower environmental impact than does not using packaging and incurring losses of fruit and vegetable mass that generates methane when it rots and thus contributes to global warming (Gooch et al. 2010).

While icing and misting are in prevalent use in many retail produce displays (Thompson and Crisosto 2002), concerns are emerging regarding the effects of free water on the quality and safety of exposed produce at the consumer level, especially if stored in a home refrigerator for any length of time (Rossman et al. 2012). Indeed, misuse of misting or icing is prevalent for packaged fruits and vegetables and can lead to problems, while not providing any benefit to such products. Recently fogging systems have been developed for commercial use (e.g. Samarketing SL 2013) and these may provide a superior humidity control for non-packaged fruits and vegetables on display while avoiding accumulations of free water on the surface.

Lack of refrigeration is a significant issue, despite the general adoption of modern technologies in the developed economies of the world. Local distribution can be subject to poor logistics practices, breakdowns and inconsistent refrigeration (Gunders 2012). In the retail stores packaged whole and fresh-cut produce on display can face significant problems associated with overstocking (Gunders 2012) which results in poor temperature control.

Waste at the consumer level exists for several potential reasons. First, many times fruits and vegetables are packaged in formats that are too large (Gunders 2012) for smaller families, single persons or couples with no children at home. This can lead to leftover produce that sits in the refrigerator after a first use. Secondly, while many households purchase nutritious fruits and vegetables with good intentions and the interest in their healthfulness, quite often in the rush of a busy life, convenience food, takeout food and meals out lead to the non-use of the purchased produce (Anon 2011; Gunders 2012; Parfitt et al. 2010). This behavior is thought to be linked with the obesity crisis in the developed world economies since many of the options have higher calories and are more energy dense than the fruits and vegetables that go uneaten (Drewnowski and Darmon 2005). Third, many consumers do not have sufficient understanding of the correct storage conditions for fresh fruits and vegetable or for managing their refrigerator to ensure proper storage conditions (Anon 2011; Gunders 2012).

Research Needs

Many of the issues related to produce losses in marketing and distribution can be resolved with improved education of produce handlers in the chain. Value chain systems are beginning to emerge which may help to spur on improvements in cold chain handling (Gooch et al. 2010). A value chain model involves ownership of responsibilities and valuation of partners in the distribution chain with the desired outcome that all partners benefit from the relationship and maximum returns accrue for each member (Gooch et al. 2010). While there is some evidence that value chain systems can result in improvements in marketing and distribution, there is a need to document issues facing the current *status quo* and research to demonstrate the benefits of a value chain approach to the enhancing retail quality and reducing shrinkage of perishable fruits and vegetables.

While packaging has been an area of research for some time (Toivonen et al. 2009), more research is required to adapt packaging to ever increasing demands for new package formats, produce combinations and enhanced convenience to the consumer and also to enhance flavor quality (Kader 2009). Packaging is essential to continue in development of a convenience factor for the consumer and reduce the losses occurring in the distribution chain. The convenience of a food for consumption will continue to become more of an issue as cities grow and the pace of lifestyle increases and hence the need to adapt fresh fruits and vegetables more and more to a convenience format (Pollack 2011). The variety of products available to the consumer in a single package is increasing in a highly competitive sector: new product introductions are important and issues around product compatibility must be resolved in the package system design (Fig. 13.3).

Technology has been developed to also cue customers to the edibility or ripeness of fruit which do not normally show visual changes with ripening. A technology to tell consumers the ripeness in green pear cultivars has provided retailers and

Fig. 13.3 Potential for a co-release technology sachet to control compatibility problems when ethylene producing tomatoes are packaged in salad mixes containing ethylene sensitive vegetables such as lettuce and carrot shreds. Packages of salad mix were obtained directly from a fresh-cut processor and stored at 5 °C for 4 weeks. A full description of the technology is provided by Lu et al. (2008)

consumers with an on package incorporated color patch that will change color as the fruit softens and develops sweetness for eating quality (http://www.ripesense.com/). Technologies providing similar cues to retailers and consumers will help to reduce waste by indicating which fruit are ready for immediate consumption and which require time to ripen. Such technologies would be useful for fruits such as kiwifruit, avocados or melons. Similar technologies could be developed for packaged fresh-cut product indicating remaining shelf life for the product, thus encouraging timely product cycling on the retail shelves and consumption for the consumer.

Is it Possible to Reduce Losses and/or Enhance Retention of Nutritional Value to the Consumer?

It is possible to both reduce losses and enhance retention of nutritional value for the consumer? Nutritional value is linked to fruit and vegetable retaining appearance and texture expectations of the consumers. Generally when produce is of good visual and tactile quality the nutritional value is high (Gil et al. 2006). Therefore, the challenge is to minimize the rate of perceptible deterioration in quality for the product and the goal of nutrition retention should be achieved. Two factors probably have most effect on both quality and nutrition retention; (1) temperature, and (2) water loss. Nutritional components such as vitamin C may decline when significant water loss occurs (Lee and Kader 2000). Temperature has a two-fold effect, it will govern the rate of biochemical processes leading to over-ripening and also warmer handling temperatures also lead to greater water loss. Modified atmospheres have also been shown however to improve vitamin C retention (Lee and Kader 2000). Losses of labile vitamins can be resolved through development of better packaging systems and through better education of the consumer regarding home refrigeration management.

Future Outlook

The challenges in this new millennium are that consumption of fruits and vegetables requires an understanding of societal values, lifestyles and environmental issues. Complex and increasingly busy cities pose challenges to the distribution and retail requirements for produce. Generally, portion-sized packages and fresh-cut product are continuing to develop since urban consumers have preference for convenience and may have limited skills or time for meal preparation (Pollack 2011). The carbon footprint for packaging is relatively small when assessed relative to the alternative of greater losses in unpackaged fruits and vegetables during distribution and marketing (Gooch et al. 2010). A key for future reductions of losses in fruits and vegetables during distribution and marketing lies in successful implementation of new models, likely involving value-chain systems (Anon 2011; Gooch et al. 2010) and introduction of intelligent packaging with formats that will encourage ongoing improvements in quality, nutrition and flavor for the consumer (Toivonen et al. 2009).

Conclusions

Many of the challenges facing success in postharvest care of fruits and vegetables do not depend on the development of new technologies, although there are still some needs that were identified. Looking in a broader perspective, some of the challenges can be met by successful adoption or adaption of existing technologies to the context of the country and economy in question. It appears however, that perhaps a larger issue is that of the constraints that societal, business and consumer behaviors place on the logistics and marketing of fruits and vegetables. Clearly, improvements in delivering quality, nutritious fruits and vegetables to consumers will depend on better co-operation and some rethinking of existing distribution systems and the goals of sellers, buyers and marketers. Technology can make all things possible, but it is willingness of the participants in the fruit and vegetable trade to take advantage of the opportunities that will determine the outcome. Since the stakes are huge in terms of current waste estimates and the challenges increase every year in terms of world population growth, the urgency to improve the situation becomes also greater.

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