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The role of post-harvest management in assuring the quality and safety of horticultural produce

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Preface

Horticultural produce plays a significant role in human nutrition by supplying vitamins, minerals, dietary fibre and anti-oxidants to the diet. The quality and safety of horticultural produce reaching the consumer hinges upon pre-harvest factors as well as proper post harvest management practices throughout the chain, from the field to the consumer. Each stakeholder along the post-harvest chain- i.e. those involved in harvesting, handling and marketing of fresh produce- has a role to play in assuring the safety and quality of fresh produce.

Basic approaches to maintaining the safety and quality of horticultural produce are the same, regardless of the market to which this produce is targeted. This document reviews the factors which contribute to quality and safety deterioration of horticultural produce, and describes approaches to assuring the maintenance of quality and safety throughout the post-harvest chain. Specific examples are given to illustrate the economic implications of investing in and applying proper post-harvest technologies. Criteria for the assessment of post-harvest needs, the selection of post-harvest technologies appropriate to the situation and context, and for extending appropriate levels of post-harvest information are also discussed.

This bulletin is targeted for use by extension workers and non-governmental organizations (NGOs) who provide training and support to the small-scale post-harvest sector. It is also intended for use as a reference source by government departments and policy makers with an interest in development of the post-harvest sector.

It is hoped that the information presented in this bulletin is helpful in improving post-harvest management practices in developing countries, thereby leading to improvement in the quality and safety of fruits and vegetables.

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1 Introduction

1.1 Value of horticultural perishables and their post-harvest losses

Fruits, nuts, and vegetables play a significant role in human nutrition, especially as sources of vitamins, minerals, dietary fibre, and antioxidants. Increased consumption of a variety of fruits and vegetables on a daily basis is highly recommended because of associated health benefits, which include reduced risk of some forms of cancer, heart disease, stroke, and other chronic diseases.

Both quantitative and qualitative losses occur in horticultural commodities between harvest and consumption. Qualitative losses, such as loss in edibility, nutritional quality, caloric value, and consumer acceptability of fresh produce, are much more difficult to assess than are quantitative losses. Quality standards, consumer preferences and purchasing power vary greatly across countries and cultures and these differences influence marketability and the magnitude of post-harvest losses.

Post-harvest losses vary greatly across commodity types, with production areas and the season of production. Losses of fresh fruits and vegetables in developed countries are estimated to range from 2 percent for potatoes to 23 percent for strawberries, with an overall average of 12 percent losses between production and consumption sites. In contrast, the range of produce losses in developing countries varies widely. Losses at the retail, food-service, and consumer levels are estimated at approximately 20 percent in developed countries and about 10 percent in developing countries. Overall, about one third of horticultural crops produced are never consumed by humans.

Reduction of post-harvest losses can increase food availability to the growing world population, decrease the area needed for production, and conserve natural resources. Strategies for loss prevention include: (1) use of genotypes that have longer post-harvest-life; (2) use of integrated crop management systems and Good Agricultural Practices that result in good keeping quality of the commodity; and (3) use of proper post-harvest handling practices in order to maintain the quality and safety of fresh produce.

Although minimizing post-harvest losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5 percent of the funding of agricultural research and extension programs worldwide is devoted to activities related to maintenance of produce quality and safety during post-harvest handling. This situation must be changed if success is to be achieved in reducing post-harvest losses of horticultural perishables.

1.2 Quality factors

Quality, the degree of excellence or superiority, is a combination of attributes, properties, or characteristics that give each commodity value, in terms of its intended use. The relative importance given to a specific quality attribute varies in accordance with the commodity concerned and with the individual (producer, consumer, and handler) or market concerned with quality assessment. To producers, high yields, good appearance, ease of harvest, and the ability to withstand long-distance shipping to markets are important quality attributes. Appearance, firmness, and shelf-life are important from the point of view of wholesale and retail marketers. Consumers, on the other hand, judge the quality of fresh fruits, ornamentals, and vegetables on the basis of appearance (including 'freshness') at the time of initial purchase. Subsequent purchases depend upon the consumer's satisfaction in terms of flavor (eating) quality of the edible part of produce. Following is a description of the factors that contribute to the various quality attributes of fresh produce:

1.2.1 Appearance (visual) quality factors.

These may include size, shape, color, gloss, and freedom from defects and decay. Defects can originate before harvest as a result of damage by insects, diseases, birds, and hail; chemical injuries; and various blemishes (such as scars, scabs, russeting, rind staining). Post-harvest defects may be morphological, physical, physiological, or pathological.

1.2.2. Textural (feel) quality factors.

These include firmness, crispness, juiciness, mealiness, and toughness, depending on the commodity. Textural quality of horticultural crops is not only important for their eating and cooking quality but also for their shipping ability. Soft fruits cannot be shipped over long distances without substantial losses due to physical injuries. In many cases, the shipment of soft fruits necessitates that they be harvested at less than ideal maturity, from the flavor quality standpoint.

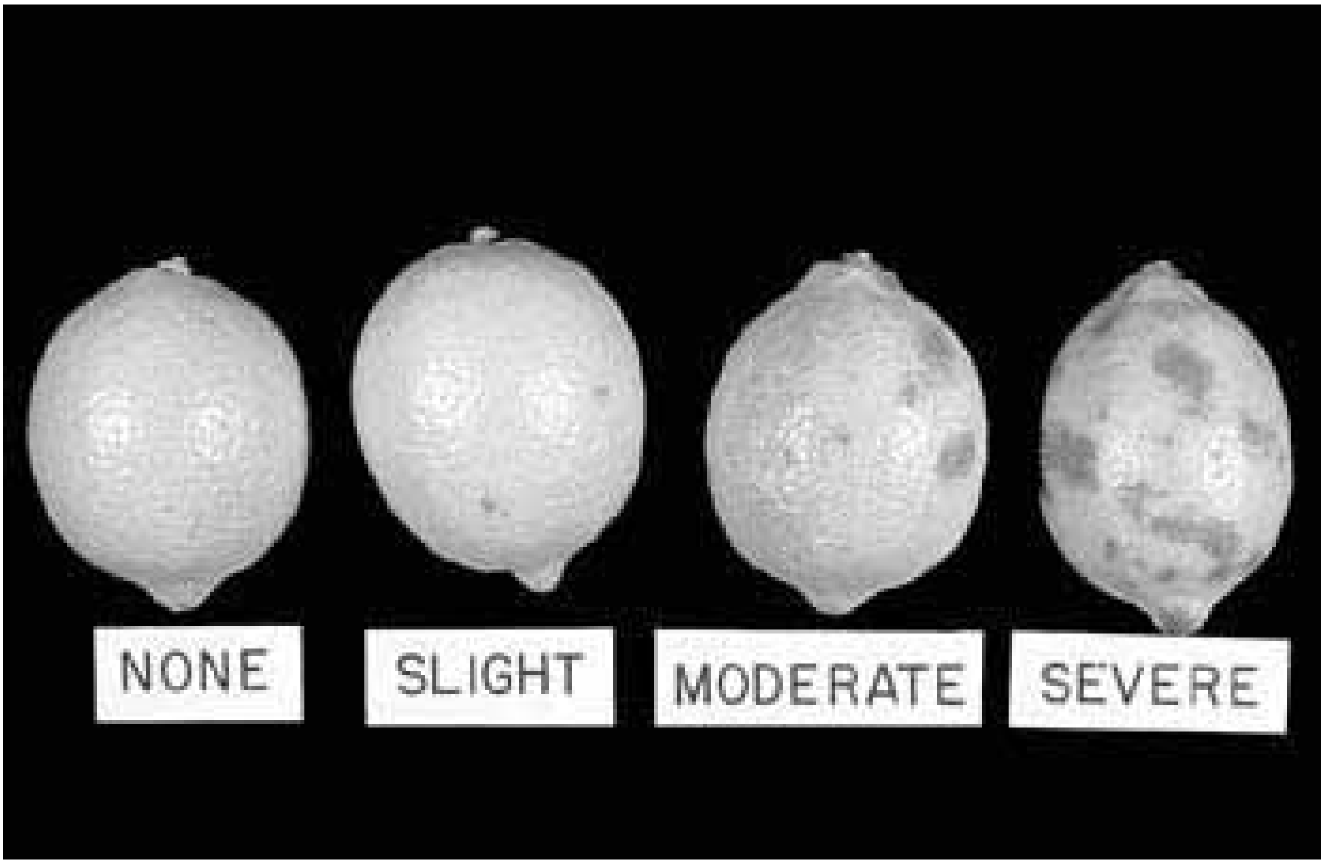

Figure 1: Oil spotting on lemons (the result of mechanical damage during the harvesting and handling of turgid lemons)

1.2.3. Flavor (eating) quality factors.

These include sweetness, sourness (acidity), astringency, bitterness, aroma, and off-flavors. Flavor quality involves perception of the tastes and aromas of many compounds. An objective analytical determination of critical components must be coupled with subjective evaluations by a taste panel to yield useful and meaningful information about the flavor quality of fresh fruits and vegetables. This approach can be used to define a minimum level of acceptability. In order to assess consumer preference for the flavor of a given commodity, large-scale testing by a representative sample of consumers is required.

1.2.4. Nutritional quality factors.

Fresh fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins (Vitamin C, Vitamin A, Vitamin B, thiamine, niacin), minerals, and dietary fibre. Other constituents of fresh fruits and vegetables that may lower the risk of cancer and other diseases include carotenoids, flavonoids, isoflavones, phytosterols, and other phytochemicals (phytonutrients).

Figure 2: Chilling injury and symptoms of mechanical damage on plantains

Grade standards identify quality attributes in a commodity that are the basis of its use and value. Such standards, if enforced properly, are essential tools of quality assurance during marketing and provide a common language for trade among growers, handlers, processors, and receivers at terminal markets.

1.3. Safety factors

A number of factors threaten the safety of fruits and vegetables. These include naturally-occurring toxicants, such as glycoalkaloids in potatoes; natural contaminants, such as fungal toxins (mycotoxins) and bacterial toxins, and heavy metals (cadmium, lead, mercury); environmental pollutants; pesticide residues; and microbial contamination. While health authorities and scientists regard microbial contamination as the number one safety concern, many consumers rank pesticide residues as their most important safety concern.

Unless fertilized with animal and/or human waste or irrigated with water containing such waste, raw fruits and vegetables should normally be free of most human and animal enteric pathogens. Organic fertilizers, such as chicken manure, should be sterilized prior to their application in fruit and vegetable production, so as to avoid the risk of contaminating fresh produce with *Salmonella, Listeria*, and other pathogens. Commodities that touch the soil are more likely to be contaminated than those that do not come in contact with the soil. The best approach to achieving and maintaining the safety of fresh fruits and vegetables is to focus on limiting potential contamination during their growth, harvesting, handling, treatment, packaging and storage. Strict adherence to Good Agricultural Practices, i.e. basic food safety principles associated with minimizing biological, chemical and physical hazards from the field throughout the distribution chain of fresh fruits and vegetables; Good Hygienic Practices, i.e. conformance to sanitation and hygienic practices to the extent necessary to protect against contamination of food from direct or indirect sources, is strongly recommended to minimize microbial contamination. Careful handling and washing of all produce to be consumed raw and the strict observance of proper sanitary measures are strongly recommended to reduce microbial contamination at the food-service, retail, and consumer levels.

2

Genetic, Pre-harvest, and Harvesting Factors that Influence the Quality and Safety of Horticultural Crops

2.1 Genetic factors

Within each commodity grouping there is a range of genotypic variation in composition, quality, and post-harvest-life potential. Plant breeders have been successful in selecting carrot, sweet potato, and tomato cultivars with comparably high carotenoid levels and vitamin A content; onion and tomato cultivars with longer shelf-lives, sweet corn cultivars that maintain their sweetness longer after harvest; cantaloupe and watermelon cultivars with higher sugar content and firmer flesh, and pineapple cultivars with higher contents of ascorbic acid, carotenoids, and sugars. These are just a few examples of how genetic manipulation has contributed to improving the quality of fruits and vegetables. However, in many cases, commercial cultivars selected for their ability to withstand the rigors of marketing and distribution, tend to lack sufficient sensory quality, in particular flavor.

Horticultural plant breeders have an unprecedented opportunity to address human nutritional needs by developing fruit and vegetable cultivars that are rich in nutrients. In so doing, a multidisciplinary approach should be taken with emphasis the enhancement of nutritional quality for maximum impact on human nutrition and wellness.

Many opportunities exist for applying biotechnology to improving the post-harvest quality and safety of fresh produce. Priority goals in this regard, should, be focused on: (1) attaining and maintaining good flavor and nutritional quality, so as to satisfy consumer demands and (2) introducing resistance to physiological disorders and/or decay-causing pathogens, so as to reduce the use of chemicals on fruits and vegetables.

2.2 Climatic conditions

Climatic factors, in particular temperature and light intensity, greatly impact on the nutritional quality of fruits and vegetables. Consequently, the location of production and the season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, thiamine, and flavonoid contents. In general, the lower the light intensity the lower the ascorbic acid content of plant tissues. Temperature influences the uptake and metabolism of mineral nutrients by plants, since transpiration rates increase with increasing temperature. Rainfall affects water supply to the plant, which may influence the composition of the harvested plant part and its susceptibility to mechanical damage and decay during subsequent harvesting and handling operations.

2.3 Cultural practices

Soil type, the rootstock used for fruit tree cultivation, mulching, irrigation, and fertilization influence the water and nutrient supply to the plant, which can in turn affect the nutritional quality of the harvested plant part. The effect of fertilizers on the vitamin content of plants is less important than are the effects of genotype and climatic conditions. The effects of mineral and elemental uptake from fertilizers by plants are, however, significant and variable. Selenium and sulfur uptake for example influence the concentrations of organosulfur compounds in *Allium* and *Brassica* species. High calcium uptake in fruits has been shown to reduce respiration rates, and ethylene production, to delay ripening, increase firmness, and reduce the incidence of physiological disorders and decay, all of which result in increased post-harvest shelf-life. High nitrogen content on the other hand, is often associated with reduced post-harvest-life due to increased susceptibility to mechanical damage, physiological disorders, and decay. Increasing the nitrogen and/or phosphorus supply to citrus trees results in somewhat reduced acidity and ascorbic acid content in citrus fruits, while increased potassium fertilization results in increased acidity and ascorbic acid content.

Numerous physiological disorders are associated with mineral deficiencies. Bitter pit of apples; blossom-end rot of tomatoes, peppers, and watermelons; cork spot in apples and pears; and red blotch of lemons are all associated with calcium deficiency in these fruits. Boron deficiency results in corking of apples, apricots, and pears; lumpy rind of citrus fruits, and cracking of apricots. Poor color of stone fruits may be related to iron and/or zinc deficiencies. Excess sodium and/or chloride (due to salinity) results in reduced fruit size and higher soluble solids content.

Severe water stress results in increased sunburn of fruits, irregular ripening of pears, tough and leathery texture in peaches, and incomplete kernel development in nuts. Moderate water stress reduces fruit size and increases soluble solids content, acidity, and ascorbic acid content. On the other hand, excess water supply to plants results in cracking of fruits (such as cherries, plums, and tomatoes), excessive turgidity leading to increased susceptibility to physical damage (such as oil spotting on citrus fruits), reduced firmness, delayed maturity, and reduced soluble solids content.

Cultural practices such as pruning and thinning determine the crop load and fruit size, which can in turn influence the nutritional composition of fruit. The use of pesticides and growth regulators does not directly influence fruit composition but may indirectly affect it due to delayed or accelerated fruit maturity. Effective pre-harvest disease control greatly influences disease incidence and severity during post-harvest handling of fruits and vegetables

2.4 Maturity at harvest in relation to quality

Maturity at harvest is the most important determinant of storage-life and final fruit quality. Immature fruit are highly susceptible to shriveling and mechanical damage, and are of inferior flavor quality when ripe. Overripe fruit are likely to become soft and mealy with insipid flavor soon after harvest. Fruit picked either prematurely or too late, are more susceptible to post-harvest physiological disorders than are fruit picked at the proper stage of maturity.

With a few exceptions all fruits attain optimal eating quality when allowed to ripen on the plant. Some fruits are, however, picked at a mature but unripe stage of development so as to allow them to withstand post-harvest handling conditions when shipped over long-distances. Maturity indices for such fruit are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide flexibility in marketing.

Fruit can be divided into two groups: (1) those that are incapable of continuing their ripening process once removed from the plant, and (2) those that can be harvested at the mature stage and allowed to ripen off the plant. Group 1 includes cane berries, cherry, citrus fruits, grape, lychee, pineapple, pomegranate, strawberry, and tamarillo. Group 2 on the other hand, includes apple, apricot, avocado, banana, cherimoya, guava, kiwifruit, mango, nectarine, papaya, passion fruit, pear, peach, persimmon, plum, quince, sapodilla, and sapote.

Fruit of the Group 1 category, produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of degreening (removal of chlorophyll); these should be picked when fully-ripe, if good flavor quality is to be ensured. Fruit of the Group 2 category on the other hand, produce comparably larger quantities of ethylene which is associated with their ripening, and undergo more rapid and uniform ripening upon exposure to ethylene.

Many vegetables, in particular leafy vegetables, and immature fruit-vegetables (such as cucumbers, sweet corn, green beans, peas, and okras), attain optimum eating-quality prior to reaching full maturity. This often results in delayed harvest, and consequently in produce of low quality.

2.5 Method of harvesting in relation to physical damage and uniformity of maturity

The method of harvesting (hand vs mechanical) can significantly impact upon the composition and post-harvest quality of fruits and vegetables. Mechanical injuries (such as bruising, surface abrasions and cuts) can accelerate loss of water and vitamin C resulting in increased susceptibility to decay-causing pathogens. Most fresh fruits and vegetables and all flowers are harvested by hand. Root crops (such as carrot, onion, potato, and sweet potato) and some commodities destined for processing (such as processing tomatoes, European plums, and tree nut crops) are mechanically harvested.

Figure 3: Harvesting Papayas

Management of harvesting operations, whether manual or mechanical, can have a major impact on the quality of harvested fruits and vegetables. Proper management procedures include selection of optimum time to harvest in relation to product maturity and climatic conditions, training and supervision of workers, and proper implementation of effective quality control. Expedited and careful handling, immediate cooling after harvest, maintenance of optimum temperatures during transit and storage, and effective decay-control procedures are important factors in the successful post-harvest handling of fruits and vegetables.

Attention must be paid to all of these factors, regardless of the method of harvesting used. These factors are nevertheless more critical in the case of mechanically harvested commodities.

It should be noted that any practice that reduces the number of produce handling steps will help minimize losses. Field packing (selection, sorting, trimming, and packaging) of produce at the time of harvest can greatly reduce the number of handling steps in preparation for marketing. Mobile field packing stations with adequate shading are used for those fruits (such as grapes and strawberries) and vegetables (such as broccoli, cauliflower, and green beans) that do not require washing as part of their preparation for marketing.

Figure 4: Field Packing of Green Beans

3
Post-harvest Management Procedures that are Critical to Maintaining the Quality and Safety of Horticultural Crops

3.1 Packing and packaging of fruits and vegetables

Preparation of produce for market may be done either in the field or at the packing house. This involves cleaning, sanitizing, and sorting according to quality and size, waxing and, where appropriate, treatment with an approved fungicide prior to packing into shipping containers. Packaging protects the produce from mechanical injury, and contamination during marketing. Corrugated fiberboard containers are commonly used for the packaging of produce, although reusable plastic containers can be used for that purpose. Packaging accessories such as trays, cups, wraps, liners, and pads may be used to help immobilize the produce within the packaging container while serving the purpose of facilitating moisture retention, chemical treatment and ethylene absorption. Either hand-packing or mechanical packing systems may be used. Packing and packaging methods can greatly influence air flow rates around the commodity, thereby affecting temperature and relative humidity management of produce while in storage or in transit.

3.2 Temperature and relative humidity management

Temperature is the most important environmental factor that influences the deterioration of harvested commodities. Most perishable horticultural commodities have an optimal shelf-life at temperatures of approximately 0 °C. The rate of deterioration of perishables however increases two to three-fold with every 10 °C increase in temperature (Table 1). Temperature has a significant effect on how other internal and external factors influence the commodity, and dramatically affects spore germination and the growth of pathogens.

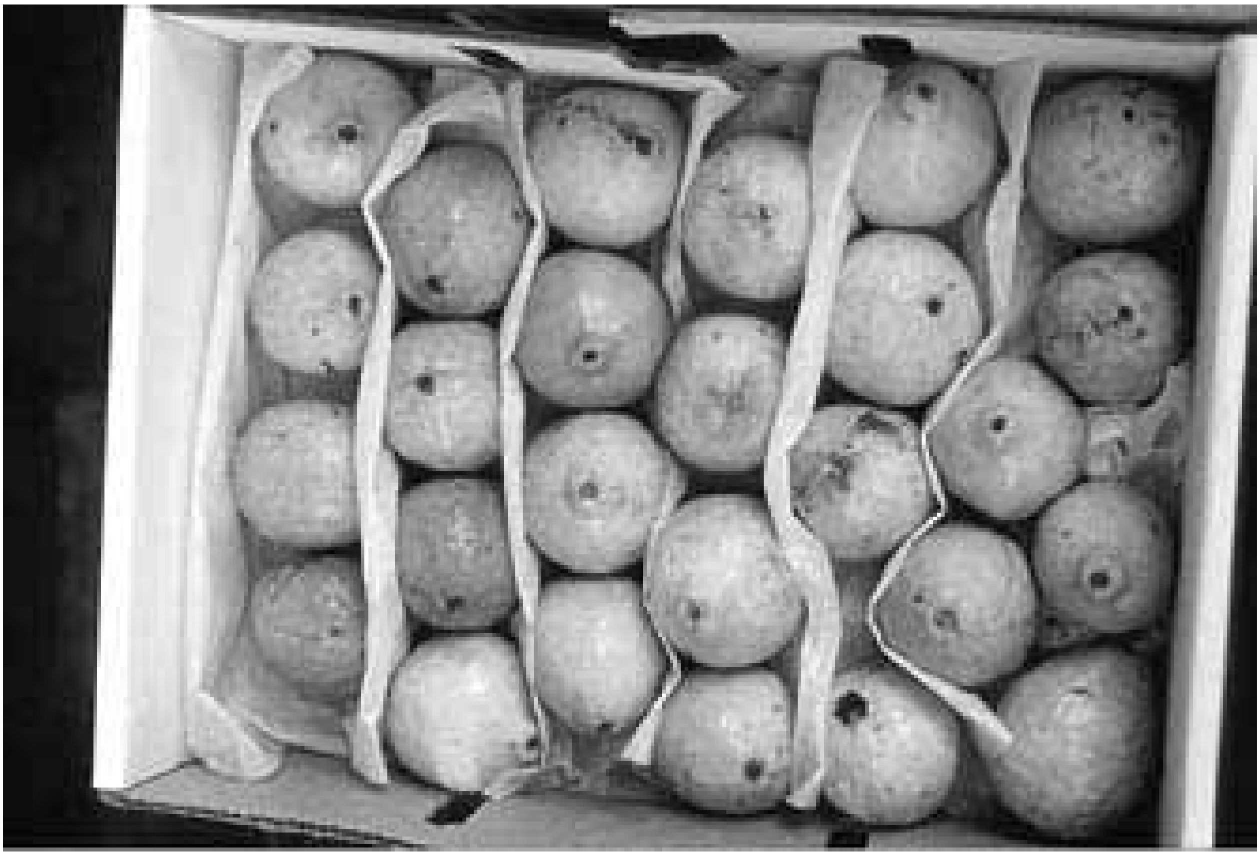

Figure 5: Packaging of Guavas

Figure 6: Sizing of Tomatoes

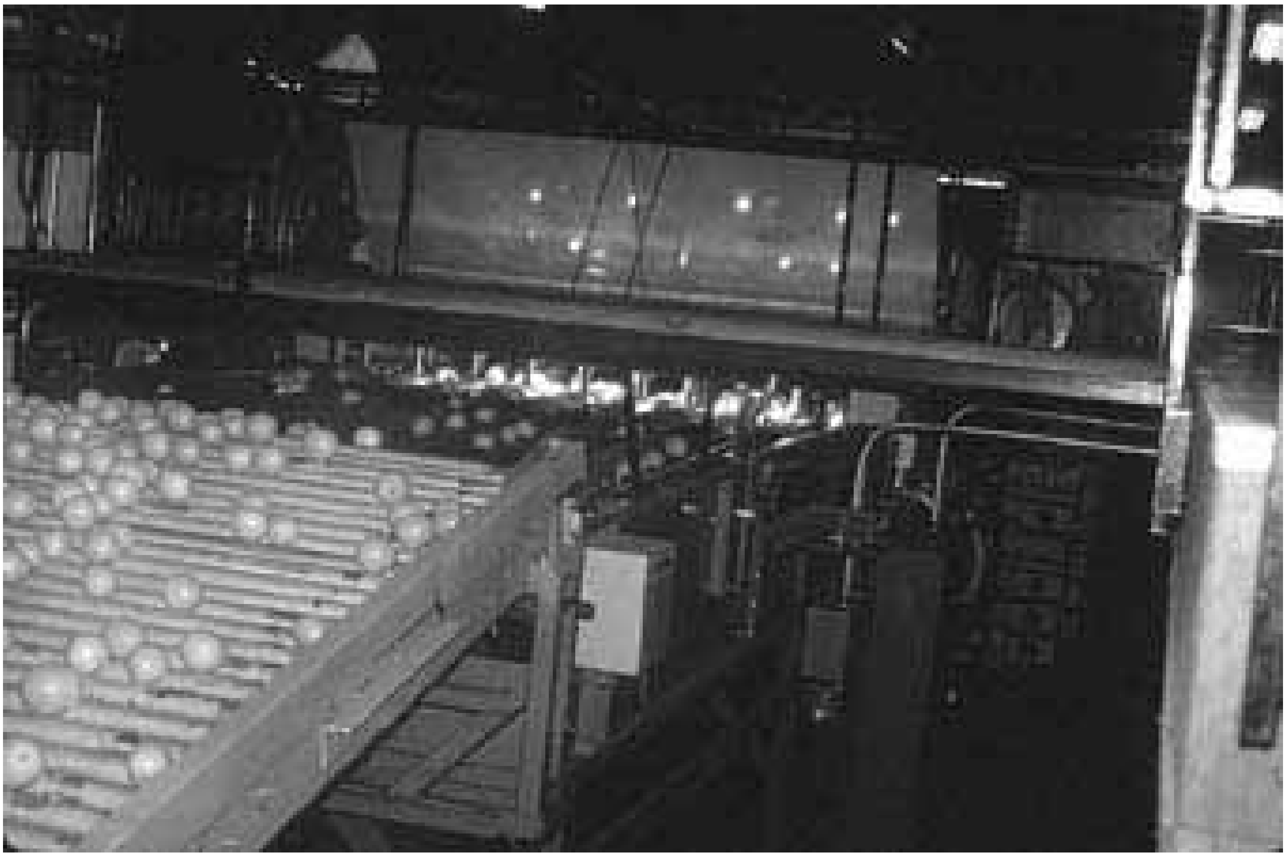

Figure 7: Machine Vision Sorting of Citrus Fruit

Table 1: Effect of temperature on the deterioration rate of a non-chilling sensitive commodity

Temperature (°C)	Assumed Q_{10}*	Relative velocity of deterioration	Relative postharvest-life	Loss per day (%)
0	——	1.0	100	1
10	3.0	3.0	33	3
20	2.5	7.5	13	8
30	2.0	15.0	7	14
40	1.5	22.5	4	25

$$*Q_{10} = \frac{\text{Rate of deterioration at temperature T + 10 °C}}{\text{Rate of deterioration at temperature T}}$$

Table 1: Effect of temperature on the deterioration rate of a non-chilling sensitive commodity

Temperatures either above or below the optimal range for fresh produce can cause rapid deterioration due to the following disorders:

<u>Freezing</u> Perishable commodities are generally high in water content, and possess large, highly vacuolate cells. The freezing point of their tissues is relatively high (ranging from -3 °C to -0.5 °C), and disruption caused by freezing generally results in immediate collapse of their tissues and a total loss of cellular integrity. Freezing occurs in cold storage systems either due to inadequate refrigerator design, or to thermostat failure. Freezing can also occur upon exposure to inclement weather conditions as occurs when produce is allowed to remain for even short periods of time on unprotected transportation docks during winter.

<u>Chilling injury</u> Some commodities (chiefly those native to the tropics and subtropics) respond unfavorably to storage at low temperatures which are well above their freezing points, but below a critical temperature termed their chilling threshold temperature or lowest safe temperature (Table 2). Chilling injury is manifested in a variety of symptoms including surface and internal discoloration, pitting, water soaking, failure to ripen, uneven ripening, development of off flavors and heightened susceptibility to pathogen attack.

Figure 8: Chilling Injury on Mangoes

Lowest safe temperature (°C)	Commodity
3	Asparagus, cranberry, jujube
4	Cantaloupe, certain apple cultivars (such as McIntosh and Yellow Newton), certain avocado cultivars (such as Booth and Lula), lychee, potato, tamarillo
5	Cactus pear, cowpeas, durian, feijoa, guava, kumquat, lima bean, longan, mandarin, orange, pepino
7	Certain avocado cultivars (such as Fuerte and Hass), chayote, okra, olive, pepper, pineapple, pomegranate, snap bean
10	Carambola, cucumber, eggplant, grapefruit, lime, mango (ripe), melons (casaba, crenshaw, honeydew, persian), papaya, passion fruit, plantain, rambutan, squash (soft rind), taro, tomato (ripe), watermelon
13	Banana, breadfruit, cherimoya, ginger, jackfruits, jicama, lemon, mango (mature-green), mangosteen, pumpkin and hard-rind squash, sapotes, sweet potato, tomato (mature-green), yam

Table 2: Classification of chilling-sensitive fruits and vegetables according to their lowest safe temperature for transport and storage

Heat injury High temperature conditions are also injurious to perishable crops. Transpiration is vital to maintaining optimal growth temperatures in growing plants. Organs removed from the plant, however, lack the protective effects of transpiration, and direct sources of heat, such as sunlight, can rapidly elevate the temperature of tissues to above the thermal death point of their cells, leading to localized bleaching, necrosis (sunburn or sunscald) or general collapse.

Relative humidity (RH) is defined as the moisture content (as water vapor) of the atmosphere, expressed as a percentage of the amount of moisture that can be retained by the atmosphere (moisture holding capacity) at a given temperature and pressure without condensation. The moisture holding capacity of air increases with temperature. Water loss is directly proportional to the vapor pressure difference (VPD) between the commodity and its environment. VPD is inversely related to the RH of the air surrounding the commodity.

RH can influence water loss, decay development, the incidence of some physiological disorders, and uniformity of fruit ripening. Condensation of moisture on the commodity (sweating) over long periods of time is probably more important in enhancing decay than is the RH of ambient air. An appropriate RH range for storage of fruits is 85 to 95 percent while that for most vegetables varies between 90 and 98 percent. The optimal RH range for dry onions and pumpkins is 70 to 75 percent. Some root vegetables, such as carrot, parsnip, and radish, can best be held at 95 to 100 percent RH.

RH can be controlled by one or more of the following procedures:

(1) adding moisture (water mist or spray, steam) to air with the use of humidifiers;
(2) regulating air movement and ventilation in relation to the produce load in the cold storage room;
(3) maintaining the temperature of the refrigeration coils in the storage room or transit vehicle to within about 1 °C of the air temperature;
(4) providing moisture barriers that insulate walls of storage rooms and transit vehicles;
(5) adding polyethylene liners in packing containers and using perforated polymeric films for packaging;
(6) wetting floors in storage rooms;
(7) adding crushed ice in shipping containers or in retail displays for commodities that are not injured by the practice;
(8) sprinkling produce with sanitized, clean water during retail marketing of commodities that benefit from misting, such as leafy vegetables, cool-season root vegetables, and immature fruit vegetables (such as snap beans, peas, sweet corn, and summer squash).

3.3 Cooling methods

Temperature management is the most effective tool for extending the shelf life of fresh horticultural commodities. It begins with the rapid removal of field heat by using one of the cooling methods listed in Table 3.

Variable	**Cooling method**				
	Ice	Hydro	Vacuum	Forced-air	Room
Cooling times (h)	0.1-0.3	0.1-1.0	0.3-2.0	1.0-10.0	20-100
Water contact with the product	yes	yes	no	no	no
Product moisture loss (%)	0-0.5	0-0.5	2.0-4.0	0.1-2.0	0.1-2.0
Capital cost	high	low	medium	low	low
Energy efficiency	low	high	high	low	low

Table 3: Comparison of methods used for cooling

Packing fresh produce with crushed or flaked ice provides rapid cooling, and can provide a source of cooling and high RH during subsequent handling. The use of crushed ice is, however, limited to produce that is tolerant to direct contact with ice and packaged in moisture-resistant containers.

Clean, sanitized water is used as the cooling medium for the hydrocooling (shower or immersion systems) of commodities that tolerate water contact and are packaged in moisture-resistant containers. Vacuum cooling is generally applied to leafy vegetables that release water vapor quickly, thereby allowing them to be rapidly cooled. During forced-air cooling on the other hand, refrigerated air is forced through produce packed in boxes or pallet bins. Forced-air cooling is applicable to most horticultural perishables.

Precise temperature and RH management are required to provide the optimum environment for fresh fruits and vegetables during cooling and storage. Precision temperature management (PTM) tools, including time-temperature monitors, are increasingly being employed in cooling and storage facilities.

Figure 9: Forced-Air Cooling of Melons

3.4 Refrigerated transport and storage

Cold storage facilities should be appropriately designed, of good construction, and be adequately equipped. Their insulation should include a complete vapor barrier on the warm side of the insulation; sturdy floors; adequate and well-positioned doors for loading and unloading; effective distribution of refrigerated air; sensitive and properly located controls; refrigerated coil surfaces designed to adequately minimize differences between the coil and air temperatures; and adequate capacity for expected needs. Commodities should be stacked in the cold room or the refrigerated vehicle with air spaces between pallets and room walls so as to ensure proper air circulation. Storage rooms should not be loaded beyond their capacity limit if proper cooling is to be achieved. Commodity temperature rather than air temperature should be measured in these facilities.

Temperature management during transportation of fresh fruits and vegetables over long distances is critical. Loads must be stacked so as to enable proper air circulation, in order to facilitate removal of heat from the produce as well as to dissipate incoming heat

Figure 10: Refrigerated intermodal transport container

from the atmosphere and off the road. Stacking of loads must also incorporate consideration for minimizing mechanical damage. Transit vehicles must be cooled prior to loading the fresh produce. Delays between cooling after harvest and loading into transit vehicles should also be avoided. Proper temperature maintenance should be ensured throughout the handling system.

As far as possible, environmental conditions (temperature; relative humidity; concentrations of oxygen, carbon dioxide, and ethylene) should be optimized in transport vehicles. Treatment with ethylene to initiate ripening during transportation is feasible, and is commercially used to a limited extent on mature green bananas and tomatoes. Produce should be cooled prior to loading and should be loaded with an air space between the palletized product and the walls of the transport vehicles in order to facilitate temperature control. Vibration during transportation should be minimized, so as to avoid damage due to bruising. Controlled-atmosphere and precision temperature management should, where possible, be observed so as to allow non-chemical insect control for markets which possess quarantine restrictions against pests endemic to exporting countries and for markets that do not want their produce exposed to chemical fumigants.

Mixing several produce items in one load is common and often compromises have to be made in selecting an optimal temperature and atmospheric composition when transporting chilling-sensitive with non-chilling sensitive commodities or ethylene-producing with ethylene-sensitive commodities. In the latter case, ethylene scrubbers can be used to remove ethylene from the circulating air within the vehicle. Several types of insulating pallet covers are available for protecting chilling-sensitive commodities when transported with non-chilling-sensitive commodities at temperatures below their threshold chilling temperatures.

3.5 The cold chain and its importance

The cold chain encompasses all the critical steps and processes that foods and other perishable products must undergo in order to maintain their quality. Like any chain, the cold chain is only as strong as its weakest link. Major limitations experienced by the cold-chain include poor temperature management due to either the lack of, or limitations in, refrigeration, handling, storage, and humidity control. Investment in cold chain infrastructure ultimately leads to a reduction in the level of losses and quality degradation in fresh produce, with overall net positive economic returns.

3.6 Return on investment in temperature and relative humidity management

Deficiencies in cold chain management whether due to limitations in refrigeration, improper handling and storage, or inadequate humidity control, can lead to losses in profits as well as in horticultural crops. Overcoming such deficiencies necessitates improvements in methodologies, operations and handling along the chain. Often the level of investment required in overcoming such deficiencies is minimal in comparison to the level of losses sustained over time.

A University of California study determined that a one-hour delay in cooling strawberries after harvest resulted in a 10 percent loss due to decay during marketing. The resulting economic loss exceeded the increased cost of expedited handling of the strawberries by more frequent deliveries of harvested fruit to the cooling facility and initiation of forced-air cooling. Similarly, a University of Georgia study showed that poor

Maintaining The Cold Chain For Perishables

Harvest	• **Minimize delays before cooling** • **Cool the product thoroughly as soon as possible**
Cooling	• **Store the product at optimum temperature**
Temporary Storage	• **Practice first in first out rotation** • **Ship to market as soon as possible**
Transport to Market	• **Use refrigerated loading area** • **Cool truck before loading** • **Load pallets towards the center of the truck** • **Put insulating plastic strips inside door of reefer if truck makes multiple stops** • **Avoid delays during transport** • **Monitor product temperature during transport**
Handling at destination	• **Use a refrigerated unloading area** • **Measure product temperature** • **Move product quickly to the proper storage area** • **Transport to retail markets or foodservice operations in refrigerated trucks** • **Display at proper temperature range**
Handling at home or foodservice outlet	• **Store product at proper temperature** • **Use the product as soon as possible**

temperature management of lettuce resulted in a net income loss of US$172.50 per truck-load of 900 cartons.

A University of California study determined that excess weight loss coupled with color deterioration resulting from delays between harvest and cooling, improper refrigeration temperature and relative humidity control during the shipping of table grapes resulted in a 15 percent loss in the value of that commodity. Resultant monetary losses were greater than the cost of improved management of temperature and RH of the grapes with perforated plastic liners in the boxes and by minimizing delays prior to cooling with humidified, forced air.

4

Post-harvest Treatments Designed to Minimize Produce Contamination and to Maximize Quality

4.1 Treatments to reduce microbial contamination

Over the past few years, food safety has become and continues to be the number one concern of the fresh produce industry. A "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables," was published by the U.S. Food and Drug Administration in October 1998. This guide is based on the following principles:

(1) Prevention of microbial contamination of fresh produce is favored over reliance on corrective actions once contamination has occurred;
(2) In order to minimize microbial food safety hazards in fresh produce, growers, packers, or shippers should use good agricultural and management practices in those areas over which they have control;
(3) Fresh produce can become microbiologically contaminated at any point along the farm-to-table food chain. Human and/or animal faeces are the source of microbial contamination of fresh produce;
(4) Whenever water comes in contact with produce, its quality dictates the potential for contamination. The potential of microbial contamination from water used with fresh fruits and vegetables must be minimized;
(5) The use of animal manure or municipal biosolid wastes as fertilizers should be closely managed in order to minimize the potential for microbial contamination of fresh produce; and
(6) Worker hygiene and sanitation practices during production, harvest, sorting, packing, and transport play a critical role in minimizing the potential for microbial contamination of fresh produce."

A training manual for trainers, entitled "Improving the Safety and Quality of Fresh Fruits and Vegetables," was published by the United States Food and Drug Administration (USFDA) in November 2002, with the objective of providing uniform, broad-based scientific and practical information on the safe production, handling, storage, and transport of fresh produce.

Figure 11: Washing Bananas

Clean water containing an appropriate concentration of sanitizers is required in order to minimize the potential transmission of pathogens from water to produce, from healthy to infected produce within a single lot, and from one lot of produce to another, over time. Waterborne microorganisms, including post-harvest plant pathogens and agents of human illness, can be rapidly acquired and taken up on plant surfaces. Natural plant surface contours, natural openings, harvest and trimming wounds and scuffing can provide points of entry as well as safe harbor for microbes. When located in these protected sites, microbes are largely unaffected by common or permitted doses of post-harvest water sanitizing treatments (Table 4). It is therefore essential that the sanitizer concentration is sufficient to kill microbes before they attach or become internalized in produce. The concentration of sanitizer is important in some pre-harvest water uses (such as spraying pesticides or growth regulators) and in all post-harvest procedures involving water, including washing, cooling, water-mediated transport (flumes), and post-harvest drenching with calcium chloride or other chemicals.

Figure 12: Washing potatoes

4.2 Treatments to minimize water loss

Transpiration, or evaporation of water from the plant tissues, is one of the major causes of deterioration in fresh horticultural crops after harvest. Water loss through transpiration not only results in direct quantitative losses (loss of saleable weight), but also causes losses in appearance (wilting, shriveling), textural quality (softening, flaccidity, limpness, loss of crispness and juiciness), and nutritional quality. Transpiration can be controlled either through the direct application of post-harvest treatments to the produce (surface coatings and other moisture barriers) or through manipulation of the environment (maintenance of high relative humidity).

Treatments that can be applied to minimize water loss in fruits and vegetables include:

a. Curing of certain root vegetables, such as garlic, onion, potato, and sweet potato.
b. Waxing and the use of other surface coatings on commodities, such as apple, citrus fruits, nectarine, peach, plum, pomegranate, and tomato.
c. Packaging in polymeric films that act as moisture barriers.

Sanitizing chemicals	Advantages	Disadvantages
Chlorine compounds Calcium hypochlorite Sodium hypochlorite Chlorine gas Chlorine dioxide	Low cost	Corrosive, irritating, trihalomethanes are a by-product
Iodine compounds	Low cost, non irritating	Slightly corrosive, staining
Ozone	Faster action on microorganisms, fewer disinfection by-products than chlorine	Higher cost than chlorine
Peroxyacetic acid Hydrogen peroxide	More effective in removing and controlling microbial biofilms	Higher cost than chlorine

Table 4: Sanitizing chemicals used in produce handling

d. Careful handling to avoid physical injuries, which increase water loss from produce.
e. Addition of water to those commodities that tolerate misting with water, such as leafy vegetables.

4.3 Treatments to reduce ethylene damage

The promotion of senescence in harvested horticultural crops by ethylene (1 ppm or higher) results in acceleration of deterioration and reduced post-harvest life. Ethylene accelerates chlorophyll degradation and induces yellowing of green tissues, thus reducing the quality of leafy, floral, and immature fruit-vegetables and foliage ornamentals. Ethylene induces abscission of leaves and flowers, softening of fruits, and several physiological disorders. Ethylene may increase decay development of some fruits by accelerating their senescence and softening and by inhibiting the formation of antifun-

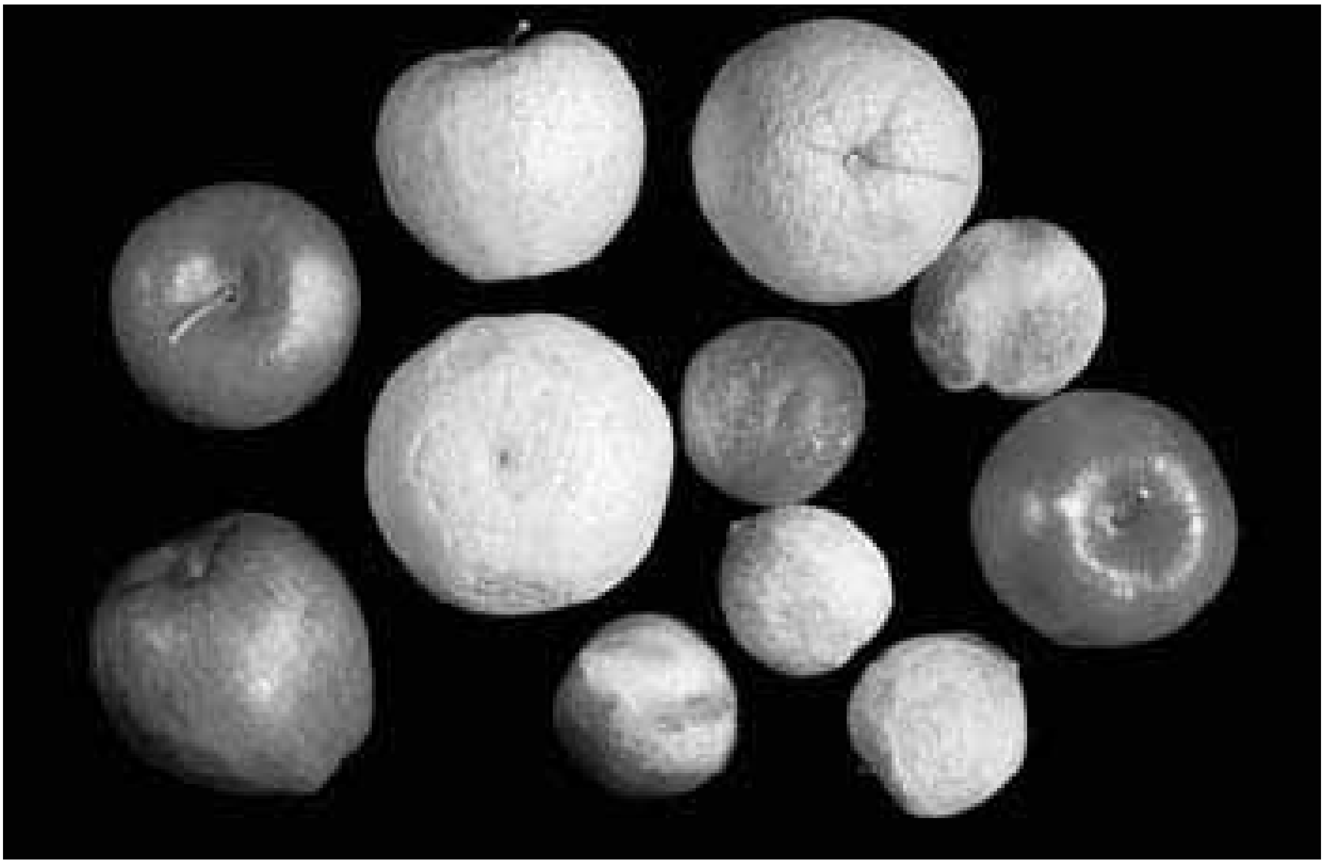

Figure 13: Water loss symptoms on fruits

gal compounds in the host tissue. In some cases, ethylene may stimulate the growth of fungi, such as *Botrytis cineria* on strawberries and *Penicillium italicum* on oranges.

The incidence and severity of ethylene-induced deterioration symptoms is dependent upon temperature, time of exposure, and ethylene concentration. The yellowing of cucumbers can, for example, result from exposure to either 1 ppm ethylene over 2 days or to 5 ppm ethylene over 1/2 day at 10 °C. Ethylene effects are cumulative throughout the post-harvest life of the commodity.

Treatment of ornamental crops with 1-methylcylopropene (1-MCP), which is an ethylene action inhibitor, provides protection against ethylene damage. The commercial use of this product at concentrations of up to 1 ppm on apples, apricots, avocados, kiwifruit, mangoes, nectarines, papayas, peaches, pears, persimmons, plums, and tomatoes was approved by the United States Environmental Protection Agency. The use of 1-MCP will no doubt be extended to several other fruits and vegetables, and to use in other regions.

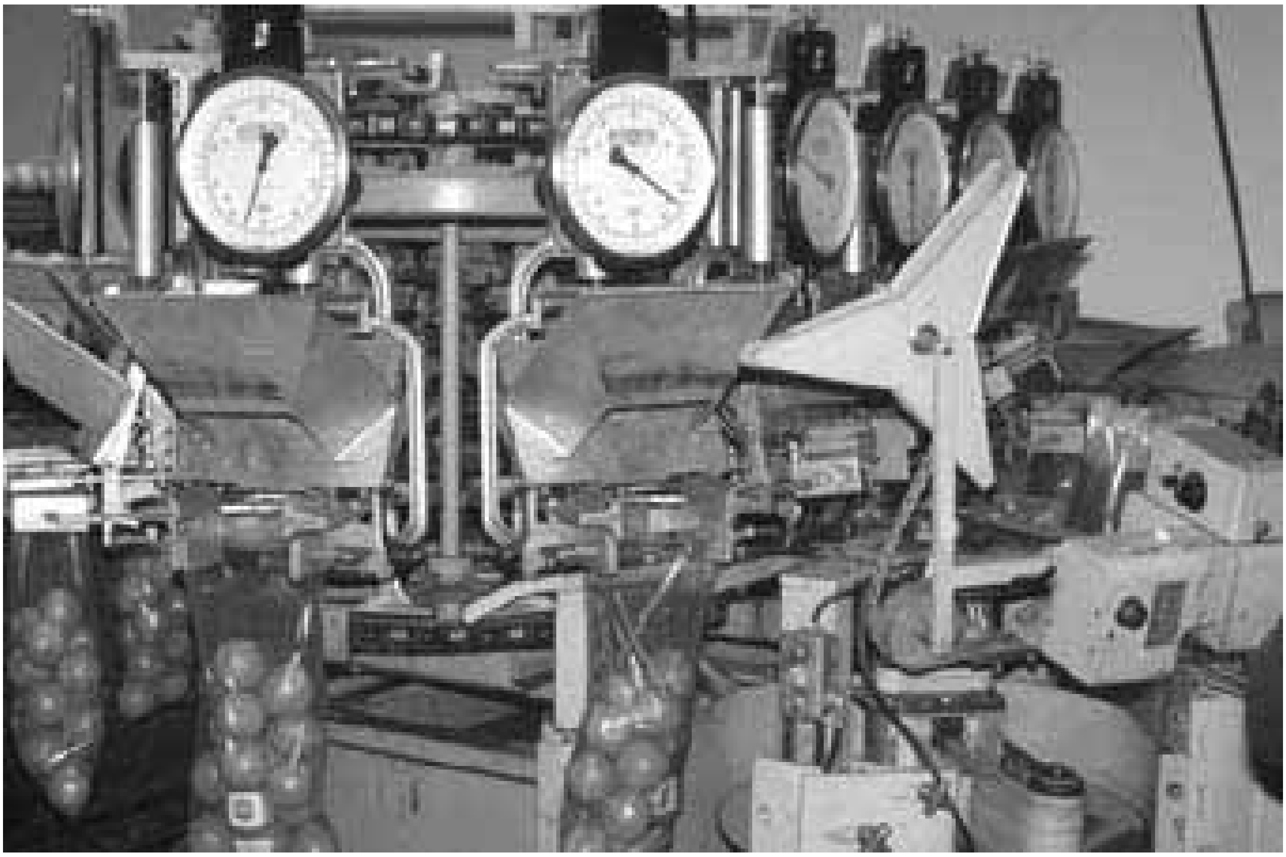

Figure 14: Packaging of oranges

4.4 Treatments for decay control

A major cause of losses in perishable crops is the action of a number of microorganisms on the commodity. Fungi and bacteria may infect the plant organ at any time. “Latent” infections, in which fungi invade fruit tissues shortly after flowering, become apparent only at the onset of ripening. Post-harvest rots frequently occur as a result of rough handling during the marketing process and are caused by a wide array of microorganisms. The grey mold *Botrytis cineria* is a very important cause of loss in many commodities (such as grapes, kiwifruit, pomegranates, raspberries, and strawberries), and is an aggressive pathogen, even at low temperatures. Virus infection frequently lowers the quality of perishable commodities, usually as a result of visual deterioration, although viruses may also affect flavor and composition.

Curing is a post-harvest treatment (Table 5) that facilitates certain anatomical and physiological changes that can prolong the storage life of some root crops. It is one of the most effective and simple means of reducing water loss and decay during subsequent storage of root, tuber, and bulb crops, such as those listed in Table 5.

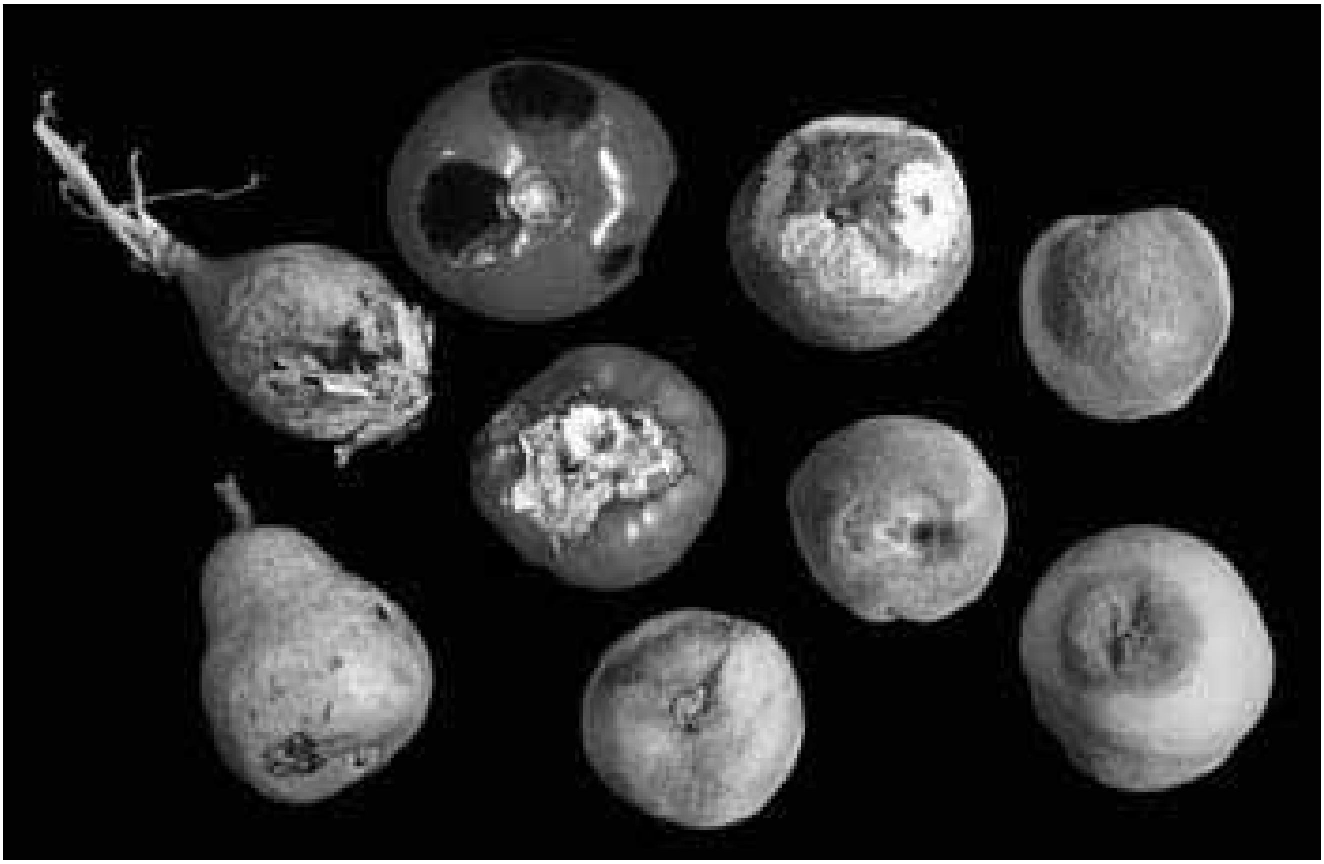

Figure 15: Symptoms of decay (caused by various fungi)

Sanitation practices include treatment to reduce populations of microorganisms on equipment, on the commodity, and in the wash water used to clean it. Water washes alone are effective in removing nutrients that allow microorganisms to grow on the surfaces of produce as well as in removing inoculum of post-harvest pathogens. The addition of sanitizers (Section 4.1) to water dumps and spray or dip washes, reduces inoculum levels of decay-causing organisms from fruit surfaces, inactivates spores brought into solution from fruit or soil and prevents the secondary spread of inoculum in water. Treatments for decay control include: (1) heat treatments, such as dipping mangoes in water at a temperature of 50 °C, for 5 minutes in order to reduce subsequent development of anthracnose; (2) use of post-harvest fungicides, such as imazalil and/or thiabendazole on citrus fruits; (3) use of biological control agents, such as "Bio-Save" (*Pseudomonas syringae*) and "Aspire" (*Candida oleophila*) alone or in combination with fungicides at lower concentrations on citrus fruits; (4) use of growth regulators such as gibberellic acid or 2, 4-D to delay senescence of citrus fruits; (5) use of 15-20 percent CO_2 in air or 5 percent O_2 on strawberries, cane berries, figs, and pomegranates; and (6) use of SO_2 fumigation (100 ppm for one hour) on grapes.

Crops	Temperature (°C)	Relative humidity %	Duration (days)
Cassava root	30-40	90-95	2-5
Onion and garlic bulbs	30-45	60-75	1-4
Potato tubers	15-20	85-90	5-10
Sweet Potato roots	30-32	85-90	4-7
Yam tubers	32-40	90-100	1-4

Table 5: Conditions for curing root, tuber, and bulb crops

4.5 Treatments for insect control

Fresh fruits, vegetables and flowers may harbor a large number of insects during post-harvest handling. Many of these insect species, in particular fruit flies of the family Tephritidae (e.g. Mediterranean fruit fly, Oriental fruit fly, Mexican fruit fly, Caribbean fruit fly), can seriously disrupt trade among countries. The identification and application of acceptable disinfestation treatments including irradiation will greatly facilitate globalization of trade in fresh produce. Criteria for the selection of the most appropriate disinfestation treatment for a specific commodity include cost, the efficacy of that treatment against insects of concern, safety of the treatment as well as the ability of that treatment to preserve and maintain produce quality. Currently approved quarantine treatments, other than irradiation, include certification of insect-free areas, use of chemicals (e.g. methyl bromide, phosphine, hydrogen cyanide), cold treatments, heat treatments, and combinations of these treatments, such as methyl bromide fumigation in conjunction with cold treatment. The use of alternative treatments, such as fumigants (carbonyl sulphide, methyl iodide, sulphuryl fluoride) and insecticidal atmospheres (oxygen concentrations of less than 0.5 percent and/or carbon dioxide concentrations ranging between 40 and 60 percent) alone or in combination with heat treatments, and ultraviolet radiation, are currently under investigation. These treatments are not, however, broad-spectrum treatments and are potentially phytotoxic when applied to some commodities.

Most insects become sterile when subjected to irradiation doses ranging between 50 and 750 Gy. The actual dosage required to produce sterility in insects varies in accordance with the species concerned and its stage of development. An irradiation dose of 250 Gy was approved by the United States quarantine authorities for application to fresh commodities, such as lychees, mangoes, and papayas in light of the efficacy of that dose in preventing the reproduction of tropical fruit flies. Irradiation doses of 250 Gy can be tolerated by most fresh fruits and vegetables with minimal detrimental effects on quality. Doses ranging between 250 and 1000 Gy (the maximum irradiation dose allowed as of 2002), can, however, be damaging to some commodities. Fruits, in general, are more tolerant to the expected dose range (250 to 500 Gy absorbed by fruits on the inside vs. those on the outside of the pallet) than non-fruit vegetables and cut flowers. Detrimental effects of irradiation on fresh produce may include loss of green color (yellowing), abscission of leaves and petals, tissue discoloration, and uneven ripening. These detrimental effects may not become visible until after the commodity reaches the market. The effects of irradiation must therefore be tested on individual commodities, prior to large-scale commercialization of the irradiation treatment.

5

Post-harvest Treatments Designed to Manipulate the Environment around Produce in Order to Enhance Quality

5.1 Modified atmosphere storage

When used as supplements to keeping fresh horticultural perishables within their optimum ranges of temperature and relative humidity, controlled atmospheres (CA) or modified atmospheres (MA) can serve to extend their post-harvest-life (Table 6). Optimum oxygen and carbon dioxide concentrations lower respiration and ethylene production rates, reduce ethylene action, delay ripening and senescence, retard the growth of decay-causing pathogens, and control insects. CA conditions which are not suited to a given commodity can, however, induce physiological disorders and enhance susceptibility to decay.

Several refinements in CA storage technology have been made in recent years. These include: the creation of nitrogen-on-demand by separation of nitrogen from compressed air through the use of either molecular sieve beds or membrane systems; use of low (0.7 to 1.5 percent) oxygen concentrations that can be accurately monitored and controlled; rapid establishment of CA, ethylene-free CA, programmed (or sequential) CA (such as storage in 1 percent O_2 for 2 to 6 weeks followed by storage in 2-3 percent O_2 for remainder of the storage period), and dynamic CA where levels of O_2 and CO_2 are modified as needed based on monitoring specific attributes of produce quality, such as ethanol concentration and chlorophyll fluorescence.

The use of CA in refrigerated marine containers continues to benefit from technological and scientific developments. CA transport is used to continue the CA chain for commodities (such as apples, pears, and kiwifruits) that had been stored in CA immediately after harvest. CA transport of bananas permits their harvest at a more advanced stage of maturity, resulting in the attainment of higher yields at the field level. In the case of avocados, CA transport facilitates use of a lower shipping temperature (5 °C) than if shipped in air, since CA ameliorates chilling injury symptoms. CA in combination with precision temperature management allows insect control without the use of chemicals, in

Range of storage duration (months)	Commodity
More than 12	Almond, Brazil nut, cashew, filbert, macadamia, pecan, pistachio, walnut, dried fruits and vegetables
6-12	Some cultivars of apples and European pears
3-6	Cabbage, Chinese cabbage, kiwifruit, persimmon, pomegranate, some cultivars of Asian pears
1-3	Avocado, banana, cherry, grape (no SO_2), mango, olive, onion (sweet cultivars), some cultivars of nectarine, peach and plum, tomato (mature-green)
<1	Asparagus, broccoli, cane berries, fig, lettuce, muskmelons, papaya, pineapple, strawberry, sweet corn; fresh-cut fruits and vegetables; some cut flowers.

Table 6: Classification of horticultural crops according to their controlled atmosphere storage potential at optimum temperatures and relative humidities.

commodities destined for markets that have restrictions against pests endemic to exporting countries and for markets with a preference for organic produce.

The use of polymeric films for packaging produce and their application in modified atmosphere packaging (MAP) systems at the pallet, shipping container (plastic liner), and consumer package levels continues to increase. MAP (usually designed to maintain 2 to 5 percent O_2 levels and 8 to 12 percent CO_2 levels) is widely applied in extending the shelf-life of fresh-cut fruits and vegetables. Use of absorbers of ethylene, carbon dioxide, oxygen, and/or water vapor as part of MAP is increasing. Although much research has been done on the use of surface coatings to modify the internal atmosphere within the commodity, commercial applications are still very limited due to inherent biological variability of commodities.

Figure 16: Retail display of fresh cut vegetables

At the commercial level, CA is most widely applied during the storage and transport of apples and pears. It is also applied to a lesser extent on kiwifruits, avocados, persimmons, pomegranates, nuts and dried fruits. Atmospheric modification during long-distance transport is used for apples, avocados, bananas, blueberries, cherries, figs, kiwifruits, mangoes, nectarines, peaches, pears, plums, raspberries and strawberries. Technological developments geared toward providing CA during transport and storage at reasonable cost (positive benefit/cost ratio) are essential if the application of this technology to fresh fruits and vegetables is to be expanded.

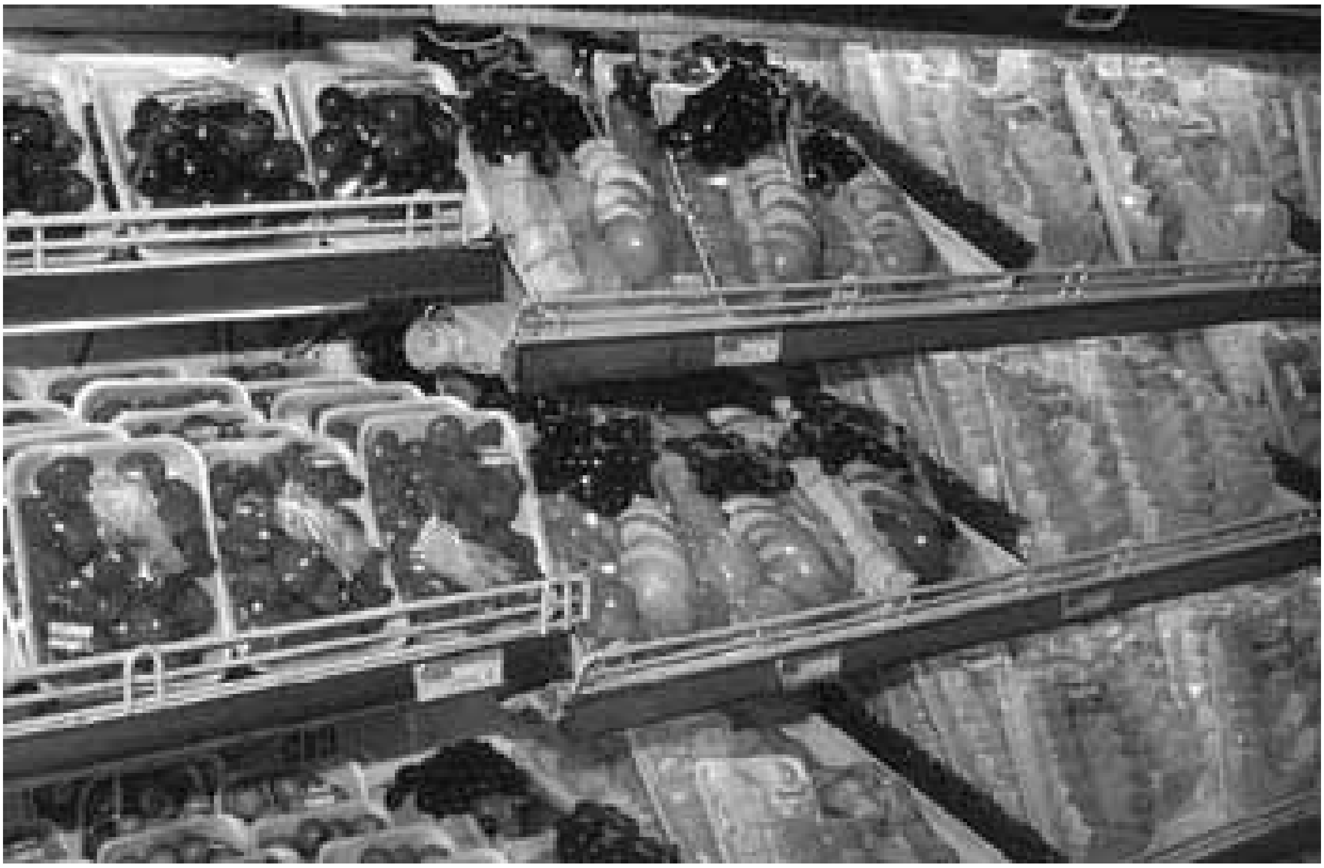

Figure 17: Retail display of fresh cut fruits

Although MA and CA have both been shown to be effective in extending the post-harvest life of many commodities (Table 6), their commercial application has been limited by the relatively high cost of these technologies. There are however a few cases in which a positive return on investment (cost/benefit ratio) can be demonstrated. In a comparison of losses due to decay during retail marketing of strawberries shipped in air and those shipped in an environment consisting of 15 percent CO_2-enriched air (modified atmosphere within pallet cover), the use of modified atmosphere was observed to reduce losses by 50 percent (an average of 20 percent losses was sustained in strawberries shipped in air vs 10 percent losses in those shipped by MA). The economic loss of 10 percent value (US$50-75 per pallet) was much greater than the cost of using MA (US$15-25 per pallet).

Use of controlled atmosphere (CA) during marine transportation can extend the post-harvest-life of those fruits and vegetables that would normally have a short post-harvest-life potential, thereby allowing the use of marine transportation instead of air transport for the shipment of such produce. In terms of cost and benefit, savings realized

Figure 18: Modified atmosphere packaging of strawberries (carbon dioxide-enriched air delays fungal growth)

with the use of marine transportation are much greater than is the added cost of CA service.

5.2 Ethylene exclusion and removal

Many green vegetables and most horticultural produce are quite sensitive to ethylene damage. Their exposure to ethylene must therefore be minimised. Ethylene contamination in ripening rooms can be minimized by 1) using ethylene levels of 100 ppm instead of the higher levels often used in commercial ripening operations, 2) venting ripening rooms to the outside on completion of exposure to ethylene, 3) at least once per day ventilating the area around the ripening rooms or installing an ethylene scrubber, 4) use of battery-powered forklifts instead of engine-driven units in ripening areas.

Ethylene-producing commodities should not be mixed with ethylene-sensitive commodities during storage and transport. Potassium permanganate, an effective oxidizer of ethylene, is commercially used as an ethylene scrubber. Scrubbing units based on the catalytic oxidation of ethylene are used to a limited extent in some commercial storage facilities.

5.3 Return on investment in reducing ethylene damage

A University of California study showed that the use of an ethylene scrubber in storage facilities used for lettuce significantly reduced russet spotting. The difference in value of lettuce that was protected from ethylene vs that which was exposed to ethylene was estimated to be 20 to 25 percent, which was greater than the cost of the ethylene scrubber. Similar results were found with kiwi fruits, which soften very rapidly when exposed to ethylene levels as low as 50 ppb.

5.4 Treatments to enhance uniformity in fruit ripening

Ethylene treatment is commercially used to enhance the rate and uniformity of ripening of fruits such as bananas, avocados, mangoes, tomatoes, and kiwifruits. Optimal ripening conditions are as follows:

Temperature:	18 °C to 25 °C (65 °C to 77 °F)
Relative humidity:	90 to 95 percent
Ethylene concentration:	10 to 100 ppm
Duration of treatment:	24 to 74 hours depending on fruit type and stage of maturity
Air circulation:	Sufficient to ensure distribution of ethylene within the ripening room
Ventilation:	Require adequate air exchange in order to prevent accumulation of O_2 which reduces the effectiveness of C_2H_4.

Figure 19: Improper mix of bananas and watermelons (ethylene produced by ripening bananas accelerates watermelon softening)

6

Criteria for the Selection of Appropriate Post-harvest Technologies

The basic recommendations for maintaining post-harvest quality and safety of produce are the same regardless of the distribution system (direct marketing, local marketing, export marketing). However, the level of technology needed to provide the recommended conditions varies in accordance with the distance and time between production and consumption sites, the intended use of the produce (fresh vs. processing) and the target market. In situations where the point of sale is only a matter of hours away from the site of harvest, careful harvesting and handling and the observance of proper sanitation practices are adequate measures for assuring the quality and safety of fruits and vegetables targeted for the fresh market. Pre-cooling, refrigeration and packaging however become essential when fresh produce must be moved over long distances. The following should be considered when selecting appropriate post-harvest technologies:

A. The technology used elsewhere is not necessarily the best for use under conditions of a given developing country. Many of the recent developments in post-harvest technology in developed countries have come about in response to the need to economize on labor, materials, and energy use, and to protect the environment. Currently used practices in other countries should be studied, but only those which are appropriate for local conditions should be adopted and used.

B. Expensive equipment and facilities are useless without proper management. Furthermore, over-investment in handling facilities can result in economic losses, if consumers in the target market are unable to absorb these added costs. Proper education of all stakeholders along the post-harvest chain (growers, harvesters, handlers and those involved in marketing) is more critical than the level of sophistication of the equipment used in post-harvest handling. Effective training and supervision of personnel must, therefore, be an integral part of quality and safety-assurance programs.

C. Commodity requirements can be met through the use of simple and inexpensive methods in many cases. Proper temperature management procedures, for example, include: (1) Protection from exposure to the sun; (2) Harvesting during cooler periods of the day or even at night; (3) Adequate ventilation in containers and non-refrigerated transport vehicles; (4) Use of simple and inexpensive cooling procedures, such as evaporative cooling or night ambient air; and (5) Expedited handling of fresh produce.

D. Mechanical injuries are major causes of losses in the quality and quantity of fresh horticultural commodities in all handling systems. The incidence and severity of mechanical injury can be greatly minimized by reducing the number of steps involved in harvesting and handling and by educating all personnel involved, about the need for careful handling.

E. Assuring food safety throughout the post-harvest handling system is very critical to successful marketing of produce and should be given the highest priority.

F. Solving the post-harvest technology problems in a given country necessitates cooperation and effective communication among research and extension personnel. Post-harvest horticulturists therefore need to coordinate their efforts and to cooperate with production horticulturists, agricultural marketing economists, engineers, food technologists, microbiologists, and others who may be involved in various aspects of the marketing systems. In most cases, solutions to existing problems in the post-harvest handling system require the use of existing information rather than new research. The following is a proposed program for improving the post-harvest handling system in a developing country:

(1) Survey the magnitude and causes of losses in quality and quantity during harvesting and post-harvest handling of major commodities.
(2) Survey available tools and facilities for harvesting, packing and packaging, transport, storage, and marketing of each commodity in the region of production and during the season of production.
(3) Evaluate the impact of simple modifications in the handling system (such as stage of harvesting, method of harvest, type of container, and quality sorting) on quality and safety maintenance.
(4) Extend information on recommended harvesting and handling procedures to all those who can use it. All appropriate extension methods for the intended audiences should be used.
(5) Identify problems which require further research, conduct the needed research and extend any new information when completed to those who can use it.

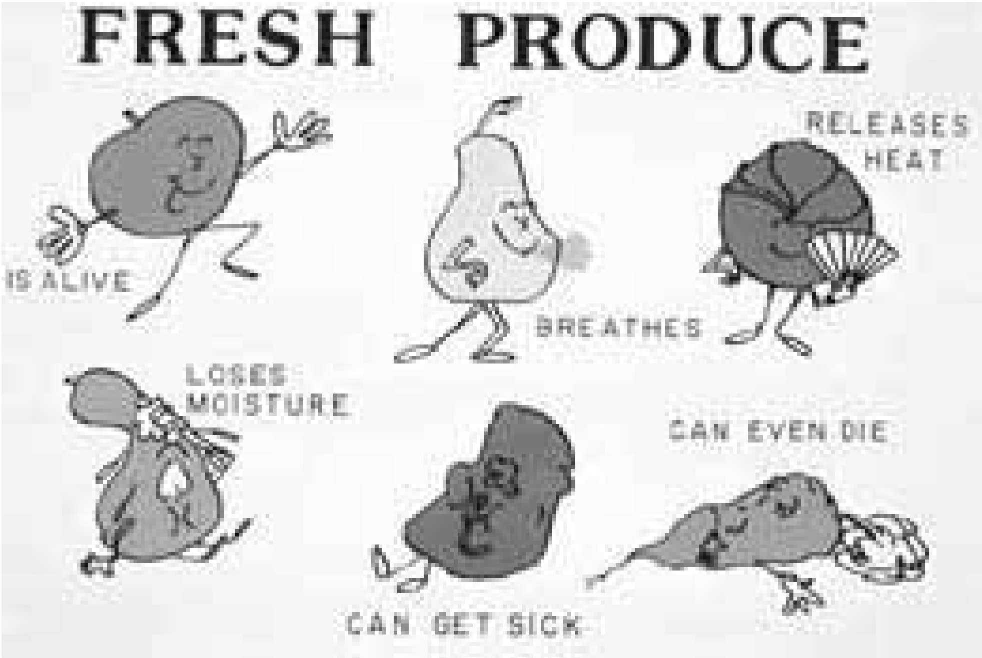

Figure 20: Communicating the message in an appropriate format for the intended audience

7

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8

Internet Resources

http://www.fao.org/inpho/ : Postharvest information site of the Food and Agriculture Organization of the United Nations.

http://postharvest.ucdavis.edu : University of California Postharvest Research and Information Center.

http://www.uckac.edu/postharv/ : University of California Kearney Agricultural Center.

http://www.postharvest.ifas.ufl.edu : University of Florida Postharvest Group.

http://www.fdocitrus.com : Florida Department of Citrus postharvest information.

http://www.postharvest.tfrec.wsu.edu : Washington State University postharvest information.

http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ : North Carolina State University postharvest information.

http://www.postharvest.com.au/ : Sydney Postharvest Laboratory postharvest information.

http://www.foodsafety.gov : Gateway to U.S. government information on food safety.

http://www.jifsan.umd.edu/gaps.html : U.S. Food and Drug Administration's Manual on "Improving the Safety and Quality of Fresh Fruits and Vegetables".

http://www.nutrition.gov : Gateway to U.S. government information on human nutrition and nutritive value of foods.

http://www.ams.usda.gov : U.S. Department of Agriculture, Agricultural Marketing Service information on quality standards, transportation, and marketing.

http://www.aphis.usda.gov : U.S. Department of Agriculture, Animal and Plant Health Inspection Service information on phytosanitary and quarantine requirements.

http://www.ba.ars.usda.gov/hb66/index.html : A draft version of the forthcoming revision to USDA, Agricultural Handbook 66 (November 8, 2002).

Basic approaches to maintaining the safety and quality of horticultural produce are the same, regardless of the market to which this produce is targeted. This bulletin reviews the factors that contribute to quality and safety deterioration of horticultural produce, and describes approaches to assure the maintenance of quality and safety throughout the post-harvest chain. Specific examples are given to illustrate the economic implications of investing in and applying correct post-harvest technologies. Criteria for the assessment of post-harvest needs, the selection of post-harvest technologies appropriate to the situation and context, and for extending appropriate levels of post-harvest information are also discussed.

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