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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

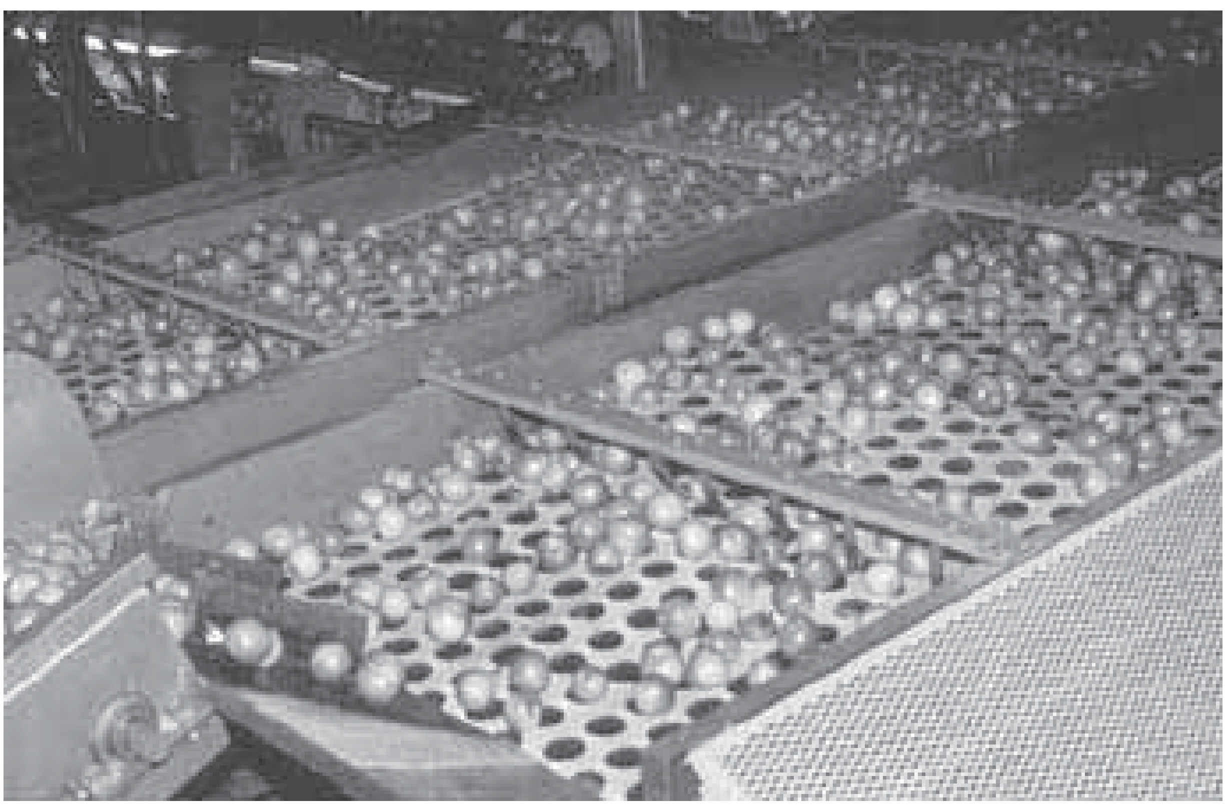

Figure 6: Sizing of Tomatoes

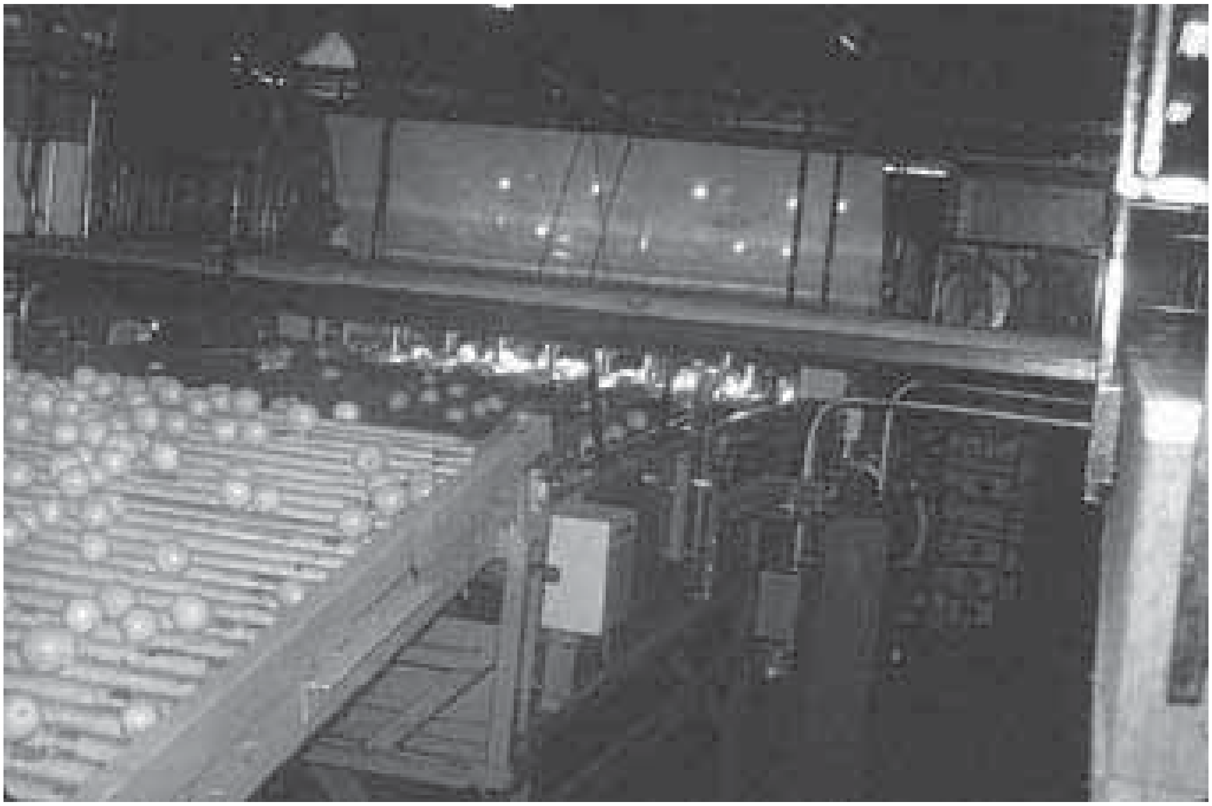

Figure 7: Machine Vision Sorting of Citrus Fruit

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:

Freezing 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.

Chilling injury 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 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-

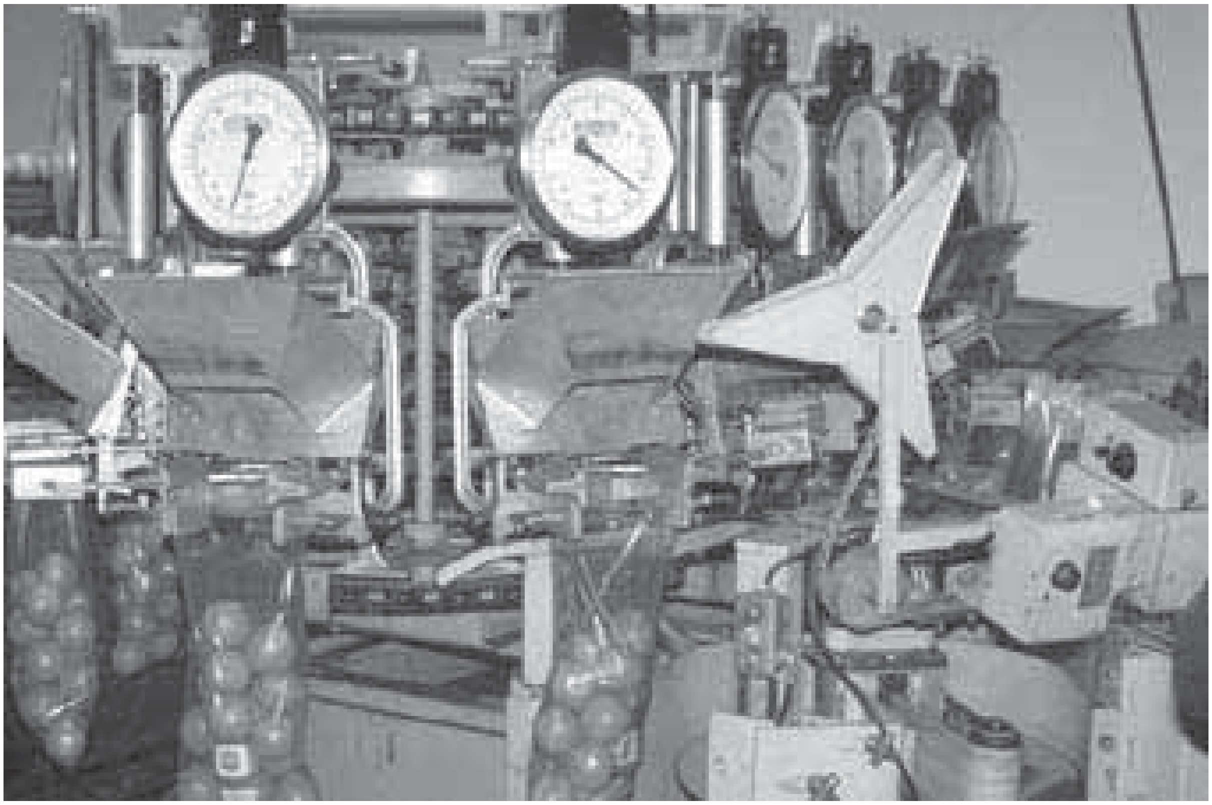

Figure 14: Packaging of oranges

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.

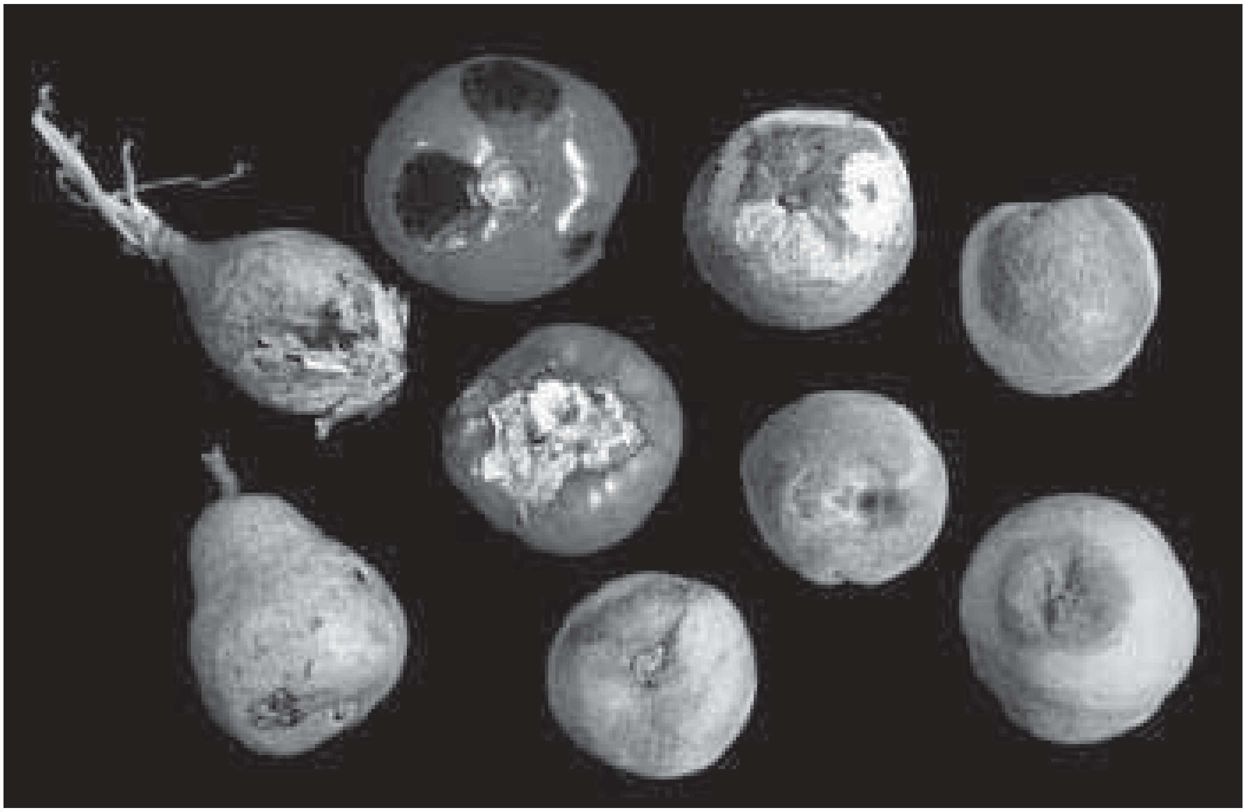

Figure 15: Symptoms of decay (caused by various fungi)

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, howe-

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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.