THE FARMING SIDE

10
Postharvest Handling and Safety of Perishable Crops

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Small farms, as mentioned in earlier chapters of this book, are usually defined on an economic basis as farms with an annual gross income of $250,000 or less (United States Department of Agriculture [USDA] ERS, 2007). It is also true, though, that small-scale farm management issues can correspond to a farm's small physical footprint, the balance of family versus nonfamily labor, and the grower's degree of control over how the agricultural output reaches the ultimate consumer. Smaller farms often have to operate differently than bigger operations because they have more limited access to harvest and postharvest management equipment and technologies and to primary marketing channels and destinations. This chapter will give you an overview of general postharvest handling considerations for fruits and vegetables, focusing primarily on practices applicable to small-scale management with moderate to low annual sales of these commodities. Details of modern postharvest technologies and long-distance transportation, which can be capital intensive, are available from a variety of resources. For more information on this, see the online Postharvest Yellowpages (http://postharvest.ucdavis.edu).

Besides the visual quality, sensory quality, and nutritive value of produce, any discussion of postharvest management of perishable horticultural foods that are eaten fresh must include an overview of food safety management. The need to minimize the potential for injury or illness to consumers is independent of a farm's scale or range of distribution and is the clear responsibility of primary producers and suppliers. Beyond the general reaffirmation of the need for commonsense measures to ensure food safety, this chapter gives some more specific guidance that can increase your awareness of preharvest risks and the need to plan for responsible postharvest management and meet the expectations of public health regulations (U.S. FDA, 2008).

PLANNING FOR POSTHARVEST QUALITY

The effort to achieve economic reward through the marketing of edible horticultural foods must begin well before harvest. Selection of the right seeds or perennial varieties or cultivars, including rootstocks, can be critical in determining the postharvest performance of any commodity. Individual cultivars vary in their inherent potential for firmness retention, uniformity of shape and characteristic color, disease and pest resistance, and shelf life in terms of visual quality and sensory quality (i.e., sugar:acid balance; aroma volatiles), to list just a few key traits. Small farm producers typically include or focus on specialty and heirloom cultivars and harvest strategies that maximize the sensory quality of produce, such as growing it to near full ripeness on the vine, in order to attract and satisfy direct-market consumer demand.

Both conventional and organic growers have recognized and responded to the expanding consumer demand for better flavor profiles in standard varieties as well as true heirloom and heirloomlike varieties. Heirloom varieties and those selected for novelty, ethnic culinary, or flavor traits are typically best suited for small-scale production and local marketing. Some heirloom or specialty varieties are not well adapted for growth in the arid Mediterranean climate of California and develop disorders or conditions in preharvest phases that become serious postharvest problems. Many varieties in this category simply do not hold up well to current postharvest handling and distribution methods. The main problems are bruising and cracking, compression damage in pallet loads, excessive softening, shriveling and wilting from water loss, and decay.

In addition to genetic traits, environmental factors such as soil type, temperature, wind during fruit set, frost, and rainy weather at harvest can adversely affect produce conformance with appearance (shape, uniformity, size) standards, storage life, suitability for shipping, and quality. Other local climatic factors such as seasonal high winds, fog, or low humidity during critical fruit development stages can result in deformities, poor shelf life, or accelerated decay compared to produce from other regions. In general, seasonally and regionally selected varieties, popular for domestic and export distribution markets, overcome most of these potential market defects, so small-scale growers often include these along with specialty varieties in an overall profitable production plan.

Cultural practices may have a dramatic impact on postharvest quality. For example, too little seedbed depth for carrots may result in sunburned shoulders and green cores in many of the specialty carrots favored most by consumers at farmers markets. As the blunt-end root penetrates into more-compacted soil, the crown pushes above the soil line where it is exposed to the sun. Carrots that develop green core tend to be bitter well beyond the margin of visible greening.

Management of the health and density of foliar parts of the carrot plant is also an important way to reduce the carrots' exposure to intense sunlight. Improper pruning, thinning, fertilization, and disease control can reduce produce quality. For example, inadequate pruning and thinning of cherry tomato plants results in excessive fruit splitting and higher rates of postharvest decay from infections that started in the field under high humidity, poor air circulation conditions.

Excessive nitrogen in the soil and inconsistent irrigation may result in a variety of quality disorders, such as thin walls and uneven ripening in sweet peppers and calcium deficiency disorders in many fruits. Quality loss also results from rough handling during and after harvest. Thus, planning, protection, and responsiveness to changing local conditions are vital, both in production and during postharvest handling, if you want to avoid immediate causes of deterioration, slow the deterioration of produce during short-term storage, and reduce losses in distribution channels.

HANDLING AT HARVEST

The inherent quality of produce cannot be improved after harvest—only maintained for the expected window of time (the shelf life) characteristic of the commodity and variety. Use commodity-specific maturity indices to determine when is the best time for harvest. While you can harvest some commodities successfully at a mature stage and let them ripen during postharvest handling (thereby improving their eating quality), the products' actual sensory and nutritive properties were fixed during preharvest production and captured at the moment of harvest.

Part of what makes for successful postharvest handling is an accurate knowledge of the length of this window of opportunity under the specific conditions of production, season, method of handling, temperature during short-term storage, distance to market, and the impacts of mixed-load handling. It is also critical to have a good understanding of how easy it is to miss this window as a result of poor planning and management. For a small farm, the grower may be more likely to harvest and market produce at or near peak ripeness than the owner of a larger operation would be.

As discussed above, small farm operations often select or include specialty varieties with shelf lives and shipping traits that are suboptimal or even inherently short. The operating principles described below are important in all operations but carry special importance for many small-scale producers who have less access to postharvest cooling equipment, covered and cooled grading, sorting, and packing areas, and refrigerated short-term storage and loading dock facilities. Resources for refrigerated transportation may also be lacking.

Field packing. Soft fruits like berries and many vegetables are packed directly in the field. This minimizes additional direct handling of the produce and can reduce the time between picking and cooling. The disadvantages are that quality control—primarily produce uniformity within a packed carton or unit—is more difficult to achieve in the field than in a packinghouse, since grading, sorting, and trimming are limited to whatever product is within immediate reach. Field uniformity, determined by variety selection and preharvest management, is critical for efficient field packing if uniformity of size and shape is an important condition of sale. Furthermore, since sorting and trimming must be done by hand, variability between workers may become an issue and necessitates close training and supervision in the field. In a field-pack operation, cleaning and application of postharvest chemicals to reduce water loss or prevent decay typically are not done. Another important consideration is that workers in the field may be exposed to less comfortable environmental conditions or even highly stressful conditions compared to those experienced by packing shed workers, and that can influence their ability to execute a quality pack.

Field packing can be as simple as a picker with a box, or you may use a harvest aid to increase worker comfort and efficiency. For strawberries, the picker places the fruit into baskets that are already loaded into a corrugated fiberboard tray. In many cases the tray is carried on a small wheeled dolly that fits easily within a single furrow. As a tray is filled, the picker takes it to a shaded holding area. Table grapes are similarly packed at the vine. The picker grades, trims, and bags the product and places the bags into boxes. Alternatively, the picker may accumulate grapes in a tote and bring the tote to a small, mobile field-side packing station that has a canopy to provide shade for both worker and product. In small operations close to a shipping facility, the time from picking to cooling can be less than 1 hour, which greatly benefits postharvest quality during transit to the final consumer.

Harvesting for packing in a central area. Most fresh market products are harvested by hand into buckets, lugs, baskets, or canvas bags, which are then emptied into field totes or larger bins for transport to a central packing area. In some operations, produce may be packed directly from the bucket or tote, which has been transported from the field on a flatbed trailer fitted with a racking structure. For highly perishable commodities—edible pod and sugar snap peas or young leafy greens, for example—quality is best maintained if you place harvest totes or lugs directly into cool conditions during harvest, such as a small cab-over refrigerated truck.

Care should always be taken for specialty crops or fruit harvested at a thin-skinned stage (e.g., specialty cucumbers) or ripe stage (e.g., apricots) to minimize abrasion from buckets and totes or sorting surfaces, including field grit, which can be abrasive. Compression injuries can result if the harvest containers are too deep. Metal or plastic picking buckets are typically used for the softer fruit such as cherries, and bottom-dump picking bags are used for fruit with less potential for compression bruising, such as citrus fruit or pears. The surfaces of the harvest container should be clean and smooth. All containers need periodic washing to remove any soil adhering to their interior walls and external surfaces, especially if they are designed for stacking and nesting. Harvest residues and juices may be an ideal location for growth and spore production of spoilage and decay organisms, which can then contaminate each harvested lot. We strongly recommend that you conduct preseason and periodic inspection of harvest containers, looking for splitting, chipping, splinters, and excessive abrasive areas.

During accumulation for centralized packing, produce can suffer physical injuries from pulling, improper clipping, fingernail cuts, grit adhering to gloves, scuffing on a gritty, worn, or poorly designed harvest-aid conveyor belt, dropping into picking buckets or bags, overfilled picking containers, striking of the containers (especially soft-sided bags) against limbs and ladders, pickers leaning against picking bags while picking, transferring of product into field lugs without due care, and overfilling of field containers. Even a short drop or tossing of a tote or lug onto a pallet can cause substantial impact bruising that is not always apparent until ripening or later stages during distribution when affected areas become discolored and show signs of advanced water loss or decay. Road vibrations and sharp shocks in a pickup, flatbed, or trailer can cause significant visible damage, even on a relatively short trip to a farmers market.

Temperature protection in the field. To maximize postharvest quality and marketability, reduce the time between produce harvest and cooling. Many products, such as strawberries, asparagus, leafy greens, and tender herbs, lose visible and measurable amounts of quality during just 1 or 2 hours of delay between harvest and cooling. Weather conditions during harvest strongly influence the length of this window of time. The characteristic respiration rate related to the rate of quality deterioration of the commodity is another important factor. (For an explanation of postharvest respiration and product quality, see *Postharvest Technology of Horticultural Crops*, ANR Publication 3311.) Frequent transfer of products to the cooler or a shaded packing area minimizes the amount of time they spend in conditions conducive to heating and respiration-related deterioration. If your harvest rate is slow, make several small trips rather than waiting until you have a full load of products to transport.

While in the field, shade products after they are harvested. Products left in the sun can warm considerably above the air temperature. Dark-colored products can warm even more quickly than light-colored products. In orchards and vineyards, you can place products in the shade of the trees or vines. If no natural shade is available, use portable shading to reduce exposure to the sun. Portable shading may be more effective than natural shading because it will not shift as much as natural shade will as the sun moves across the sky. Placing empty packages or lugs over the top of stacks of packages provides some protection. Shading keeps products from warming above the ambient air temperature, but even a mild breeze can cause harvested product in the shade to quickly warm to near the ambient air temperature. Especially in hotter climates, lugs and totes that are stacked and held for more than a few hours should have adequate venting to prevent low oxygen conditions that lead to off-flavors and increase spoilage.

During periods of high field temperatures, products should be harvested early in the day to reduce product warming. This also maintains product turgidity (firmness), size, and gloss, and reduces the amount and cost of cooling needed. Because of their high turgidity early in the day, some products with sensitive skin (such as citrus) or prone to splitting and bruising (such as tomatoes if turgid and cool) are purposely harvested later in the day to avoid injury to the skin. Sometimes harvesting must be delayed to allow condensation or dew to evaporate and so reduce postharvest skin staining and decay.

As a general approach, the following practices can help you maintain product quality:

- Harvest during the coolest time of day to maintain low product respiration and transpiration (water loss) rates.
- Minimize the extent of harvest cut or picking wounds, bruising, crushing, or damage from humans, equipment, or harvest containers.
- Shade the harvested product in the field to keep it cool. Covering harvest bins or totes with a foam-backed reflective pad greatly reduces heat gain from the sun, water loss, and premature senescence.
- If possible, move the harvested product into a cold storage facility or postharvest cooling treatment as soon as possible. For some commodities such as berries, tender greens, and leafy herbs, 1 hour in the sun is too long.
- Do not compromise high quality product by mingling it with damaged, decayed, or decay-prone product in a bulk or packed unit.
- Only use cleaned and, as necessary, sanitized packing or transport containers.

Preparation for Packing

Cleaning and washing. Some commodities—in particular, root and tuber vegetables and leafy greens grown close to the soil—may need or benefit from cleaning to remove soil, small adhering insects, and other contaminants. In small farm operations, the degree to which this kind of cleaning is necessary depends on the requirements or expectations of the specific market. Food-grade detergent washes and fruit and vegetable wash-aides (typically, approved plant extracts) are sometimes used along with soft brushes or sponges followed by clear water rinsing. Many peaches are wet brushed to remove the trichomes (peach fuzz). Oranges are sometimes washed with a high-pressure (350 psi) spray to remove scale insects and surface mold, while vine-ripe tomatoes and specialty melons may receive a gentle disinfectant water spray and be individually hand-rubbed with a clean cloth for better presentation.

Special operations. A wide range of special operations may be needed to prepare the products for final sorting. Unwanted leaves, stems, and roots are removed from some vegetables. Removal of the calyx or additional trimming of the stem may be done prior to packing for some fruits and fruitlike vegetables. Other products such as asparagus spears, celery, and green bunching onions are trimmed to a uniform length. For many high-end direct markets and value-added products, small farm enterprises are increasingly introducing specialty consumer packing and microwave-ready trays, which generally include or require trimming (of sweet corn, squash, or green beans, for instance) or careful brush washing (for new potatoes).

Disease control. Careful handling to prevent product damage and careful monitoring of storage conditions to maintain the lowest safe temperature for the product (see "Importance of Optimal Storage and Shipping Temperatures," later in this chapter) are the two most effective strategies for controlling postharvest diseases. For products that are washed or cooled with water, disinfection of both single-pass and recirculated water is an important preventive and control step. See "Sanitation and Water Disinfection," later in this chapter and also *Postharvest Chlorination: Basic Properties and Key Points for Effective Distribution* (ANR Publication 8003). Some postharvest disease control treatments may be applied during packing. Fungicide applications, if used, are commonly applied when the fruit is spread on conveyor belts or rollers, often immediately after washing. Fungicides are often incorporated into fruit waxes to help achieve a uniform surface application. Background and information on postharvest fungicides and alternative decay control strategies may be found in *Postharvest Technology of Horticultural Crops* (ANR Publication 3311) as well as from other sources specific to small farms and organic producers and handlers, including ATTRA National Sustainable Agriculture Information Service (http://attra.ncat.org/). All chemical applications must be made in strict conformity to government regulations.

Heat treatment, especially in the form of hot water treatment, has been shown to be effective for postharvest disease control of many products. It is widely used on papayas and oranges, typically before or at the start of packing, and has been found to be beneficial for tomatoes and melons. The use of gaseous ozone is increasing in cold storage facilities, including small farm operations, to reduce the build-up of mold spores and the transfer of decay from fruit to fruit in bins and packed cartons. See *Ozone Applications for Postharvest Disinfection of Edible Horticultural Crops* (ANR Publication 8133).

Sorting and Grading

Many growers hand-sort their produce to segregate it by maturity, color, size, and grade. Small fruit and vegetables require more sorting decisions per package than do larger products. Light levels of 500 to 1000 lux at the sorting surface are usually adequate; older workers may need twice as much light as their younger co-workers. The level of lighting in the sorting and grading area should be uniform: workers should not have surfaces in their field of view that vary in luminance (level of reflected light) by more than 3 to 1. Hand-sizing guides or rings and good-quality placards or photos of grades and defects are simple tools that help packers make quick and consistent sorting decisions. Machines are also available that sort fruit by size based on weight, volume, or electronic images. Fruit pass on a conveyor through the sizing equipment and are then packed by machine or delivered to a work station for final pack quality judgment.

Packing the Product

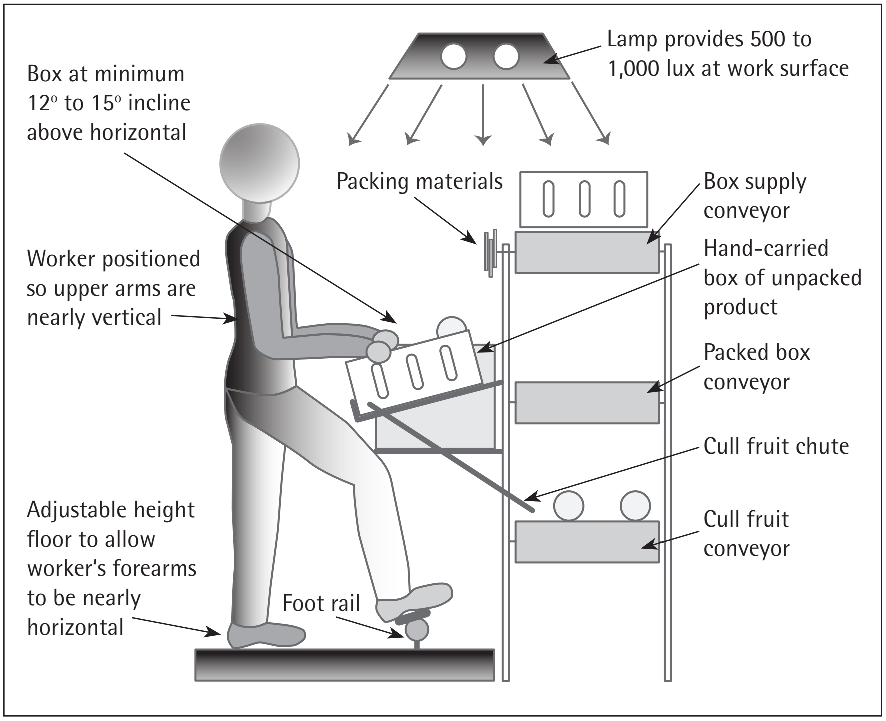
Packaging serves a number of functions including protection of the product from damage during transport, unitization, and advertising and display of the product at retail markets. Packaging performance issues include box strength under the conditions of use, location and degree of ventilation for product cooling, and container size and shape. Function and performance needs vary with the fruit or vegetable product. Other issues to consider include content of recycled material, capacity to be recycled, disposal fees associated with packaging materials, and suitability of containers for retail display. The reuse of corrugated fiberboard containers is strongly discouraged because of the risk of cross-contamination with pathogens or chemicals. Reuse of corrugated containers and trays is prohibited in some states and for certain commodities. Clean, sanitized, or new containers are strongly recommended for produce regardless of the scale of operation.

One-touch merchandising, where the packed produce is loaded directly into reusable, high-quality containers, shipped through existing supply chains, and merchandised at retail outlets with minimal handling, is becoming increasingly popular, even for smaller suppliers and handlers. Reusable plastic containers (RPCs) and high-quality display-sized fiberboard boxes have been established as fulfilling this need, but the substantial cost of the RPCs is typically borne by the shipper. There has been considerable growth in the use of consumer packages such as vented bags, netted bags or sleeves, and clamshell containers. These containers provide extra protection for products such as berries and cherries, maintaining high relative humidity and providing protection from mixing and spillage during retail display. One point of caution: conditions in clamshell containers and bags that reduce water loss may also promote growth of surface molds or decay pathogens at warmer storage and transport conditions.

A variety of netted plastic sleeves or sacks and bags with interlocking closures are especially popular for consumer value packs and ready-to-eat or ready-to-cook value-added produce. Packed bags are also used increasingly to help maintain the quality of whole fruit. Bags provide no protection from impact bruising, but they do reduce moisture loss by maintaining a high relative humidity around the product. Tight-filled bags can also reduce damage from high-frequency road vibrations during transport by preventing rolling abrasions. Bags can sometimes provide a modified atmosphere, depending on the type of polymer film used and how well the bag is sealed. Recommendations for use of modified atmospheres can be found online at the UC Postharvest Technology Research and Information Center's Web site (http://postharvest.ucdavis.edu/Producefacts).

Product is often hand-packed in small-scale operations. The goal is to pack a fixed count in trays or boxes and always immobilize the product within the package. The packer may also sort, grade, and trim the product before placing it in a box. Workers need adequate lighting, and their work space should be organized to reduce physical stress by minimizing the need for reaching (figure 10.1).

Figure 10.1. Components of a hand-pack operation.



The machinery used in hand-packing is mainly for materials handling, not for sorting, grading, or box filling. Product is either hand-carried to the packer or a return-flow belt is used, where the packer selects product of a desired size from the belt. An efficient rate of delivery for product and packaging materials to the packers and prompt, efficient removal of filled packages are important to packing efficiency.

Reducing Water Loss

Temperature management plays a key role in limiting water loss in storage and transit. As the primary means of lowering respiration rates of fruits and vegetables, temperature has an important relationship to relative humidity and thus directly affects the product's rate of water loss. The relative humidity of ambient air conditions in relation to the relative humidity of the crop (essentially, 100%) directly influences the rate of water loss from produce at any point in the marketing chain. Water loss can be rapid even though the resulting postharvest damage may not be immediately visible. The effects of water loss are cumulative and may result in wilting, shriveling, loss of crispness, browning, stem separation, or other defects. For some commodities such as table grapes, strawberries, specialty peppers, and squash, as little as 2 percent water loss will drastically reduce their market attractiveness and consumer appeal.

Transport to and display at roadside stands or farmers markets often result in extended periods of exposure of sensitive produce to direct sun, warm (or even hot) temperatures, and low relative humidity. Rapid water loss under these conditions can result in limp, flaccid greens and a loss of appealing natural sheen or gloss in fruits and vegetables. By providing postharvest cooling before and during transport and a shading structure during display, you can minimize rapid water loss at these market outlets.

Fruit and vegetable waxes are effective at reducing water loss and enhancing product appearance, but it is important that the produce receive uniform application and coverage of waxes or oils using proper packing-line brushes or rolling sponges. Waxes applied to some fruits and fruit-like vegetables reduce water loss, replace natural waxes removed during washing, act as carriers for fungicides, minimize scuffing injury during sorting and grade handling, or improve the product's cosmetic appearance. Waxes must be approved food-grade materials. The two most common types are mineral oil–based waxes and natural waxes such as carnauba. They can be formulated as water-based emulsions or with a solvent. Solvent-based formulations dry quickly but their use may be restricted by air pollution regulations. Water emulsions are commonly used in California and require hot air drying after application. Studies indicate that if waxes reduce the rate of water loss by more than about one-third, they also reduce product gas exchange and may interfere with normal aerobic respiration, leading to off-flavors or decay. Formulations are available that have been approved for use in certified organic production, but in general these are only available in large, bulk containers, which may be problematic for smaller growers.

Packing and packaging can also be designed to minimize water loss. As discussed earlier, plastic bags are a popular way to improve unitized sales and help reduce water loss. To minimize condensation inside the bag and reduce the risk of microbial growth, the bags may be vented, microperforated, coated with a condensation dispersant, or made of material permeable to water vapor. However, it is important to remember that barriers to water loss may also function as barriers to cooling. Packing systems should be carefully selected for the specific application, with cooling and other postharvest handling needs in mind. The exposure of bagged or tightly wrapped produce to direct sunlight—or, to a lesser degree, to fluctuating temperatures during transport, distribution, and display—will cause the products' internal temperature to rise, potentially at a rapid rate. Water loss will result and, when cooling follows, free water will condense, generally leading to an unappealing growth of superficial mold or accelerated decay of the produce. During transportation and storage, relative humidity (or, more properly, vapor pressure deficit) is critical, even at low temperatures. For a more complete discussion of optimal relative humidity for fruits and vegetables and the principles for prevention of water loss, see *Commercial Cooling of Fruits, Vegetables, and Flowers* (ANR Publication 21567).

COOLING AND STORAGE

Without question, optimal temperature management is the single most important tool for maintaining post-harvest quality. For products that are not field cured or exceptionally durable, the removal of field heat as rapidly as possible is the most highly desirable and optimal step that may be taken to maintain quality and prevent loss.

Harvesting cuts a commodity off from its source of water, but it is still alive and will lose water and turgor (firmness) through respiration and transpiration. Field heat can accelerate the rate of respiration, and with it, the rate of quality loss. Proper cooling protects quality and extends both the sensory (taste) and nutritional shelf life of produce. The capacity to cool and store produce gives the grower more flexibility both in harvest timing and in getting the product to market. When designing mechanical cooling facilities or scheduling for their use, growers and shippers have a tendency to underestimate the refrigeration capacity that will be needed to meet peak cooling demands. It is often critical that fresh produce rapidly reach the optimal pulp (internal tissue) temperature for short-term storage or shipping if it is to maintain its highest visual quality, flavor, texture, and nutritional content all the way to market. The four most common cooling methods suitable for small farms are described below.

Room cooling. For room cooling, growers use an insulated room or mobile container (such as a marine refrigerated shipping container) equipped with units designed to deliver conditioned air by controlled air flow. Room cooling is much slower than other methods. Depending on the commodity, packing unit, and stacking arrangement, the product may cool too slowly in some parts of the stack or packed unit to prevent water loss, premature ripening, or decay. By increasing air circulation in the room, using vented containers or boxes, and, where space allows, spacing the containers within the room or on pallets with vents aligned to allow airflow among stacked units, it is possible to increase the rate of cooling. As discussed earlier, any carton or bin liners or packaging materials have the potential to further extend the amount of time necessary to cool the product, and product in the middle of a container or pallet may never reach the desired temperature.

Forced-air cooling. Often called pressure cooling in some areas, forced-air cooling uses fans in conjunction with a cooling room to pull cold air through packages or bins of produce covered by a tarp to create a tunneling or air-channeling effect. Although the actual rate of cooling depends on the air temperature, the rate of airflow, package venting, and the volumetric size of the product, this method is usually 75 to 90 percent faster than simple room cooling. Design considerations for a variety of small- and large-scale units are available in *Commercial Cooling of Fruits, Vegetables, and Flowers* (ANR Publication 21567). Low-cost forced-air cooling systems are possible even for just a small stack of cartons, such as might be needed for cut flowers (see Kitinoja and Kader 2003).

Hydrocooling. The term *hydrocooling* refers to various system designs to shower produce with chilled water in order to remove heat and possibly clean the produce somewhat at the same time. The use of a disinfectant in the water is essential in recirculating systems; details of sanitizer use are discussed later in this chapter. Hydrocooling is not appropriate for all produce since some fruit and vegetables are susceptible to physical injury or water-soaking damage. Even for produce varieties that are not susceptible, the system must be carefully designed to prevent water-beating damage. Waterproof containers (such as plastic totes or RPCs) or water-resistant waxed corrugated cartons are required. Currently, waxed corrugated cartons have limited recycling or secondary use outlets, so reusable, collapsible plastic containers are gaining popularity. A list of products suitable for hydrocooling is available in *Postharvest Technology of Horticultural Crops* (ANR

Publication 3311) as well as in *Commercial Cooling of Fruits, Vegetables, and Flowers* (ANR Publication 21567).

Top icing or liquid icing. Icing is an effective method for cooling some commodities and is equally adaptable to small- and large-scale operations. Ice-tolerant produce varieties are also listed in *Postharvest Technology of Horticultural Crops* and in *Commercial Cooling of Fruits, Vegetables, and Flowers* and include broccoli, sweet corn, and a number of other vegetables. The ice you use must be free of chemical, physical, and biological hazards, and the packages and packing you use must be designed to suit this cooling method.

The criteria you need to consider when you select the appropriate cooling method and storage temperature and humidity conditions for perishable crops are, once again, discussed in *Postharvest Technology of Horticultural Crops* and in *Commercial Cooling of Fruits, Vegetables, and Flowers*.

IMPORTANCE OF OPTIMAL STORAGE AND SHIPPING TEMPERATURES

Although we stress rapid and adequate cooling and protection from heat gain as primary elements of postharvest handling, many fruits and vegetables produced in temperate-zone climates are subtropical in origin and susceptible to chilling injury. Chilling injury occurs when sensitive crops are exposed either before or after harvest to low temperatures (but above the freezing point) for an extended period. Even a brief exposure often causes damage, though it may not become apparent for several days or until the produce is transferred to warmer display conditions. Some examples of chilling-sensitive crops are basil, tomato, bell peppers, eggplant, green beans, honeydew melon, sweet potato, watermelon, okra, yellow crookneck squash, mango, cherimoya, and Fuyu persimmons. Individual parts of some commodities have distinct sensitivities. In eggplant, the cap or calyx is more sensitive and turns black before the fruit itself is affected. The effects of chilling injury are cumulative and become irreversible after exposure to a commodity-specific time-temperature combination. For fruits and fruitlike vegetables, the temperature and duration of exposure to cause chilling injury typically change with maturity and ripeness. Peaches, plums, and nectarines as well as honeydew melons and tomatoes, for example, show a great reduction in chilling defects as they increase in their degree of ripeness. Depending on the duration and severity of chilling, chilling symptoms become evident in the ways listed below a few hours or days after the product is returned to warmer temperatures. Symptoms may include some of the following:

- pitting and localized water loss
- browning or other skin blemishes
- internal water-soaking or discoloration
- increased susceptibility to superficial lesions from molds and decay
- failure to ripen or uneven color development
- loss of flavor, especially from characteristic volatiles
- development of off-flavors

POSTHARVEST ETHYLENE EFFECTS: POSITIVE AND NEGATIVE

Ethylene, a natural hormone produced by plants, is involved in many natural functions during preharvest growth, stress response, and induction of maturation and subsequent ripening. The management of ethylene is another postharvest consideration that can help you manage the timing of ripening events and maintain quality during storage and transportation. Ethylene treatments can be used to degreen citrus fruits and control ripening events in fruits harvested at a mature but unripe developmental stage, such as mature green tomatoes and pears. In organic handling, application of ethylene gas produced by catalytic generators has recently been allowed for tropical fruits such as bananas and mangoes, but not for subtropical fruits such as citrus and tomatoes. This has little relevance, however, for small-scale growers marketing locally and regionally, since the majority of their ethylene-responsive products are harvested nearly or fully ripe and have no need for ethylene application. For a detailed discussion of the role of ethylene in ripening and postharvest management, see *Postharvest Technology of Horticultural Crops* (ANR Publication 3311).

In contrast to the beneficial role of ethylene in controlling ripening, ethylene produced by harvested produce (either as a result of ripening events or of deterioration and decay) or introduced from environmental sources (e.g., exhaust from propane-powered lift trucks) can be very damaging to sensitive commodities. Ethylene-producing fruits should not be stored with fruits or vegetables that are susceptible to ethylene damage. Ethylene-sensitive commodities should not be handled in packinghouses or warehouses or held in cold storage areas where damaging concentrations of ethylene are present, whether due to combustion engine exhaust or venting of catalytic ethylene generators from degreening and ripening rooms. Ethylene concentrations of 1 ppm or more will stimulate loss of quality, reduced shelf life, and increased disease, and will induce specific symptoms of ethylene injury such as the following:

- russet spotting of lettuce
- yellowing or loss of green color (e.g., in cucumber, broccoli, kale, spinach)
- increased decay of radicchio
- increased toughness in turnips and asparagus spears
- bitterness in carrots and parsnips
- yellowing and abscission (dropping) of leaves in Brassicas (cabbage, many Asian greens)
- softening, pitting, and development of off-flavor in peppers, summer squash, and watermelons
- softening of avocado, Fuyu persimmons, and kiwifruit
- browning and discoloration in eggplant pulp and seed
- discoloration and off-flavor in sweet potatoes
- increased ripening and softening of fruits when not desired

Adequate venting or fresh air exchange is the most important way to minimize ethylene levels in a storage area. Another approach is to use an ethylene adsorption material or conversion system designed to prevent damaging levels (as low as 0.1 ppm for some commodities) from accumulating in storage rooms and transportation vehicles. Potassium permanganate ($KMnO_4$) is one material commonly used in air filtration for postharvest storage rooms or in blankets, pads, or individual sachets of pellets placed in cartons during transport. For greatest effectiveness, room or container air must be circulated through these filters. These $KMnO_4$ air filtration systems or sachet absorbers are allowed for organic postharvest handling, so long as handlers maintain strict separation (no actual contact) between the $KMnO_4$ materials and the organic product.

Other air filtration systems available for ethylene removal in cold rooms work by circulating room air through units that contain glass rods treated with a titanium dioxide catalyst and an ultraviolet light source that activates the catalyst and triggers ethylene destruction. Corona discharge or ultraviolet light–ozone-based purification systems are commercially available for both ethylene elimination and killing airborne spores. You can find sources of these materials in the online Postharvest Yellowpages (http://postharvest.ucdavis.edu).

SANITATION AND WATER DISINFECTION

Sanitation of equipment and food contact surfaces and disinfection of water used in processing should be integrated into every facet of postharvest handling in order to maintain quality, optimal storage life, and food safety. Adequate washing and cleaning of produce (for those fruits and vegetables that can tolerate postharvest water contact) to optimize customer presentation, control decay and spoilage, and minimize the risk of foodborne illness should be provided by growers or handlers at all scales of production. Preshipping washing is common with tolerant crops, especially in advance of any extended storage period or longer-distance distribution. Besides reducing decay pathogens, you can reduce the risk of (but not entirely eliminate) contamination by human pathogens including bacteria such as *Escherichia coli* (*E. coli*) O157:H7, *Salmonella, Shigella,* and *Listeria,* parasites such as *Cryptosporidium* and *Cyclospora,* and viral pathogens such as hepatitis virus A and norovirus by using a properly designed wash system in combination with approved antimicrobials. These and other pathogens have been isolated from or associated with illnesses that resulted from consumption of domestic and imported fresh vegetables. Cases of such illness are not unique to large-scale production and shipping or fresh-cut processors. We will discuss the topic of food safety in greater depth later in this chapter.

Harvest and postharvest water quality. The source, condition, and prior use of the water used for field trimming and packing operations such as hydration or harvest cut washing after field harvest or immediately before retail display, application of postharvest chemicals, and the use of washing and cooling water in packing sheds or value-added pack lines deserve special consideration and attention. The water used for all applications should be free of chemical, physical, and biological hazards. Assurance of its continuing high quality in any recirculation and reuse applications is essential to prevention of cross-contamination within a lot and among lots. Water quality is best maintained through integrated management of the cleanliness of incoming product, filtration, the addition of approved disinfection chemicals or treatments, the verification of dose by means of continuous or periodic measurement, and the periodic partial or complete clean-out and fresh water exchange of the system. A daily clean-out and sanitization of the system and complete water exchange is strongly recommended.

As a general practice, it is best to keep field soil on product, bins, totes, and pallets to a minimum by brushing or washing any adhering soil from harvest containers. Careful harvesting to minimize the presence of nonsalable plant material (vines, leaves, roots, damaged and decay product) will also help maintain water quality and reduce the need for more frequent flushing. Both steps are among the practices that will significantly reduce the demand (i.e., the amount of material that must be added for effective control or to achieve a target dose activity level) for disinfectant in the water and lower the total volume of antimicrobial agents required. A simple explanation and approach to hypochlorite (bleach) dose calculation for postharvest handling is described in *Water Disinfection: A Practical Approach to Calculating Dose Values for Preharvest and Postharvest Applications* (ANR Publication 7256). A light spray of water mixed with appropriate levels of needed disinfectants at harvest—for example, prewashing the butt end of lettuce or celery—removes plant exudates that have been released from harvest cuts or wounds, which can otherwise react rapidly with oxidizers such as hypochlorite and ozone, thereby neutralizing their effectiveness to some degree and requiring their reapplication at higher rates in order to maintain the originally intended effective level of activity.

Properly used, a disinfectant in postharvest wash and cooling water can help prevent both postharvest diseases and foodborne illnesses. Because most municipal water supplies are chlorinated and the vital role of water disinfection is well recognized, organic growers, shippers, and processors may use chlorine within specified limits. All forms of chlorinated materials (chlorine gas, liquid sodium hypochlorite, granular calcium hypochlorite, and chlorine dioxide) are restricted materials as defined by existing organic standards. Their application must conform to maximum residual disinfectant limit rules under the Safe Drinking Water Act, currently 4 mg/L (4 ppm), expressed as Cl_2. California Certified Organic Farmers (CCOF) regulations have in the past permitted this threshold of 4 ppm residual-free chlorine, measured downstream of the product wash. As this rule may change according to location and the degree of interpretation allowed, growers who are registered through the California Department of Food and Agriculture (CDFA) and certified by other agencies than CCOF should check with the state and their certifying agent. For a more complete discussion of water disinfection, see *Postharvest Chlorination: Basic Properties and Key Points for Effective Disinfection* (ANR Publication 8003) and *Making Sense of Rules Governing Chlorine Contact in Postharvest Handling of Organic Produce* (ANR Publication 8198).

Liquid sodium hypochlorite is the most common form of chlorine used in both organic and conventional operations. For optimum antimicrobial activity with a minimal concentration of applied hypochlorite, the pH of the water must be between 6.5 and 7.0, and you can add approved materials to adjust the pH into this range. At this pH range, there will be adequate amounts of chlorine in the form of hypochlorous acid (HOCl), which delivers the highest rate of microbial kill and minimizes the release of irritating and potentially hazardous chlorine gas (Cl_2). Chlorine gas will form and exceed safe levels if the water is highly acidic. Products used for pH adjustment include food-grade citric acid, hydrochloric acid (muriatic acid), phosphoric acid, sodium bicarbonate, lactic acid, and vinegar (acetic acid). Calcium hypochlorite, properly dissolved from granular or tablet form, may provide the benefit of reducing sodium injury to sensitive crops (e.g., some apple varieties, light-skinned cucumbers, immature yellow squash), and limited evidence points toward reduced decay from wound-healing and extended shelf life for tomatoes and bell peppers as a result of calcium uptake from the application. Useful guides, tables, and links to other sites that can help you determine the amounts of sodium or calcium hypochlorite to add to clear, clean water for disinfection per makeup water and total use volume are available from several sources, including the following:

UC Postharvest Technology, Research, and Information Center. http://postharvest.ucdavis.edu

UC Vegetable Research and Information Center. http://vric.ucdavis.edu/veginfo/veginfor.htm

ATTRA National Sustainable Agriculture Information Service. http://attra.ncat.org

Oxidation-reduction potential. Another method for monitoring, controlling, and documenting the chlorine dose and pH status of any water is oxidation-reduction potential (ORP), or the redox potential, measured in millivolts (mV). Some operators specify both a redox potential target (≥650 mV) and a pH window of operation (pH 6.5 to 7.5), but the latter is an inaccurate measurement in the case: the mV value is the determining criterion. Sensors for ORP measure the oxidizing (or reducing) potential or activity of a solution. The higher a water's ORP value, the greater the oxidizing action and the shorter the microbial kill time in water. The relationship between ORP and traditional dose measurements (parts per million [ppm]) is nonlinear in the range most commonly used in postharvest management. This means that you typically cannot use ORP millivolt values to demonstrate that you have met a set ppm specification. For a more complete discussion of ORP benefits and limitations, consult *Oxidation-Reduction Potential (ORP) for Water Disinfection Monitoring, Control, and Documentation* (ANR Publication 8149).

Oxidation-reduction potential has been found to be a functional and practical single-value measurement of disinfection power under most conditions. It can be a verifiable, successful method for assessing the antibacterial and antifungal status of washout, flume, washline, or cooling water systems. As mentioned earlier, ORP measurements in surveys of commercial systems have not proven to provide a direct or repeatable correlation to an exact concentration of free chlorine, regardless of water pH. Tests do, however, demonstrate that the ORP status of water over a broad pH range correlates well with microbial lethality or control that results from the oxidizing activity of the solution. Clearly, ORP sensors, like any equipment, need to be calibrated, maintained, and replaced as necessary if you want accurate readings. ORP sensors, particularly in-line probes, may be prone to oxidizer saturation or fouling and may therefore give readings that do not reflect the current water quality conditions. It is always advisable—if not essential—to have redundant systems for verification that the process is under control. A well-managed system includes periodic testing with hand-held ORP and pH sensors at multiple points along with cross-checks against direct measurements of available free chlorine to make sure all measurements agree within a practical range.

Rapid pathogen inactivation will occur at a specific threshold ORP, whether the water pH status is above or below 7.0, and this is well documented in the literature and matches the chapter authors' applied research experience. Among hand-held and in-line device results, the ORP value is the best measure of the availability of the hypochlorous acid (HOCl) form of chlorine in water at any given pH. HOCl is reported to be at least 80 times stronger at killing harmful microbes than the hypochlorite ion (OCl^-) form, which is more abundant at elevated pH levels (approximately 20% HOCl and 80% OCL^- at pH 8.0).

The accuracy of ORP for detecting levels of surviving microbes is not perfect or without occasional uncertainties in total microbial inactivation rates when you move from single-pass water to multiple-use recirculated water, the latter of which accumulates suspended organic and inorganic solids and salts. This lack of accuracy is particularly evident in water with a high sediment content and short residence (contact) time prior to chlorine neutralization and after sample collection. You can get a reasonably short response time and be free of any wide flux or instability in the measured values from ORP sensors for a moderate range of water quality consistent with the conditions in many packing and wash process systems. However, in surveys of packing sheds with larger recirculating systems, the authors have found that the frequently cited target of 650 mV is often too hard to maintain uniformly and is too low a value to adequately meet bacterial and fungal inactivation objectives. Depending on the specific application, product, and microbial control objectives, users often set the injection point dose targets or set points at 725 to 850 mV. With increasing water complexity (i.e., poorer-quality water), the concentration of free chlorine necessary to maintain a constant or target ORP increases.

Nonchlorine oxidizers for water disinfection. Ozone is an attractive option for water disinfection and other postharvest applications, and you can find a detailed discussion of postharvest ozone in *Ozone Applications for Postharvest Disinfection of Edible Horticultural Crops* (ANR Publication 8133). Ozonation, a powerful oxidizing treatment, is effective against chlorine-tolerant decay microbes such as some *Fusarium* and *Alternaria* spore forms and against foodborne pathogens, and acts quickly in clean water systems. The reactivity of ozone may give it a distinct advantage in cooling or wash procedures that feature a short contact time or in long

RECOMMENDED STEPS TO OPTIMIZE POSTHARVEST CHLORINATION*

1. Minimize all sources of chlorine demand (soil, plant debris, heavily wounded or decayed produce) on incoming product.
2. Inspect incoming product during precooling stage for excessive amounts of adhering soil and nonproduct plant material (such as leaf or vine trash) on totes, cartons, and pallets. Remove as practical.
3. Provide feedback as needed to supervisors of harvest operations and crews to improve performance in reducing sources of chlorine demand at the field level.
4. For fruit and vegetable products that will tolerate it, light mechanical cleaning (such as dry brushing or brush washing) may significantly reduce chlorine demand and extend the clarity of the process water and the functional disinfection activity.
5. Manage and monitor postharvest water to maintain a pH of 6.5 to 7.0 and a level of free chlorine sufficient to achieve disinfection goals. Organic handlers should not exceed 4 ppm free chlorine, measured at the point where the product is removed from that operational step. For example, adjust the chlorine level in dump and flume tank injection water to maintain 50 ppm and maintain the chlorine level in recirculating water at 4 ppm or less at the return sump (the farthest point from injection—for example, where the product transfers to a lift conveyor).
6. For products that will tolerate it (such as tomatoes and melons), heated chlorinated water is more effective for disinfection. This benefit must be balanced, however, against reduced stability of the chlorine and increases in irritating chlorine levels from off-gassing. Heating the initial receiving water to 10°F above the temperature of the incoming product also minimizes the potential for water infiltration into the product, which may trigger or accelerate decay and presents a known risk for foodborne illness if pathogens are present.
7. If necessary, add approved flocculants to capture suspended sediments in the water and hold the water in a retention sump or basin. Screening and filtration of recirculating water will reduce chlorine demand and improve the performance of any oxidizer (such as ozone and peroxides) or nonoxidizing disinfectant (such as a UV system).
8. Dump tank, flume, and hydrocooler sump basins and any sediment collection points in the equipment must be cleaned daily. Sediments are a common reservoir for decay pathogens and pathogens of concern for human food safety.
9. Develop a system of periodic partial or full replacement with clean water that balances the costs and time delays involved in cooling or heating postharvest water, with the goal of minimizing turbidity and electrical conductivity (salt buildup) in the water. Develop a simple rating system to assess turbidity thresholds for periodic water exchange. A simple turbidity tube with standard Secchi disk (with a black-and-white pattern viewed through the tube) is very affordable and easy to make. (See http://www.cee.mtu.edu/sustainable_engineering/resources/technical/Turbidity-Myre_Shaw.pdf.)
10. Ensure that responsible personnel are trained in the function and operation of equipment and monitoring kits. Define the timing and frequency of procedures to be used in monitoring in written form and post standard procedures for each water use, whether it involves using a bucket in the field, a small wash line, or a more extensive chopping, slicing, and packaging system.
11. Use redundant systems of measurement to ensure adequate dosing, such as calibrated ORP sensors and free-chlorine and pH test strips or titration kits.
12. Ensure that responsible personnel are trained to safely handle concentrated chemical sanitizers and to implement and document any corrective actions that must be taken to meet product quality and safety.

*For a discussion of issues related to chlorine use and organic integrity, see *Making Sense of Rules Governing Chlorine Contact in Postharvest Handling of Organic Produc*e (ANR Publication 8198).

flume systems. Organic postharvest handlers may find they prefer to use ozonation rather than chlorination since it may help them meet the requirements of certain markets that do not allow food that has been in contact with chlorine or help them appeal to particular consumer sectors. Ozone oxidative reactions create far fewer disinfection by-products than chlorination (e.g., trihalomethanes, which are a health and environmental concern). However, be aware that capital and operating costs are typically higher for ozonation than for chlorination or other available methods that do not require on-site equipment.

Ozone must be generated on-site at the time of use and is very unstable, lasting as few as 20 minutes even in clear water, and so has no residual activity. This rapid breakdown to molecular oxygen (O_2) is desirable because it means the ozone is nonpolluting, but naturally it also means that maintaining effective ozone levels even in small volumes of water is very challenging. Still, it can be effective. Ozone systems are in use by fruit and vegetable packers and fresh-cut processors, both conventional and organic, typically at a focused point in the handling process. Ozonation of the final rinse water has become fairly common. Clear water is essential for optimal performance, and the process requires adequate to superior filtration of input or recirculating water. Depending on scale and ozone generation output, costs for a complete system start at about $10,000. Small-scale units available for a few thousand dollars are suitable for limited water use and small-batch applications. For specifications and installation, consult an experienced ozone service provider. Sources of these services and suppliers can be found in the online Postharvest Yellowpages (http://postharvest.ucdavis.edu).

Food-grade hydrogen peroxide (0.5 to 1%) and peroxyacetic acid are additional options for nonchlorine treatment. In general, peroxyacetic acid (PAA; 11% hydrogen peroxide, 15% acetic acid) has good efficacy in water dump tanks and water flume sanitation applications. Reports indicate that PAA has very good performance, when compared to chlorine and ozone, in killing yeasts and molds and in removing and controlling microbial biofilms (tightly adhering slime) in dump tanks and flumes. These peroxide formulations have a higher per-unit cost than hypochlorite. Approved peroxide-based materials are available for organic uses, and as a result of growing interest in nonchlorine alternatives, treatment containers are now available in volumes designed for use in smaller operations.

Other examples of organically allowed postharvest treatments include organic acids from natural sources (e.g., acetic acid–vinegar, malic acid), spice extracts and plant essential oils (e.g., rosemary, thymol, clove, spearmint, peppermint, cinnamaldehyde), thiosulfinates (e.g., allicin and garlic extracts), and copper ions. Commercial formulations that include these antimicrobials are available.

Planning for Postharvest Safety

Planning for postharvest food safety should be included in any edible crop management plan. Regardless of the scale of operations or whether conventional, organic, biodynamic, or any other crop management approach is practiced, no farming operation should be viewed as exempt or excluded from the regulatory requirements, consumer expectations, and moral responsibilities that bear on food safety. Beyond the commonsense notions that we all learn regarding health, hygiene, and good crop husbandry, specific prerequisite programs that are consistent with good agricultural practices (GAP) need to be understood, customized, and formalized by each grower, handler, and operator and for each crop and specific production field. This will help minimize the risks associated with a variety of hazards and contaminants, including chemicals (e.g., heavy metals carryover), physical contaminants (e.g., sand and soil, wood, glass, plastic or metal shards), and biological hazards (e.g., pathogenic *E. coli, Salmonella, Listeria,* parasites, mycotoxins). You can find a detailed outline of the key points and principles of preharvest and postharvest GAPs in *Key Points of Control and Management of Microbial Food Safety: Information for Growers, Packers, and Handlers of Fresh-Consumed Horticultural Products* (ANR Publication 8102) and Suslow et al. (2003), as well as other resources available from the National GAPs Program Web Links at Cornell University (http://www.gaps.cornell.edu/gapsd/Weblinks.html) and UC Davis (http://ucgaps.ucdavis.edu).

In addition to noting that many elements of a GAP plan are likely to be incorporated into their existing crop management program and activities, growers commonly realize improvements in efficiency and benefits to product quality after they implement a GAP and food safety system. Programs already in place to ensure produce quality may, with minor modifications, be made to apply directly to food safety. Though it has rarely been documented, growers often share strong empirical evidence indicating that the application of food safety programs has proven to have a direct benefit on postharvest quality and market access.

Chemical safety. Chemical inputs may be needed to fertilize crops or control pests during production and postharvest handling. These products must always be used according to product labeling to avoid unsafe levels of residues. The label will tell you which products the chemical may be applied to, how close to harvest the materials can be applied, and the proper application rate. Take particular care when using several products at the same time. Take preventive measures to ensure that mechanical lubricants, fuels, and solvents used around the farm and on equipment do not come into contact with produce handling surfaces or into direct contact with product in the field, at harvest, during packing, or during transportation.

Physical safety. Harvesting and packaging processes should be managed to keep harvested products from becoming contaminated with foreign matter such as plastics, wood chips, rocks, and glass or metal fragments.

Biological safety. Prior land use, adjacent land use, water source and method of application, fertilizer choice (such as the use of manure), compost management, equipment maintenance, field sanitation, movement of workers between different operations, personal hygiene, domestic animal and wildlife activities, and other factors all have the potential to adversely impact food safety. A variety of resources available to growers are listed later in this chapter under "Other Resources," and you can use them to guide you in the development of a GAP program and on-farm self-audit. All growers, handlers, and marketers of fresh vegetables should be aware of the U.S. Food and Drug Administration (FDA) Primary guide to GAPs, which is available in English, Spanish, Hmong, Lao, Llocano, Portuguese, French, and Arabic (Portal to FDA Food Safety Information, http://www.fda.gov/food/foodsafety).

Packing and cold storage facility operators need to make special considerations for management of *Listeria monocytogenes,* due to its common presence in the field on vegetation, in soil, and in cool, wet facilities and drains, and its ability to grow on surfaces, equipment, and most fresh produce under refrigeration temperatures *Guidelines for Controlling* Listeria monocytogenes *in Small- to Medium-Scale Packing and Fresh-Cut Operations*. (See ANR Publication 8015).

SUMMARY

To protect your investment in the fruits and vegetables you have produced, you need to ensure that they receive careful treatment after harvest. Handle produce in a gentle but expedited fashion in order to both reduce the time from harvest to cooling and prevent physical damage. Optimum postharvest quality and safety begins with the selection of the appropriate varieties and the use of good agricultural practices. Good temperature management and a shortened time from harvest to market are key factors to maintaining fruit and vegetable appearance, flavor, and nutritional quality.

FOR SPECIALTY CROPS, MAKE EDUCATED GUESSES

When dealing with new crops and determining how they should be handled postharvest, one can make a few educated guesses based on the answers to the following questions:

1. Is the crop of tropical or temperate origin? This will likely tell you whether it is chilling sensitive.
2. Is the crop a leaf, a root, or a fruit? This can help determine how susceptible it is to water loss.
3. If the crop is a fruit, are there noticeable ripening changes after harvest? The degree of change after harvest is generally related to its rate of deterioration.
4. Are you harvesting the crop when it is rapidly growing or when it has completed its growth phase? Rapidly growing crops generally have a very high respiration rate and high deterioration rate.
5. If the crop is a leafy product, are there rapid color changes? This may indicate how susceptible the product is to deterioration and how sensitive it may be to exposure to the contaminant ethylene.
6. If the crop is a fruit, are there rapid textural and compositional (starch-to-sugar conversion) changes? This may indicate a climacteric type fruit that produces a lot of ethylene.
7. What are the postharvest characteristics of a related product (another species of the same genus, another genus of the same family, etc.)? Refer to tables 10.1 and 10.2 for information on various products.
8. What is the estimated storage temperature? Try to place the product into one of the following categories:
   A. low temperature (32° to 41°F)
   B. moderate temperature (41° to 50°F)
   C. moderately high temperature (50° to 60°F)
9. What is the estimated shelf life? Try to fit it into one of the following categories:
   A. short shelf life: 1 to 6 days
   B. moderate shelf life: 7 to 21 days
   C. long shelf life: 3 to 12 weeks or longer
10. Is the product very tender and delicate? Does it bruise easily? This will help to determine what sort of packaging system might be appropriate.

Examples of Defects that Do Not Affect Postharvest Life Potential of Fresh Produce

- healed frost damage
- healed scars and scabs
- well-healed insect stings
- irregular shape
- suboptimal color uniformity or intensity

Examples of Defects that Do Affect Postharvest Life Potential of Fresh Produce

- softening
- sunburn and sunscald
- cracks
- bruising
- sprouting
- chilling injury
- scald
- decay
- cuts, abrasions, and skin breaks

COMPARISON OF POTENTIAL ADVANTAGES AND DISADVANTAGES OF PLASTIC CONTAINERS VS. CARTON BOXES

Potential advantages	Potential disadvantages
PLASTIC CONTAINERS	
Significant cost reduction in closed loop systems	Less product protection and cushioning; need for packing materials and interior materials
Returnable, reusable, and recyclable	High initial investment
Easy to clean and sanitize	Increased shipping costs due to weight and back-shipping
Any size and color; color-code products	Mandatory cleaning
Moistureproof; no collapsing or resulting product damage	Tracking and inventory costs; storage space requirements
Reduced labor costs and handling steps	Replacement costs due to theft, damage
CARTON BOXES	
Product protection good in a well-designed carton box	Stacking strength greatly reduced under high moisture conditions
Can print with high-resolution graphics for attractive product merchandising	Handling costs at distribution centers to recycle
Can custom design containers rapidly	Box-making labor and equipment costs
Low shipping costs; no back-shipping cost	Not returnable and reusable
Storage of cartons is space efficient	Wax-impregnated and other carton containers difficult to recycle
One-way container, no cleaning	Cannot be cleaned

Source: Compiled by Marita Cantwell from various industry sources, including Fiber Box Association (http://www.fibrebox.org).

Table 10.1. Examples of postharvest requirements for selected vegetables and melons

Product	Harvest quality	Storage		Shelf life (days)	Ethylene sensitivity	Observations
		°F	% RH			
Artichoke, globe	size, tender bracts	32	95	14	low	sprinkle lightly
Asparagus	bracts at tip closed	36	95	14	low	stand in water
Basil	fresh, tender leaves	55	95	7	moderate	stand in water
Beans, lima	seeds developed, plump	40	95	7	moderate	sprinkle lightly
Beans, pole and snap	crisp pods, seeds immature	40	95	7	moderate	sprinkle lightly
Beets, bunched	firm, deep red roots	32	95	14	low	sprinkle, cut tops
Broccoli	firm head, buds not open	32	95	14–21	high	sprinkle; ice
Brussels sprouts	firm sprouts	32	95	21–28	high	sprinkle; ice
Cabbage	crisp, firm, compact head	32	95	30–180	high	sprinkle lightly
Cantaloupe melon	stem separates; rind color	36	95	14	moderate	ice
Carrots, topped	tender, crisp, sweet roots	32	95	28–180	high	sprinkle; cut tops
Cauliflower	compact, white curds	32	95	14–21	high	sprinkle
Celery	crisp, tender petioles	32	95	14–21	moderate	sprinkle; ice
Corn, sweet	plump tender kernels	32	95	7	low	ice
Cucumber	crisp, green, firm	50	95	10	high	sprinkle lightly
Eggplant	seeds immature; shiny, firm	50	95	10	moderate	
Endive, escarole	fresh, crisp, tender leaves	32	95	14–21	moderate	sprinkle lightly
Greens, leafy, and herbs	fresh, crisp, tender leaves	32	95	10–14	moderate	sprinkle lightly
Honeydew melon	waxy, creamy colored, heavy	45	90	21	high	
Lettuce	compact head, crisp, tender	32	95	21	high	sprinkle lightly
Onions, dry	firm bulbs, tight necks	32	65	30–180	low	
Onions, green	crisp stalks, firm white bulbs	32	95	10	moderate	sprinkle; ice
Parsley	crisp, dark green leaves	32	95	21	high	sprinkle; ice
Peas	tender, green, sweet pods	32	95	7–10	moderate	sprinkle
Peppers, chili	firm with shiny appearance	45	95	14	low	
Peppers, green	firm with shiny appearance	45	95	14	low	
Potatoes, early crop	well-shaped tubers, defect-free	50	90	14	Low	if washed, dry well
Potatoes, late crop	well-shaped tubers, defect-free	45	90	60–180	moderate	if washed, dry well
Pumpkin	hard rind, good color, heavy	55	65	30–160	moderate	
Radish, with tops	firm, crisp, dark green leaves	32	95	14–21	Moderate	sprinkle; ice
Rutabagas	roots firm with smooth surface	32	95	60–120	low	cut tops; sprinkle
Spinach	dark green, fresh, crisp leaves	32	95	10	high	sprinkle lightly
Squash, summer	firm, shiny fruits, right size	45	95	10	moderate	
Squash, winter	hard rind, corked stem, heavy	55	65	60–120	moderate	allow cut stems to heal
Tomatoes, green	firm, jelly present, light green	55	90	21	high	
Tomatoes, ripening	firm, uniform coloration	50	90	14	high	avoid temperatures <50°F
Turnip	firm, heavy roots	32	95	60–120	low	cut tops; sprinkle
Watermelon	crisp, good flesh color, heavy	55	90	14	high	

Table 10.2. Examples of postharvest requirements for selected fruits

Product	Harvest quality	Storage		Shelf life (days)	Ethylene sensitivity	Observations
		°F	% RH			
Apple	crisp, color typical of variety	32	95	90–180	high	varieties differ a lot in postharvest life
Apricot	firm, well colored	32	95	7–21	moderate	
Avocado	% dry matter, % oil, size	41	90	14–28	high	varieties differ a lot in chilling sensitivity
Banana	finger size, color	55	95	7–14	moderate	
Blueberry	blue color, firmness	32	95	14–21	low	
Carambola	yellow skin color	40	95	14–21	moderate	
Cherimoya	firmness, skin color	55	95	14–21	high	
Cherry, sweet	fruit color typical of variety	32	95	7–14	low	
Cranberry	fruit color	36	95	30–60	low	
Currant, gooseberry	firm, color typical of variety	32	95	10–21	low	
Date	color, sugar content	32	75	180–360	low	
Fig	firm but near ripe, skin color	32	95	7	low	
Grape, table	color typical of variety, sugar	32	95	14–90	low	gray mold ends life
Grapefruit	skin color, sugars-to-acid ratio	55	95	30–40	low	
Guava	skin color, firm	45	95	14–21	moderate	varieties differ a lot
Kiwifruit	firmness, soluble solids	32	95	120–150	high	
Lemon	juice content	45	95	30–120	moderate	
Lime	juice content, skin color	50	90	21–50	high	
Litchi	red skin color, soluble solids	36	95	14–28	moderate	
Loquat	fruit color typical of variety	32	95	14–28	low	
Mandarin	peel color, sugars-to-acid ratio	41	95	14–28	low	
Mango	skin color, shape for variety	55	95	14–21	moderate	
Nectarine	skin ground color, firmness	32	95	14–28	moderate	
Olives	color (green or black)	45	95	14–28	low	harvested olives are processed
Orange	skin color, sugars-to-acid ratio	41	95	30–60	moderate	
Papaya	skin color	55	95	14–21	High	
Passion fruit	skin color change	45	90	7–14	moderate	
Peach	skin ground color	32	95	14–28	moderate	
Pear, Asian	firm, skin color of variety	32	95	30–120	moderate	
Pear, European	firmness, skin color	32	95	30–120	High	
Persimmon	skin color	32	95	14–28	High	
Pineapple	skin yellowing; "eye" flatness	50	95	7–21	moderate	
Plum, fresh prune	skin color typical of variety	32	95	10–30	moderate	
Pomegranate	size, skin color	45	95	60–120	low	
Prickly pear cactus	firm, jelly present, light green	41	95	14–21	low	
Quince	skin ground color changes	32	90	30–90	low	
Strawberry	fruit color	32	95	7–10	low	
Tamarillo	peel and pulp color	41	90	14–28	low	
Tamarind	pulp and shell brown, brittle	68	75	14–28	none	keep 6 months at 41°F

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California Certified Organic Farmers, Certification Handbook. http://www.ccof.org/certification.php.

Organic Materials Review Institute. http://www.omri.org.

UC Postharvest Technology Research and Information Center. http://postharvest.ucdavis.edu.

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