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Harvesting and Handling Techniques

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I. INTRODUCTION

Quality is the most important factor for the success of any vegetable marketing program. It is axiomatic that the quality of a vegetable is never better than at the time it is harvested. Consequently, every step from harvest, through packing and transportation, to the consumer can help to maintain that initial level of quality. Of course, one may point out that there are a few examples, such as mature green tomatoes (*Lycopersicon esculentum* Mill.), for which the crop at harvest is not as desirable as it will eventually be after ethylene or some other treatment. Nevertheless, the at-harvest quality of those crops is still the most important determinant of how well they respond to subsequent treatments and what their ultimate quality will be (Maul et al., 1998).

In most cases, the postharvest handling process is composed of numerous steps (Fig. 1) that, hopefully, will serve to keep the crop in a state as close to fresh-picked as possible. This is accomplished by minimizing handling, cooling the crop as thoroughly and efficiently as possible, and maintaining the cooled crop in a refrigerated, high humidity environment. Also, due to the highly perishable nature of most vegetables, the harvest, packing, cooling, and transport systems should be geared for efficiency and speed. Quality assurance is achieved by first understanding the production and processing systems and how they interact. It is useful to list the steps or procedures involved in the total system (Table 1), as a first step toward creation of a quality assurance manual for the operation. The list should identify the responsibilities of each group or person and the exchanges of information necessary between different parties, for example harvest crew and packinghouse foreman (Lidror and Prussia, 1993).

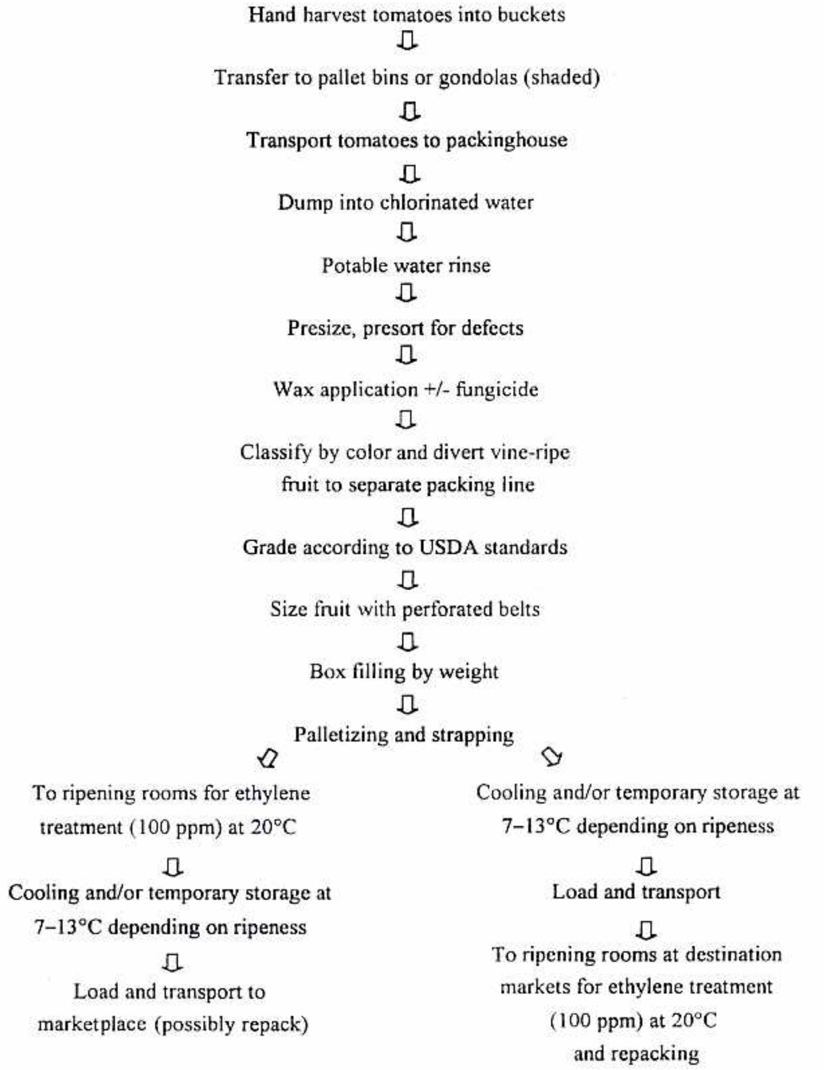


Figure 1 Postharvest handling system for fresh market tomatoes.

Successful postharvest handling requires knowledge of the postharvest physiology and pathology of the crop being handled. This is because the physiology and pathology of the vegetable determines the best handling practices to maintain high quality. What are the important compositional components of the vegetable and what are their patterns of accumulation on the plant? Is the edible plant organ climacteric or nonclimacteric? Is it chilling sensitive or not? Can it tolerate exposure to water before packing and storage? In this chapter, I consider the key harvest and handling factors for ensuring high-quality vegetables, taking into account the variety of physiological and other requirements of these crops. Detailed descriptions of the harvesting and handling systems for individual vegetable crops can be found in Kader (1992) and Ryall and Lipton (1979).

Table 1 Quality Assurance Records for Vegetables

Field packing

- Maturity/ripeness stage and uniformity
- Harvest method (hand or mechanical)
- Temperature of product (harvest during cool times of the day and keep product shaded)
- Uniformity of packs (size, trimming, maturity)
- Well-constructed boxes; palletization and unitization
- Condition of field boxes or bins (no rough or dirty surfaces)
- Boxes not overfilled
- Cleaning and sanitization of bins and harvest equipment

Packinghouse

- Time from harvest to arrival
- Shaded receiving area
- Uniformity of harvest (size, trimming, maturity)
- Washing/hydrocooling operation (sanitation)
- Change water daily and maintain constant sanitizer levels in dump tanks
- Decay control chemical usage
- Sorting for size, color, quality, etc.
- Discard product that falls on the floor
- Check culls for causes of rejection and for sorting accuracy
- Sanitize facilities and equipment regularly
- Well-constructed boxes; palletization and unitization
- Boxes not overfilled; compliance with grade, size, and weight regulations

Cooler

- Time from harvest to cooler
- Time from arrival to start of cooling
- Package design (ventilation)
- Speed of cooling and final temperature
- Temperature of product after cooling
- Temperature of holding room
- Time from cooling to loading

Loading trailer

- First-in, first-out truck loading
- Temperature of product
- Boxes palletized and unitized
- Truck condition (clean, undamaged, precooled)
- Loading pattern; palletization and unitization
- Duration of transport
- Temperature during transport (thermostat setting and use of recorders)

Arrival at distribution center

- Transit time

II. THE HARVEST OPERATION

The harvest operation may be divided into three parts: (a) selection of the individual items to be picked; (b) removal of those items from the plant; and (c) collection of the individual items into containers. The reason for the predominance of hand harvesting over mechanical harvesting of vegetables is probably because, depending on the crop, one or all of these operations are done more effectively or more efficiently and with less damage by humans.

A. Selection: Maturity, Physical Aspects, and Decay

Selection and use of maturity indices is very important because harvesting at the proper maturity has arguably the greatest effect on the postharvest quality of vegetables. Too often, harvesting is scheduled according to market conditions, when it should be scheduled according to the optimum maturity of the crop. Vegetables harvested at optimum maturity help to ensure a continuing market for subsequent crops. Vegetables harvested immature may be more prone to mechanical injury and water loss, have poor flavor due to low levels of sugars or other flavor components, and be more susceptible to certain physiological disorders such as chilling injury. Vegetables harvested overmature may have undergone secondary growth that makes them less tender or succulent, may be more prone to senescent deterioration or decay, and may have developed bitter flavor. In practice, the actual time of harvest is affected by field conditions, distance and transportation time to the intended market, and market economic conditions.

Since market forces inevitably come to bear on any decision of harvest timing, objective measures of maturity are desirable so that the grower knows whether or not he will be sacrificing quality by harvesting at a particular time, and so that he can back up his decision with numbers that give buyers and consumers confidence in purchasing the commodity. If the objective parameter chosen as a maturity index is some property or component of the crop that changes regularly over time, so much the better, for then it can potentially be used to predict the proper harvest date. This allows the grower to more effectively plan for labor and equipment as well as decide if harvest time may be sped up or delayed in order to take advantage of changing market conditions.

The optimum horticultural maturity for individual vegetable crops can occur at any point during development (Fig. 2). There is a ''harvest window'' for each vegetable that is related to the rate of change in growth, composition, or other factors, and an acceptable range of quality. The harvest window may be as short as a few days (e.g., sweet corn, *Zea mays* var. rugosa Bonaf.) or as long as several weeks (e.g., winter squash, *Cucurbita maxima* Duchesne ex Lam.). For many vegetative organs and immature fruit-type vegetables, there can be a conflict between attainment of profitable size and the flavor and tenderness that are necessary for optimum culinary quality. For mature fruit-type vegetables, delaying harvest usually means better culinary quality if ripening is allowed to commence on the plant, but the postharvest life and the ability of the crop to physically withstand the rigors of handling and transportation are reduced in ''vine-ripe'' fruit.

The picker is required to make a number of important decisions during the process of harvesting, such as visually judging the size, shape, and color to determine the optimum developmental stage; judging the soundness or absence of defects for each item; judging by touch the firmness, density or texture of each vegetable, or its ease of removal from the plant. Because so much of the responsibility for high-quality vegetables rests on the pickers, it is important that they receive adequate training and supervision. Pickers must be trained to leave immature, overmature, defective, and decayed vegetables in the field.

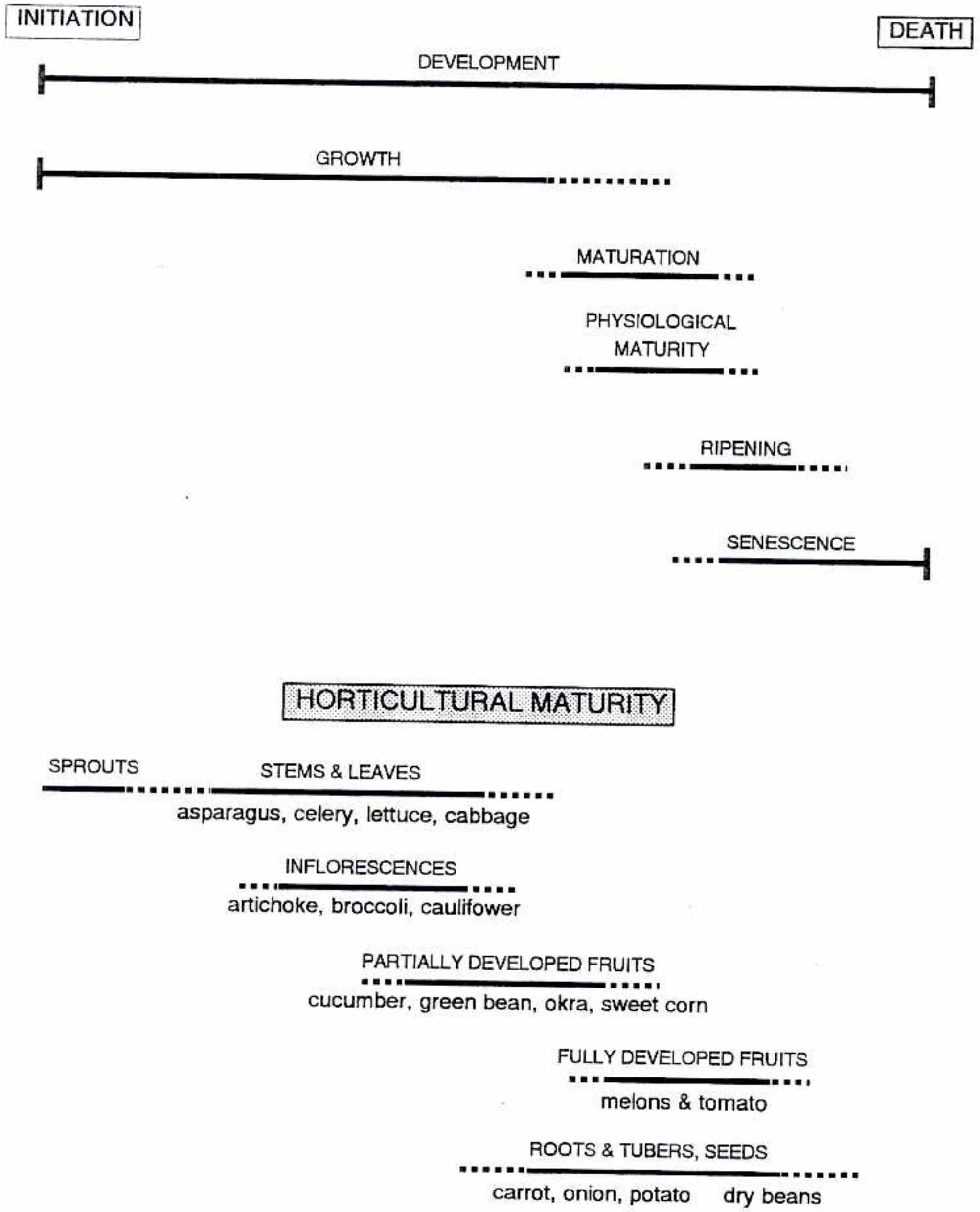


Figure 2 Horticultural maturity in relation to developmental stages of [illegible]

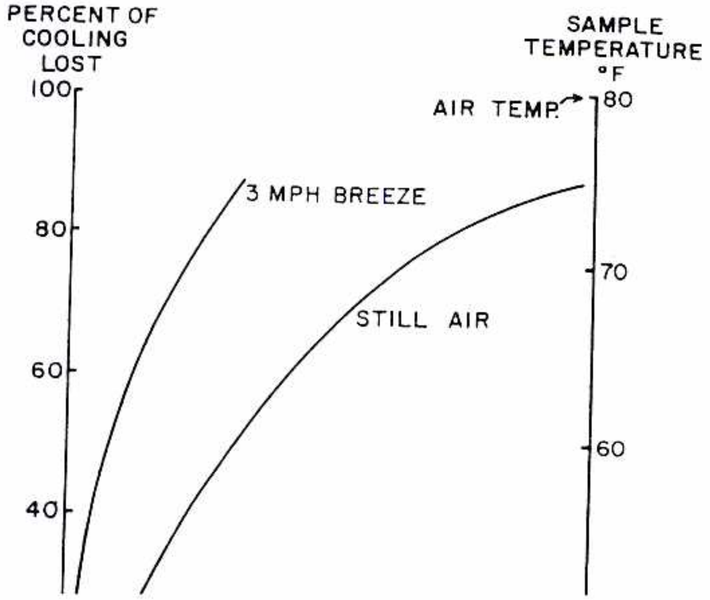
tissue that makes up the abscission zone. Rupture of the abscission zone signals the attainment of maturity and the beginning of ripening for many of these fruits. Development of the abscission zone can be a useful and important maturity index, as for example with muskmelons (*Cucumis melo* L. Reticulatus Group), which have their maturity stages described in terms of the degree of separation of the abscission zone (i.e., half-slip, full-slip). Most vegetables, including the immature fruit-type vegetables, have to be separated from the plant by cutting or snapping. Knives or shears may be used for crops that cannot be removed easily by snapping or pulling. The opportunity to inflict mechanical injury during removal from the plant is always present. Vegetables will typically be warm and turgid at the time they are harvested, which makes them particularly sensitive to bruising and other types of mechanical injury (see Chap. 7). Thus, vegetable harvest requires a gentle touch.

C. Collection: Containers, Liners, and Transfers

Once removed from the plant, individual vegetables must be collected for ease of handling. A few vegetables are primarily or commonly collected directly into the shipping carton (e.g., vine-ripe tomatoes or watermelons, *Citrullus lanatus* [Thunb.] Matsum. & Nak.). More commonly, vegetables are collected into metal or plastic buckets or small plastic or wooden lug boxes and taken to a collection area in the field, either for packing in the field or for further consolidation for transport to a packing facility. Because the implements, buckets, lugs, and bins used in the harvest operation are continually reused, there is high potential for spread of disease-causing organisms. Injuries received during harvest allow entry of microbial pathogens existing in soil and on dirty tools, buckets, lugs, pallet bins, and machinery. Chances for such cross-contamination can be reduced by eliminating harvesting injuries and by not introducing decayed vegetables into the marketable population. All harvest implements and containers should be regularly cleaned and sanitized to minimize pathogen buildup. Injuries can occur during transfer of vegetables into collection buckets and lugs or into pallet bins, when the vegetables are dropped or tossed—especially when the interior surfaces of the buckets, lugs, and bins are rough or dirty. Plastic pallet bins are superior to plywood bins in this regard; although plastic surfaces can also become rough over time, they are easier to clean and sanitize than wood bins. Separate plastic liners can be placed within field bins to reduce abrasion injury and to reduce cross-contamination.

During the time when the vegetables are being collected for loading and transport to the packing or cooling facility, they can accumulate large amounts of heat, especially if directly exposed to the sun. Temperatures of up to 49°C have been measured for tomatoes on the exposed, top layer of pallet bins during normal harvest operations in Florida (Showalter, unpublished). Kasmire et al. (1962) reported essentially the same for muskmelons. This can easily result in development of heat damage and sun scald (Kader et al., 1974; Ryall and Lipton, 1979). Solar injury can occur in a few minutes to an hour when the surface tissues of many vegetables reach 40–50°C, including, in addition to those mentioned above, snap beans (*Phaseolus vulgaris* L.), cabbage (*Brassica oleracea* L. Capitata Group), cauliflower (*B. oleracea* L. Botrytis Group), lettuce (*Lactuca sativa* L.), onions (*Allium cepa* L.), garlic (*Allium sativum* L.), peppers (*Capsicum annuum* L. Grossum Group), and potatoes (*Solanum tuberosum* L.). Solar injury can also occur from contact with the soil surface, which may reach 55–65°C by early afternoon (Ryall and Lipton, 1979). Potatoes are particularly prone to injury of this type. Symptoms of solar injury include softening, discoloration, and collapse of the affected tissues, as well as increased susceptibility to decay. Particularly insidious is the fact that the symptoms are not necessarily apparent until after packing, and the injured vegetables may become unmarketable during transit or after arrival in the marketplace.

Delays in the field cause greater deterioration in general because of high respiration rates, increased water loss, and the opportunity for infections to become established that will later result in decay. Nunes et al. (1995) showed that a 6-h delay at 30°C before forced-air cooling strawberries (*Fragaria* × *ananassa* Duchesne) to 4°C then storing them for 1 week at 1°C plus 1 day at 20°C resulted in 50% greater water loss, increased softening, poorer color, and greater losses of ascorbic acid (vitamin C) and sugars compared to fruit that were cooled immediately. Crisosto et al. (2001) found water loss (and associated stem browning) to be the major negative impact of field delays before cooling for grapes (*Vitis vinifera* L.). Mitchell et al. (1964) reported that as little as 2 h delay in the field at 29°C before cooling to 4°C resulted in noticeable reduction in the percentage of marketable strawberries, primarily due to more severe bruise symptoms and increased decay. Brennan and Shewfelt (1989) similarly found that a 3-h delay in the field at 17°C before slush-ice cooling broccoli (*B. oleracea* L. Botrytis Group) negatively affected head compactness, floret opening, turgor, and aroma during subsequent holding at 4°C and 65% relative humidity compared to a delay of less than 0.5-h before cooling.



Some temperature protection in the field can be achieved by shading the harvested vegetables. However, even a slight breeze can still cause harvested vegetables to quickly warm to the ambient air temperature (Fig. 3). A tarpaulin tightly covering a truckload of vegetables can act as a heat trap—resulting in even higher-than-ambient temperatures. Thus, it is advantageous to schedule harvesting operations for the cooler morning hours and to minimize delays between harvest and transport to the packing or cooling facility.

III. HARVEST STRATEGIES

A. Hand Harvest Versus Machine Harvest

Most fresh-market vegetables (i.e., those intended for fresh consumption) are harvested by hand. Vegetables intended for processing and some fresh-market vegetables that are less perishable and less easily injured are mechanically harvested (e.g., carrots [*Daucus carota* L.], potatoes, radishes [*Raphanus sativus* L. Radicula Group], and sweet potatoes [*Ipomoea batatas* (L.) Poir]). A person is better able than a machine to accurately select for color, size, shape, and freedom from defects and decay. People, generally, are also more capable of removing vegetables from the plant without inflicting injury compared with mechanical harvesters. However, supervision of hand-harvest operations is critical in minimizing injuries to the product. Improper picking procedures, rough handling during picking, collection or consolidation of the product, and overfilling of containers must be avoided.

B. Field Packing

Field packing systems are gaining popularity for a number of vegetables, partly due to reduced capital expenses compared with packinghouse facilities, but also due to other advantages such as reduced injuries to the products because of reduced handling. Field packing may mean that vegetables are placed directly into the shipping container by the picker as he moves through the field. Another option is to set up shaded packing tables at the ends of rows where the vegetables are collected, sorted, and packed. Mobile packing facilities (''mule trains'') are self-propelled packing units that move through the field along with the pickers, who place the vegetables on conveyors for sorting, grading, and packing by workers on the harvester. Field packing is mostly used for vegetables that do not require extensive sorting, sizing, trimming, and cleaning, and that do not need to be waxed or treated with fungicides after harvest. Cleaning is especially difficult, but some mobile packing systems carry water that is used to rinse and sanitize the product as it moves along the conveyor toward the packers. Because there is limited opportunity for additional quality inspection, it is critical that field-packing operations be well supervised. Vegetables that are commonly field-packed include most of the leafy and succulent crops such as lettuce, celery (*Apium graveolens* L. var. *dulce* [Mill.] Pers.), cabbage, broccoli, cauliflower, etc., and a number of immature and mature fruit-type vegetables such as snap beans, sweet corn, cucumbers (*Cucumis sativus* L.), squash (*Cucurbita* spp.), eggplants (*Solanum melongena* L.), melons, and vine-ripe tomatoes.

IV. TRANSPORT TO PACKINGHOUSE

Vegetables are typically transported by truck from the field to a packinghouse or cooling facility. Because of the detrimental changes that can occur during delays at high field temperatures noted above, it is better to transport small lots of produce from the field to the packing/cooling facility on a more frequent basis to minimize heat accumulation and water loss. Higher vegetable temperatures not only speed deterioration, but also increase cooling costs.

Vibration and bouncing of vegetable bins as they are moved within the field, and transport of loads from the field to the packing or cooling facility, can be major sources of mechanical injury (bruising). During transport of vegetables within and from the field, there are several steps that can be taken to reduce injuries and maintain quality. These include minimizing the distance that pallet bins are moved by forklifts, grading farm roads and avoiding rough public roads, reducing tire air pressure, using air suspension on transport trucks, and restricting transport speed. Bouncing and dropping cause impact bruises; compression bruises occur in overfilled buckets, lugs, and bins; and vibration causes impact and compression bruising (see Chap. 7).

V. PACKINGHOUSE OPERATIONS

A. Receiving

Vegetables delivered to the packinghouse should be processed as soon as possible. The same comments made with regard to delays in the field apply here. If vegetables cannot be packed immediately, ideally, there should be sufficient cooling and storage space so that they can be held at their proper storage temperature. More commonly, however, vegetables delivered to the packinghouse are consolidated in the shade while awaiting their turn to be run through the packing line.

Inspection of vegetables should take place as they are delivered to determine the incoming levels of defects, including undersize, immature/overmature, mechanical injury, disorders, decay, and appropriate feedback communicated to the harvest crew. Lidror and Prussia (1993) presented a sample receival inspection form for peaches (Fig. 4) and cited Kramer (1973) indicating that receival inspections are the most critical part of quality assurance for fruits and vegetables.

B. Dumping, Cleaning, and Washing

The first operation at the packinghouse as vegetables are processed is their transfer from bulk containers (typically pallet bins) onto the packing line. The goals of this operation should be to introduce the product onto the packing line at a uniform rate and with minimum injury. The rate at which dumping occurs is important because it determines the flow of vegetables through the packing line. The dump rate must be adjusted to accommodate the degree of sorting and grading that each lot of vegetables requires (the ''packout rate'') so that the packing line workers can most effectively

Peach Quality Control—on receiving.

Date ______________

Specifications: Size (diameter) ["]

Ground Color (chip #) [ ]

Crew (opt.) __________

Serious defects ______________

Sample size = *50*

Warning limit = *30* defectives, for under size only.
(sign W for warning, near to findings #).

				Findings			Marks		
Code (crew)	Arrival time	Bins		Under-size #	Under color #	Serious defects #	Under Quality	Quality value	Calculated bonus (%)
			1						
			2						
			3						
			4						
			5						
			6						
			7						
			8						
			9						
			10						

$$\text{Under quality} = \frac{\%\ \text{undersize}}{100} + \frac{\%\ \text{under color} + \%\ \text{serious defects}}{200}$$

Quality value = 1.00 − under quality

Calculated bonus = 20% × quality value (= % of additional payment)

Figure 4 An inspection form for receival inspection of produce (e.g., peaches) at the packinghouse. (From Lidror and Prussia, 1992.)

gondola to cause the vegetables to flow through a door in the side of the gondola and into the dump tank. The dump tank is a recirculating water system and, as such, is a critical point in a packinghouse sanitation program (see Chap. 23).

Vegetables are elevated from dump tanks by roller or chain conveyors to enter the packing line. They may be washed or rinsed next to remove sap, dirt, debris, and pesticide residues. A detergent wash with soft brushes or sponges is usually followed by a spray rinse with potable and/or chlorinated water. Even vegetables that are dry dumped are often rinsed before further packing line steps occur. After rinsing, excess water is removed from the vegetables by sponge rollers or by fans that blast the adhering water off the vegetable surface. Mature onions are never wetted, but rather are dry-brushed to remove loose, dry scales. Melons are also often dry-brushed only to remove field dirt.

C. Disease Control

For most vegetables, disease control is primarily a preharvest concern. Very few vegetables are treated with pesticides of any kind after harvest. By controlling pathogens in the field, growers minimize opportunities for postharvest decays to develop. Sanitation of water in dump tanks, spray rinses, and other hydrohandling operations is done to avoid cross-contamination of sound vegetables by microbes carried from the field, and is usually accomplished by chlorination (see Chap. 23). Since most postharvest vegetable rots occur in conjunction with breaks in the epidermal layer, careful harvesting to minimize mechanical injuries and efficient sorting on the packing line to remove injured vegetables also serve to minimize decay incidence.

D. Sorting, Grading, and Sizing

The next step on the packing line is usually a presizing or presorting operation in which trash and undersized or obviously defective individual vegetables are removed. Trash elimination and presizing (''undersize elimination'') are often mechanical steps. Trash, such as leaves, can be blown away through spaced rollers, and undersized items are usually allowed to drop through appropriately sized roller sizers or perforated belt sizers.

Sorting, grading, and sizing are interrelated operations on the packing line. Sorting implies selection or separation of vegetables according to one or more physical attributes, such as maturity, shape, or color, and may also include size when sizing is done manually by diameter or length. Grading is a type of sorting that involves separating vegetables by grades, usually related to legal labeling requirements such as those associated with the U.S. Department of Agriculture's Standards for Grades of Fresh Produce (USDA 2001) or various marketing orders. Grading usually precedes sizing in most packinghouses. If some proportion of the crop will be used for something other than fresh market (e.g., processed) or if different grades require separate packing procedures (e.g., mature-green versus vine-ripe tomatoes), it is more efficient to separate the vegetables by grade immediately after the washer.

E. Trimming

Leafy crops often need to have overmature or damaged outer leaves removed. Other vegetables may need to have unwanted stems or roots removed. Asparagus (*Asparagus officinalis* L.) spears may be trimmed at the butt end to achieve uniform lengths. Trimming may be part of the harvest operation, especially for field-packed vegetables, or it may be regulated by the Food and Drug Administration (FDA) in the United States (see Chap. 17). Some of the fruit-type vegetables, such as cucumbers, eggplants, bell peppers, summer squashes (*Cucurbita pepo* L.), and tomatoes may be coated with vegetable oil or mineral oil or a mineral oil-paraffin wax mixture. Cassava (*Manihot esculenta* Crantz) and jicama (*Pachyrrhizus erosus* Urban) roots are coated with paraffin wax by dipping them directly into heated vats of liquid wax.

G. Packing: Place Pack Versus Volume Fill (mechanical)

Many vegetables are wrapped or packed into consumer packages such as sleeves, bags, and trays. Some leafy and succulent vegetables and root vegetables harvested with tops attached (carrots and radishes) may be bunched using wire twists or rubber bands. The final packing line operation is the transfer of the vegetables into shipping containers. For most vegetables, this is a manual operation involving place packing the items in some regular pattern in the container. The patterns for individual vegetable crops may vary according to unit size and, especially in field-packing operations, these vegetables are often sized as part of packing. Container filling is automated by weight or volume for most of the vegetables packed in packinghouses. This includes filling consumer packages of small items like bags of radishes and clamshell trays of cherry tomatoes (*Lycopersicon esculentum* Mill. var. *cerasiforme*), as well as master containers of all but the largest fruit-type vegetables (i.e., melons, winter squashes), which are also place packed. Box fillers that automatically adjust the box height or angle as boxes are filled in order to minimize drop height have been shown to lower impact forces and reduce mechanical injury (Sargent et al., 1992).

VI. PACKAGING

A. Protection: Stacking Strength, Immobilization, and Moisture

Packages should be designed to protect the commodity from physical injury, to minimize contamination and/or infestation with soil, insects, fungi, etc., and to reduce losses from pilferage. The dimensions of shipping containers must be designed to contain the produce being packed without possibility of compression injury from overpacking. In other words, the container must bear the weight of upper layers of stacked containers, not the produce. The compression (i.e., stacking) strength of corrugated fiberboard containers must be sufficient to bear the weight of a pallet-height stack of produce, taking into account that fiberboard in equilibrium with 90% relative humidity has only 40% of its certified compression strength measured at 50% relative humidity. Most of a box's compression strength is in its corners. Therefore, reinforcing the corners of shipping containers can provide increased compression strength for less expense than increasing the fiber weight of the entire box. Unitizing the pallet load by strapping or netting helps keep the corners of adjacent boxes vertically aligned. Fiberboard that will come in direct contact with water needs to be surface-coated with a poly-wax emulsion or impregnated with wax for moisture resistance in order to maintain necessary stacking strength; however, waxed fiberboard is more expensive and presents some problems related to recycling. Returnable plastic containers are not affected by moisture.

Proper package design can also reduce impact and vibration bruising of vegetables. Impacts from dropping packages can be lessened by bottom and top cushion pads and cup trays. Besides their cushioning effect, these also serve to reduce mechanical injury by isolating and immobilizing individual vegetables. However, pads and trays also add cost to the packaging and may interfere with temperature management. Vibration bruising is most practically reduced by ensuring that the shipping containers are tightly filled in order to immobilize the produce. Unitized handling (palletization) greatly reduces individual shipping container handling and thus reduces the number of opportunities for impacts and impact bruising.

B. Exchange of Heat, Respiratory Gases, and Moisture

Proper temperature management requires good contact between the refrigerated air in the postharvest environment and the product in the package. Since package materials such as corrugated fiberboard can insulate the product from the environment, ventilation holes are necessary in most vegetable packaging. A longtime rule of thumb is that 5% ventilation of shipping container side or end panels is sufficient for rapid forced-air cooling and subsequent temperature management without overly weakening the package (Mitchell et al., 1972). However, positioning vent holes near the vertical edges (i.e., corners) of a box substantially reduces the stacking strength. Thus, vent holes should be positioned near the centers of the side and end panels or horizontal edges of the box. The location of the vent holes must be designed so that, when the boxes are stacked, the holes on adjacent boxes line up to allow air to flow through the boxes and over the produce inside. A venting design that facilitates efficient temperature management without compromising stacking strength is illustrated in Figure 5 for a shipping container designed for peppers (Talbot et al., 1992). Some shipping containers are intentionally designed without venting or with restricted venting, either to restrict heat exchange, as in packages used to slow product warming or protect it from freezing during air transport, or for package-ice-cooled vegetables.

Exchange of water vapor and respiratory gases between packed vegetables and the environment outside needs to also be considered when designing packaging. Water loss is something that, generally speaking, should be avoided, but this is usually better achieved by vegetable surface coatings and by maintaining high relative humidity levels in the postharvest environment than by adding plastic liners within shipping containers, which tend to interfere with proper temperature management and gas exchange. Modified atmosphere packaging (MAP) is a technique by which the exchange of respiratory gases is intentionally restricted using semipermeable plastic films, perforations, or microporous patches in order to achieve and maintain a beneficial combination of reduced O_2 and elevated CO_2 within the package (see Chap. 9). The packaging levels at which such MAP systems are applied include consumer packages, shipping containers, and pallet loads.

C. Efficient Handling: Unitization and Palletization

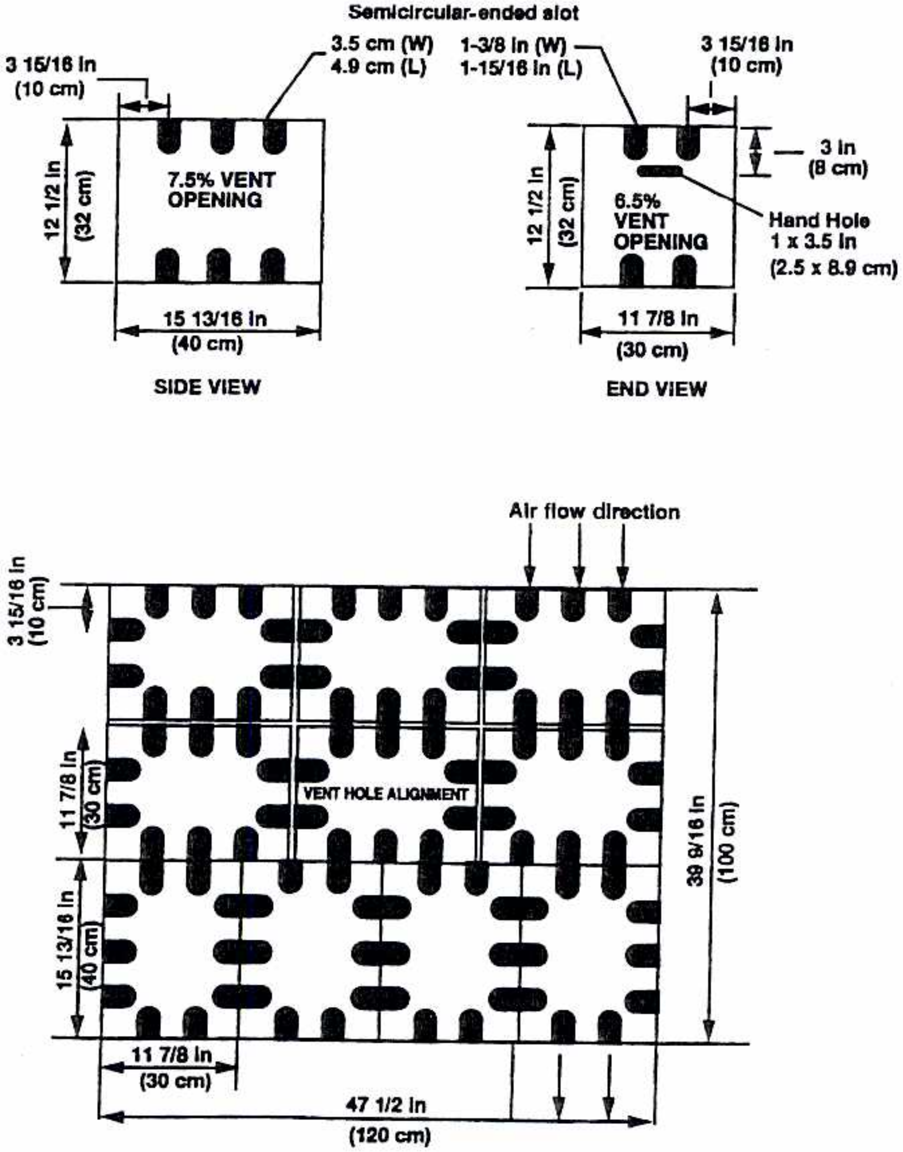


Figure 5 A shipping container designed for peppers with vent holes positioned at the upper and lower edges of the side- and end-panels showing alignment of the openings in a pallet load for optimal cooling. (a) Side and end views of a 40 × 30 cm container showing dimensions and percent vent openings. (b) Top view of pallet showing cross-stacked layer and matching vent openings. (Adapted from Talbot et al., 1992.)

side dimensions designed to cover 100% of the surface area on a pallet measuring 120 × 100 cm, approximately equal to the standard 40 × 48-in. pallet currently used in the United States. Depending on the base dimensions, these cartons can be stacked 5, 6, 8, or 10 containers per layer on the standard pallet. Those sizes that cannot be cross-stacked require strapping or netting to secure the pallet during handling and shipping.

Packages not only unitize products but also provide a vehicle for identification of the product (name, size, weight, grade, special treatments) and of the producers or shipper.

VII. PACKINGHOUSE DESIGN

A. Layout

A typical packinghouse consists of a receiving area, a packing line, a stacking or palletizing area, refrigerated storage rooms, and a loading dock. A logical packinghouse sequence, as illustrated in Figure 1 for tomatoes, moves sequentially and linearly through those five areas. A well-designed packinghouse should allow for the efficient flow of product through the various operations without backtracking or cross-traffic from forklifts. The main criterion to be determined before designing a packing line is the desired capacity of the line. This depends on the area of the conveying surface and the linear speed of the conveyors. A wider line (within reason—see Sec. VII.B) can handle larger capacities at slower speeds than a narrow line. Thus, a wider line allows for greater flexibility in grading, as well as allowing for increased capacity in the future. Ideally, a packing line should be as nearly linear and level as possible because of the negative effects of drops and turns in terms of mechanical injury to the product being packed.

If pallet bins from the field are to be held in cold storage, those storage rooms should be physically separate from the rooms used to hold the packed product in order to avoid cross-contamination by microbes. Similarly, the cull disposal area should be located outside the packinghouse structure and away from the loading dock to minimize the potential for contamination.

B. Ergonomics: Lighting, Belt Speed/Fill, and Grading Line Height

Sorting and grading (and manual sizing, if done) are the most labor-intensive operations in a vegetable packinghouse. Thus, ergonomics and management are critical considerations.

The following ergonomic considerations are necessary for efficient sorting and grading:

1. Ability to clearly view the product. Adequate lighting is essential. Each worker should be able to clearly see the entire product surface as it passes by. This means that roller conveyors that turn and rotate the vegetables as they move along the conveyor are preferable to a belt.
2. Minimize reaching and lifting. Cull elimination chutes should be positioned at the same height as the conveyor. Center belts used for diverting minor grades should be only as high as necessary to clear the fruit on the main conveyor. Belt width should allow

2. Each worker should have a specific responsibility and experienced workers should always be placed "downstream" from inexperienced workers.

Grierson et al. (1986) pointed out that there is a tendency for graders to remove a given number of items per minute, regardless of quality. However, the number of decisions per minute that need to be made by the graders is determined by packout rate, individual item size (number per unit belt area), and conveyor speed. Therefore, the packing line manager should be able to adjust the number of workers, the product volume (dump rate), and the conveyor speed so as not to exceed the maximum number of items per minute that the graders can either observe or pick up. An operational interlock and synchronized speed control system for the bin dump through grading conveyor, using a programmable control, on a tomato packing line was shown to significantly increase the number of cartons packed per hour (+35%) while reducing fruit impacts (and bruising), compared to the same packing line with only the bin dump rate being adjustable (Gilbert et al., 1992). This was because varying only the bin dump rate with a constant conveyor belt speed results in variable product densities on the line, while being able to vary the line speed along with the bin dump rate allows the manager to maintain maximum product density at any line speed. Maintaining full coverage of the conveyors causes gentler transfers by reducing roll and drop distances as the tomatoes cushion each other. At the same time, productivity is enhanced because the packing line speed can be quickly adjusted to match worker grading capabilities based on the quality of the tomatoes being packed.

C. Avoiding Injury: Drops, Transfers, and Shears

The initial transfer of vegetables onto the packing line with a dry dump can be very damaging unless the flow of vegetables from the pallet bin is controlled to avoid excessively high drops. This can be achieved simply by installing a curtain of belting material at the top of the dump unit frame so as to restrict the flow of product as the bin is tilted forward for dumping. A more effective solution is a pneumatic door covering the opening of the bin that slowly opens to allow the product to drop only from the front edge of the bin onto the receiving conveyor. The dump rate should be adjusted to maintain a relatively solid, single-layer deep flow of vegetables over the conveyers if possible, which minimizes injury from vegetable-to-vegetable and vegetable-to-equipment impacts (Sargent et al., 1992).

As vegetables move through the packing line, there are often many changes in elevation and direction as they are transferred from one piece of machinery to another. These transfers are one of the primary causes of mechanical injury during packing. The number and height of drops should be minimized and sloping transfer plates installed between conveyors so that the vegetables roll rather than drop from one conveyor to the next. Padding should be used wherever shears (i.e., turns) in the packing line cause vegetables to hit a wall. Damage at shears can also be reduced by keeping the shear angle to no more than 30°, sloping the lower edge of the shear toward the oncoming product, and sloping the belt about 5° in the exit direction to aid the flow of product (Grierson et al., 1986).

The speed of individual components on the packing line should be compatible in order to allow gentle transfers and thus avoid vegetables being launched from one packing line component to another. Curtains or counter rotating brushes with long, soft bristles can be placed above a conveyor perpendicular to the direction of product flow to moderate the flow and maintain a single layer of product. Center belts used for diverting minor grades should have a curtain hanging above the belt along its length to decelerate the vegetables when they are tossed onto the belt so that they do not hit the far side wall. When vegetables drop from one conveyor onto a lower, perpendicular conveyor as typically occurs during sizing, the support plate or rollers under the lower belt should be removed to avoid impact bruises. Modifications such as these were shown to reduce impact levels in tomato and bell pepper packing lines by over 50% (Sargent et al., 1992).

VIII. TRANSPORTATION

Most vegetables are not stored for any appreciable amount of time either because of their inherently short potential postharvest lives or because market conditions do not provide an economic incentive to store a crop—for most vegetables there are always fresher products entering the market from successive harvests or other growing regions. Thus, for most vegetables, the transportation period is the most significant ''storage'' period in their postharvest life. The rise of international marketing in perishable commodities has made transport periods of 2–4 weeks almost commonplace, severely challenging the ability of shippers and transporters and their equipment to maintain acceptable vegetable quality during posttransport marketing.

A. Loading/Stacking Patterns

The two types of air delivery systems used in truck trailers and marine containers require very different loading patterns in order to efficiently manage air-flow and temperature in transit. Truck trailers use top-air delivery, in which the air is discharged from the refrigeration unit in the front of the trailer, blown along the top of the load to the back of the trailer, then forced around the outside of the load (down the back and sides of the trailer) and back through and under the load to return to the refrigeration unit. Airflow through the load is through air channels created by the stowage pattern. A solid front return-air bulkhead with a space open near the floor forces the returning air to move to the return-air side of the fan. An air delivery chute delivers most of the supply air to the rear of the load, facilitating more uniform air distribution. The load in a top-air delivery unit should be loaded toward the center of the trailer, leaving space between the product and the sides and back of the trailer. This facilitates the intended air-flow pattern and also reduces the effect on the load of heat infiltration through the trailer walls. The load is stabilized with air bags, blocks, and other bracing devices to keep the load from shifting and blocking the side or rear spaces. If the intended front-to-rear and back under-and-through the load circuit is blocked, most of the refrigerated air will circulate over the top of the load and back to the refrigeration unit without cooling the load.

Marine containers use bottom-air delivery, in which the air-flow is almost the opposite of a top-air delivery system. The fans in bottom are cross-stacked (containers on alternating layers turned 90°) or stacked in register (corners aligned vertically). The space under the load acts as a plenum, and by stacking the load to a consistent height, uniform air-flow is encouraged. The greater air-flow, more even air distribution, and shorter air channels in bottom-air delivery systems result in better temperature management than for top-air delivery systems.

B. Equipment Features

There are several desirable features that both truck trailers and marine containers should have. These include a high capacity fan, a solid return-air bulkhead, a deep channel floor, and grooved walls to reduce the amount of heat conducted to or from the load. Discharge-air temperature sensor control is preferable to return-air sensor control (if only one sensor) because this ensures that the coldest air—that being discharged from the refrigeration unit—does not drop below the set point. Shippers should supply their own portable temperature recorders to generate temperature data for their own records and protection. The best location for a portable temperature-recording device is near the air discharge from the refrigeration unit. Some miniaturized temperature recorders are now available that can be easily placed along with the product in cartons to monitor load temperatures. Other desirable features in truck trailers and marine containers include dual discharge-return-air temperature controls, microprocessor controllers with diagnostic features to measure and control discharge- and return-air temperatures and document refrigeration unit performance, automated fresh air exchange, and temperature probes for cargo temperature recording. Some marine containers are equipped to modify and control the O_2 and CO_2 levels within the container via modified atmosphere systems that use product respiration to maintain a desirable atmosphere in sealed load or controlled atmosphere systems that actively monitor and adjust the atmosphere.

C. Mixed Loads

Mixed loads of vegetables, or vegetables transported with fruits, create a unique set of problems and generally require some level of compromise in selection of the ''best'' (i.e., least damaging) temperature. In mixed loads, several product compatibility factors must be considered. The most important is temperature compatibility, primarily related to chilling sensitivity (see Chap. 19 for chilling threshold temperatures of specific vegetables). It is necessary to consider the requirements of the most chilling-sensitive commodity in a mixed load when choosing the thermostat setting. In some cases, it may be possible to use a slightly lower temperature than the highest chilling threshold temperature if the length of the transit time is taken into account and judged to be short enough to allow a lower thermostat setting without danger of inducing chilling injury. In most cases, the requirements of the most perishable or the most valuable commodity (often the same) in a load have to be considered in arriving at a compromise temperature.

Another important compatibility factor to be considered is ethylene production and sensitivity to ethylene exposure. Care must be taken not to ship ripening climacteric fruits (avocados [*Persea americana* Mill.], bananas [*Musa acuminata* Colla], pome fruits [*Malus* spp.], stone fruits [*Prunus* spp.] except cherries [*P. avium* L.], tomatoes, and muskmelons) with vegetables that may be damaged by ethylene (leafy and succulent vegetables, especially lettuce, and immature fruit-type vegetables). Nevertheless, such mixtures still do occur and ethylene absorbents are usually packed in the load to reduce ethylene levels in such mixed loads. Odor volatiles produced by some crops (e.g., onions and garlic) are readily absorbed by some other crops, causing those crops to have an objectionable aroma and become unmarketable.

Moisture compatibility is important for those vegetables such as onion, garlic, ginger (*Zingiber officinale* Roscoe), and pumpkin and winter squash (*Cucurbita pepo* L.) that do not tolerate high humidity and liquid water. This becomes a more important consideration as transit time increases. Cartons containing package ice should obviously not be stacked above unwaxed cartons or cartons containing crops that do not tolerate exposure to water.

In some cases, using MA or CA or packaging products in MA packages can provide some added measure of protection against compromise low temperatures or ethylene effects by reducing chilling sensitivity or ethylene sensitivity and production (see Chaps. 9 and 19). This is currently being researched, and it will be some time before reliable recommendations for specific commodity mixtures and beneficial atmospheres are available. However, this appears to be a promising approach for application of MA/CA/MAP technology. A technique for designing a combination CA/MAP system to maintain optimal atmosphere conditions throughout the postharvest handling chain has been described (Silva et al., 1999).

Detailed information on compatibility of produce with regard to transport can be found in Thompson et al. (2000).

IX. COMMODITY TREATMENTS

A. Ripening

Ripening continues after harvest for the climacteric fruit-type vegetables: muskmelons, peppers, and tomatoes. The temperature range of 15–25°C is most conducive to ripening, but in most cases these vegetables are handled at lower temperatures in order to slow ripening during transportation and marketing. Mature green tomatoes are commonly treated and honeydew melons are occasionally treated with ethylene, usually at the packinghouse level, to initiate and coordinate ripening.

B. Curing

Curing is a simple and effective way of reducing water loss and decay during subsequent storage of onions, garlic, potato, sweet potato, and other tropical underground storage organs, and also winter squashes (Ryall and Lipton, 1979). Curing of onions and garlic is strictly a process of drying the outer scales of the bulbs, which then become a barrier to water loss and infection by microorganisms. This is done in dry regions by leaving harvested onions and garlic in the field in windrows for a few days, or by using

Table 2 Vegetables for Which Methyl Bromide Is Approved as a Quarantine Treatment in the U.S.A. and Targeted Insects

Commodities	Targeted insects
Asparagus	Red-legged earth mite,[a] *Noctuidae* spp., *Thrips* spp., *Copitarsia* spp.[b]
Beans (snap, string)	*Maruca testulalis*, *Epinotia aporema*, *Cydia fabivora*
Cabbage[b]	Surface feeders
Cantaloupe[b]	Surface feeders, external feeders
Carrot[b]	External feeders
Cassava[b]	External feeders
Celery[b]	Surface feeders
Chayote[b]	Surface feeders
Chicory[b]	Not specified
Cipollini	*Exosoma lusitanica*
Corn[a]	Not specified
Cucumber[b]	Not specified
Dasheen (malanga)[2]	External and internal feeders
Endive[b]	Surface feeders
Faba bean	Bruchidae[b]
Garlic	*Brachycerus* spp. and *Dyspessa ulula*
Ginger[b]	External and internal feeders
Horseradish	Imported crucifer weevil
Leafy vegetables	Surface feeders[b]
Melons (honeydew, muskmelon, watermelon)	Surface feeders such as *Noctuidae* spp., *Thrips* spp., *Copitarsia* spp.
Okra	Pink bollworm
Onion	Internal feeders[b]
Potato[a]	*Graphognathus* spp., *Ostrinia nubilalis*, *Phthorimaea operculela*
Pumpkin	Surface feeders[b]
Squash (summer, winter, zucchini)[b]	Surface feeders
Sweet potato	Surface feeders[b]
Tomato	Fruit flies
Yam	Internal feeders[b]

[a] Mentioned in 1985 PPQ Treatment Manual only.

[b] Mentioned in 1992 PPQ Treatment Manual only.

Source: From Brecht, 1994.

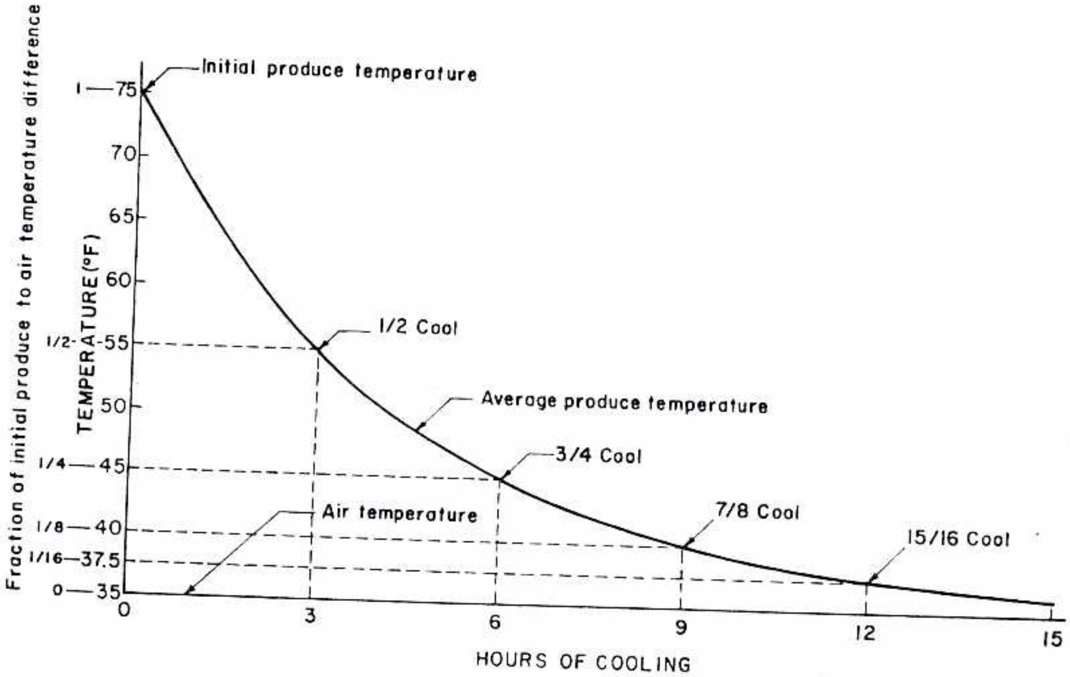


Figure 6 Cooling curve showing ⅞ cooling time of 9 h. (From Mitchell et al., 1972.)

C. Disinfestation (insect quarantine)

Although more attention is generally paid to quarantine issues involving fruits, a number of vegetables are also subject to quarantine for various insect pests (Table 2). The primary treatment available for these vegetable crops and their associated insect pests has been methyl bromide, the use of which is to be phased out by 2005 (US EPA, 1993). The only other significant quarantine treatment that is available for vegetables is vapor heat, which is approved for control of fruit flies on eggplant, pepper, squash, and tomato (USDA, 1992). Methyl bromide fumigation can be done using temporary facilities or even under a tarpaulin (USDA, 1992), but vapor heat treatment requires dedicated, permanent facilities. The search for alternative insect quarantine treatments for vegetables is focusing more and more on treatments such as hot water and combination treatments (heat-cold, heat-CA, etc.) that can be incorporated into existing vegetable handling systems or that can be applied in transit (Brecht, 1994).

X. COOLING AND TEMPERATURE MANAGEMENT*

vacuum cooling, that the difference between the product temperature and the intended storage temperature is reduced by ⅞. The time required to remove ⅞ of the field heat is known as the *⅞ Cooling Time*. Removal of ⅞ of the field heat during cooling is strongly recommended to provide adequate shipping life for shipment to distant markets; also, ⅞ of the heat can be removed in a fairly short amount of time. Removal of the remaining ⅛ of the field heat will occur during subsequent refrigerated storage and handling with little detriment to the product.

The rate of heat transfer, or the cooling rate, is critical for efficient removal of field heat in order to achieve cooling. As a form of energy, heat always seeks equilibrium. In the case of cooling, the sensible heat (or field heat) from the product is transferred to the cooling medium. The efficiency of cooling is dependent on time, temperature, and contact. In order to achieve maximum cooling, the product must (a) remain in the precooler for sufficient time to remove the heat; (b) the cooling medium (air, water, or ice) must be maintained at constant temperature throughout the cooling period; and (c) the cooling medium also must have continuous, intimate contact with the surfaces of the individual vegetables. For reasonable cooling efficiency, the cooling medium temperature should be at least at the recommended storage temperature for the commodity found in Table 3. Inappropriately designed containers with insufficient vent or drain openings or incorrectly stacked pallets can markedly restrict the flow of the cooling medium, increasing cooling time.

A. Cooling Methods

1. Room Cooling

The simplest, but slowest, cooling method is room cooling, in which the bulk or containerized commodity is placed in a refrigerated room for several days. Air is circulated by the refrigeration system fans past the evaporator coil to the room. Vented containers and proper stacking are critical to minimize obstructions to air-flow and ensure maximum heat removal. Room cooling is not considered precooling and is satisfactory only for commodities with slow respiration rates, such as mature potatoes, dried onions, and cured sweet potatoes. Under certain circumstances these latter crops may require precooling, such as when harvested under high ambient temperatures.

2. Forced-Air Cooling

The cooling efficiency of refrigerated rooms can be greatly improved by increasing the air-flow through the product. This principle led to the development of forced-air, or pressure cooling, in which refrigerated room air is drawn at a high flow rate through specially stacked containers or bins by means of a high-capacity fan. This method can cool as much as four times faster than room cooling. In many cases, cold storage rooms can be retrofitted for forced-air cooling, which requires less capital investment than other precooling methods. However, in order to achieve such rapid heat removal, the refrigeration capacity of the room may need to be increased in order to be able to maintain the desired cooling air temperature.

With either room cooling or forced-air cooling, precautions must be taken to minimize water loss from the product load. A refrigeration system dehumidifies cold-room air as water vapor in the air condenses on the evaporator coil. This condensation lowers the relative humidity in the room, creating a greater water vapor pressure deficit between the product and the surrounding air. As a result, the product loses moisture to the air. To torage Conditions and Cooling Methods for Maximum Postharvest Life of Vegetables

	Temperature °C	Relative humidity (%)	Approximate storage life	Cooling methods^a
	0	95–100	2–3 weeks	HY, ROOM
	−0.5–0	90–95	4–5 months	ROOM
	0–2	95–100	2–3 weeks	HY
	4–10	40–50	6–10 months	ROOM
	4–7	95	7–10 days	HY, FA
	3–5	95	5–7 days	HY
	0	95–100	7–9 days	ROOM
	0	98–100	10–14 days	HY
	0	98–100	4–6 months	ROOM
	0	95–100	10–14 days	HY, ICE
	0	95–100	3–5 weeks	HY, VAC
	0	98–100	3–6 weeks	ROOM
	0	98–100	5–6 months	ROOM
	0	95–100	2–3 months	HY, VAC
	0	95–100	2 weeks	HY
	0	98–100	7–9 months	HY
	0	98–100	4–6 weeks	HY
	0–5	85–90	1–2 months	ROOM
	0	95–98	3–4 weeks	HY, VAC
	0	97–99	6–8 months	ROOM
	0	98–100	2–3 months	HY, VAC
	0	95–100	10–14 days	HY, ICE, VAC
	7	85–90	4–6 weeks	ROOM
ve	0	95–100	2–4 weeks	HY, ICE, VAC
	0	95–100	10–14 days	HY, ICE, VAC
	0	95–98	5–8 days	HY, ICE, VAC
	10–13	95	10–14 days	HY
	8–12	90–95	1 week	FA
	0	95–100	2–3 weeks	HY, ICE, VAC

Table 3 Continued

Commodity	Temperature °C	Relative humidity (%)	Approximate storage life	Cooling methods[a]
Garlic	0	65–70	6–7 months	ROOM
Ginger	13	65	6 months	ROOM
Greens (collards, kale, mustard)	0	95–100	10–14 days	HY, ICE, VAC
Horseradish	−1.0–0	98–100	10–12 months	ROOM
Jicama	13–18	65–70	1–2 months	ROOM
Kale	0	95–100	2–3 weeks	HY, ICE, VAC
Kohlrabi	0	98–100	2–3 months	ROOM
Leek	0	95–100	2–3 months	HY, ICE, VAC
Lettuce	0	98–100	2–3 weeks	VAC
Malanga[b]	10	90–95	4–5 months	ROOM
Melons				
Cantaloupe (¾-slip)	2–5	95	15 days	FA, HY
Cantaloupe (full-slip)	0–2	95	5-14 days	FA, HY, ICE
Casaba	10	90–95	3 weeks	ROOM
Crenshaw	7	90–95	2 weeks	ROOM
Honeydew	7	90–95	3 weeks	ROOM
Persian	7	90–95	2 weeks	ROOM
Watermelon	10–15	90	2–3 weeks	ROOM
Mushroom	0	95	3–4 days	FA, VAC
Okra	7–10	90–95	7–10 days	FA
Onion, green	0	95–100	3–4 weeks	HY, ICE
Onion, mature bulb[b]	0	65–70	1–8 months	ROOM
Onion sets	0	65–70	6–8 months	ROOM
Parsley	0	95–100	2–2.5 months	HY, ICE
Parsnip	0	98–100	4–6 months	ROOM
Pea, green	0	95–98	1–2 weeks	HY, ICE

4–5	95	6–8 days	HY
0–10	60–70	6 months	ROOM
7–13	90–95	2–3 weeks	FA
4	90–95	4–5 months	HY, ROOM
4	90–95	5–10 months	ROOM
10–13	50–70	2–3 months	ROOM
0	95–100	3–4 weeks	HY
0	95–100	2–4 months	ROOM
0	95–100	2–4 weeks	HY, ROOM
0	98–100	4–6 months	ROOM
0	95–98	2–4 months	ROOM
0	95–100	10–14 days	ICE, HY, VAC
5–10	95	1–2 weeks	FA, HY
10	50–70	Depends on type	ROOM
0	90–95	5–7 days	FA
13–16	85–90	4–7 months	ROOM
3–4	85–95	10 weeks	ROOM
7–10	85–90	4–5 months	ROOM
13–21	90–95	1–3 weeks	FA, ROOM
8–10	90–95	4–7 days	FA, ROOM
0	95	4–5 months	ROOM
0	95–100	10–14 days	HY, ICE, VAC
0–2	98–100	1–2 months	ROOM
0	95–100	2–3 weeks	HY, ICE, VAC
16	70–80	6-7 months	ROOM

hydrocooling; ICE = package ice or slush Ice; ROOM = room cooling; VAC = vacuum cooling.

n storage. "Curing" of dry onions actually involves drying the outer bulb scales, reducing the fresh weight by 5 to 6%.

et al., 1986, and Ryall and Lipton, 1979.

minimize water loss during cooling and storage, the ambient relative humidity should be maintained at the recommended level for the particular crop (Table 3), and the product should be promptly removed from the forced-air precooler upon achieving 7/8 cooling. Forced-air cooling is recommended for most fruit-type vegetables and is especially appropriate for vegetables such as peppers and tomatoes that are susceptible to infiltration of waterborne organisms.

3. Hydrocooling

Hydrocooling removes heat at an even faster rate than forced-air cooling. The heat capacity of refrigerated water is greater than that for air, which means that a given volume of water can remove more heat than the same volume of air at the same temperature. Hydrocooling is beneficial in that it does not remove water from the commodity. It is most efficient (and, therefore, most rapid) when individual vegetables are cooled by immersion in flumes or by overhead drench, since the water completely covers the product surfaces. Cooling becomes less efficient when the commodity is hydrocooled in closed containers, and even less efficient when containers are palletized and hydrocooled. It is important to continuously monitor the hydrocooler water and product temperatures and adjust the residence time of the product in the hydrocooler accordingly to achieve thorough cooling.

Sanitation of the hydrocooling water is critical, since it is recirculated. Decay organisms present on vegetables can accumulate in the water, inoculating subsequent product being hydrocooled (see Chap. 23). Cooling water should be changed frequently. Commodities that are hydrocooled must be sufficiently resistant to withstand the force of the water drench. The container must also have sufficient strength so as to resist application of water. Crops recommended for hydrocooling include sweet corn, snap beans, cucumbers, and summer squash.

4. Ice Cooling

Ice is used for both cooling and temperature maintenance during shipping. Prior to the development of vacuum cooling, ice distributed between layers of product was the primary cooling method for many leafy and succulent vegetables. When ice melts, 80 kcal of heat energy are absorbed for each kg of ice melted. Heat from the product is absorbed by the ice, causing the ice to melt. As long as the contact between the ice and produce is maintained, cooling is fairly rapid, and the melted ice serves to maintain a very high humidity level in the package, which keeps the produce fresh and crisp. Nonuniform distribution of ice reduces the cooling efficiency.

There are two types of ice cooling: top icing and package icing. Top icing involves placement of crushed ice over the top layer of product in a container prior to closure. Although relatively inexpensive, the cooling rate can be fairly slow since the ice only directly contacts the product on the top layer. For this reason, it is recommended that top icing be applied after precooling to crops with lower respiration rates such as leafy vegetables and celery, but not for fruit of warm season crops. Prior to shipping, ice is blown on top of loaded truck trailers to aid in cooling and maintenance of higher relative humidity. However, care should be taken to avoid blockage of vent spaces in the load; this restricts air-flow, which results in warming of product in the center of the load during shipment. Ice should also be tempered with water to bring the temperature to 0°C to avoid freezing of the product.

Package icing involves the use of crushed ice distributed within the shipping container to cool the contents. Package icing cooling is faster and more uniform than for top icing, but it can be more labor-intensive to apply. A modified version of package icing utilizes a slurry of refrigerated water and finely chopped ice drenched over bulk or containerized produce or injected into side handholds. This ''slush ice'' method has been widely adopted for commodities tolerant to direct contact with water and requiring storage at 0°C. The water acts as a carrier for the ice so that the resulting slush, or slurry, can be pumped into a packed container. The rapidly flowing slush causes the product in the container to float momentarily until the water drains out the bottom. As the product settles in the container, the ice encases the individual vegetables by filling air voids, thus providing good contact for heat removal. Slush icing is somewhat slower than forced-air cooling, but it does effectively reduce pulp temperatures to 0°C within a reasonable amount of time and maintains a high relative humidity environment. Container selection is critical. The container must be oversized to accommodate sufficient ice to provide cooling. Corrugated fiberboard cartons must be resistant to contact with water (usually impregnated with paraffin wax) and must be sufficiently strong to prevent deformation. Shipping operations must also tolerate water dripping from the melting ice during handling and storage. Package icing is successfully used for leafy crops, sweet corn, green onions (*Allium cepa* L.), and muskmelons.

5. Vacuum Cooling

Vacuum cooling is a very rapid method of cooling, and is most efficient for commodities with a high surface-to-volume ratio. This method is based on the principle that, as the atmospheric pressure is reduced, the boiling point of water lowers. The phase change from liquid water to water vapor requires 540 kcal/kg of water. The field heat of the vegetables provides the energy for evaporation of the water. This also means that there is about 0.2 g of water lost per kg of product for every 1°C of cooling. Because water is removed uniformly throughout the product, it does not tend to result in visible wilting of vacuum-cooled vegetables.

In commercial practice, containerized or bulk product is thoroughly wetted before being placed in a vacuum chamber (tube) and sealed. The pressure in the chamber is reduced until the water on the product surface boils at the desired precooling temperature. As water on the product surface evaporates, it removes field heat; the resultant vapor is condensed on evaporator coils within the vacuum tube to maintain a low external water vapor pressure and increase cooling efficiency. This procedure minimizes the amount of water lost from the product tissues. Precautions must be taken so as not to cool the products below their freezing point temperature. Vacuum coolers are costly to purchase and operate and are normally used only in high-volume operations or are shared among several growers. Commodities that can be readily cooled by vacuum cooling include leafy crops, such more, slush ice continued to cool the sweet corn at a relatively fast rate after it was transferred to cold rooms or truck trailers compared to hydrocooled corn, which cooled slowly (i.e., room cooled).

B. Storage/Transport Temperature Control

Temperature control in storage rooms and transportation vehicles means more than just maintaining the air leaving the refrigeration coils at the desired temperature for the commodity being held; the goal of temperature management in vegetable storage rooms and transportation vehicles should be to maintain uniform *product* temperature (within 1°C) throughout the load at the desired temperature for the commodity being held. The first step in achieving this goal is thorough precooling (as described in the previous section) so that the vegetables are already at or near the desired storage temperature when they are loaded into the room or vehicle. This avoids placing excessive demands on the refrigeration system beyond those for which it was designed. When relatively warm produce is loaded, hot spots will inevitably develop as produce in different locations cools at different rates due to variation in exposure to cooling air. The worst case is when respiratory heat is able to build up in certain locations, causing the product temperature to increase. This is an all-too-common occurrence in truck trailers and marine containers, for which the refrigeration systems are easily overtaxed. The storage room or transportation vehicle also must be cooled to the desired product temperature prior to loading. However, transportation vehicles that are loaded from an open (i.e., unrefrigerated) dock should not be cooled below the ambient air dew point and their refrigeration unit should be turned off during loading to avoid condensation, which can weaken fiberboard boxes and cause icing of the evaporator coils. Designing the storage or transportation system with sufficient insulation in the floors, walls, and ceilings to minimize outside environmental influences is also necessary to maintain uniform temperature inside.

Adequate and uniform air circulation is also necessary for maintaining uniform product temperature. A rule of thumb for air-flow is 0.06 to 0.12 $m^3 s^{-1}$/ton of produce capacity to maintain produce temperature (Thompson, 1992). These rates of air movement require that the produce be loaded in such a way that air flows uniformly past all the pallets or containers. Load patterns should allow air to contact at least two sides of each pallet and the pallets should not contact the walls. An exception is marine containers with bottom-air delivery, which are loaded in a solid block covering the entire floor, with air-flow directed through venting in the individual boxes, much like forced-air cooling. Because air follows the path of least resistance, nonuniform load patterns allow refrigerated air to short-cycle back to the refrigeration unit, bypassing some portion of the load. This can be particularly serious in truck trailers and marine containers, because part of the load may receive no refrigerated air-flow at all if the air-flow is short-circuiting or the path for air to return to the refrigeration unit is blocked.

XI. HUMIDITY CONTROL

In addition to maintaining storage rooms and transportation vehicles at proper storage temperatures, the relative humidity should also be controlled to reduce water loss from the crop. Temperature management and humidity control are closely related. Rapid cooling reduces water loss because as the vegetable temperature approaches the refrigerated air temperature, the difference in water vapor pressure between the vegetable tissue and the

Table 4 Cooling Rates and Moisture Loss for Bell Peppers with Several Air Velocities[a]

Air velocity ($m\ s^{-1}$)	Cooling time to 7.2°C (h)	Moisture loss (%)
0.023	14.5	1.25
0.054	6.0	0.53
0.118	3.5	0.24
0.445	1.5	0.20
2.012	0.75	0.20

[a] Initial fruit temperature: 32.2°C; air temperature: 1.7°C; relative humidity: 90%.

Source: Adapted from Gaffney and Baird, 1977.

air (the vapor pressure deficit) is less. The faster the vegetables reach the storage air temperature, the less water is lost to the air during cooling. Thus, significantly less water is lost when vegetables are forced-air cooled than when they are room cooled with air of the same relative humidity (Table 4). The lower the storage temperature, the easier it is to maintain the air in a saturated state and thus minimize water loss because the moisture holding capacity of air is less at lower temperatures. Chilling sensitive vegetables that require storage temperatures >10°C are therefore more likely to require supplemental humidification in storage rooms and transportation vehicles. Refrigeration design has an important effect on humidity management because wide fluctuations in storage room or transportation vehicle air temperatures can increase water loss, as can poorly designed refrigeration systems that do not allow a sufficiently small difference in temperature (ΔT) across the evaporator coils. Temperature fluctuations above and below the dew point temperature of the air result in repeated condensation events that dry the air and increase water loss from the plant tissues (see Chap. 5). Loading storage rooms and transportation vehicles with precooled product reduces water loss by helping to minimize the cooling coil-air temperature difference. Minimizing fresh-air exchange in transportation vehicles also helps to maintain higher humidity levels.

Because most vegetables should be kept at >90% relative humidity, mechanical humidification systems are sometimes necessary. This is especially so for chilling sensitive vegetables, because their higher optimum storage temperatures make it more difficult to maintain such high humidity levels without supplemental moisture. The humidification system should be able to maintain uniform (within 2–3%) humidity levels and be designed to distribute the moisture uniformly throughout the storage space. This will minimize problems of high humidity and condensation leading to weakening of fiberboard boxes

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