Chapter 18.
Handling, Cooling and Sanitation Techniques for Maintaining Postharvest Quality[1]

S.A. Sargent, M.A. Ritenour, J.K. Brecht and J.A. Bartz[2]

More than half of Florida-grown vegetables are shipped out of state, and an increasing amount is being exported to Canada, the Caribbean, Europe and the Pacific Rim countries. To successfully compete in these distant markets, Florida shippers must overcome the detrimental effects of longer shipping times on produce quality. With such a dependence on distant markets, packers and shippers are necessarily concerned with methods and technologies that minimize postharvest losses, since estimates for produce losses during wholesale and retail handling alone range from 9% to 16%.

Successful postharvest handling of vegetable crops requires careful coordination and integration of the various steps from harvest operations to consumer level in order to maintain the initial product quality. **Horticultural quality** refers to those characteristics that consumers associate with each commodity and which are dependent upon the particular end-use, such as sweetness in strawberries and melons, tenderness in snap beans and sweetcorn, and crispness in carrots and celery. Quality also refers to freedom from defects such as blemishes, mechanical injury, physiological disorders, decay, and water loss. It is important to keep in mind that quality loss in fresh vegetables is cumulative: each incident of mishandling reduces final quality at consumer level.

Several factors reduce quality during postharvest handling, including:

- harvest at the incorrect maturity stage
- careless handling at harvest and during packing and shipping
- poor sanitation
- delays to cooling or sub-optimal cooling
- shipping/storage above or below optimal temperature
- lack of proper relative humidity
- for some sensitive commodities, exposure to ethylene gas

Numerous technologies and procedures can significantly reduce the rate of quality losses during handling. These include the use of drying, curing, temperature conditioning, disinfestation (for exports/imports), ethylene treatment, application of surface coatings, sanitation treatments, controlled atmosphere storage and shipping, and modified atmosphere packaging. These applications are, in many cases, crop-specific.

Two of the most critical means for maintaining vegetable quality during postharvest handling are minimizing mechanical injury and managing temperature. Proper handling and temperature management will significantly reduce losses due to decay and accelerated senescence. Since vegetables are typically handled several times from harvest to retail level, personnel handling the crop must be properly trained and supervised.

This chapter will focus on methods and techniques for reducing losses in postharvest quality during typical commercial handling operations.

MINIMIZING POSTHARVEST LOSSES

Vegetables undergo a number of transfers during harvest, handling, packing and shipping operations. Each of these transfer points has the potential to reduce quality and therefore, subsequent postharvest life, by inflicting injuries such as bruises, cuts, punctures and abrasions or inoculating the product with microorganisms that cause decays. Mechanical injury has been determined by the USDA to be the leading cause of quality loss at wholesale and retail levels for head lettuce, potatoes and strawberries. In contrast, the primary cause of losses for Florida and California tomatoes at retail and consumer levels was microbial decay. However, there is a strong linkage between mechanical injury and decay since the predominant causal organisms for the decays found at retail and in the home were those that require mechanical injury and/or internalization (introduction into air spaces between cells within the fruit) for infection to occur. Minimizing mechanical injury, therefore, should be one of the primary goals of produce handlers during postharvest operations. Additionally, steps should be taken to minimize the likelihood of water uptake by the product since that route is most likely to lead to an internalization of microbes into the plant tissues.

Following harvest, vegetables lose firmness due to senescence processes, ripening, and water loss. As a result, they become increasingly susceptible to mechanical injury.

This document is HS719, Horticultural Sciences Dept., UF/IFAS, Fla. Coop. Ext. Serv., September, 2007

Table 1. Incidence and severity of internal bruising in 'Solar Set' tomatoes as affected by ripeness stage and drop height. Tomatoes were dropped twice, once each on opposite sides.

Green Stage				Internal Bruising Severity Rating (%)[y]		
cm	inches	Number of Tomatoes	Fruit with Internal Bruising (%)[z]	slight	moderate	severe
0	0	20	0.0	0.0	0.0	0.0
10	4	20	5.0	0.0	0.4	0.0
20	8	20	5.0	5.4	0.7	0.0
30	12	20	45.0	0.0	8.5	1.8
Breaker Stage						
0	0	15	0.0	0.0	0.0	0.0
10	4	15	73.0	0.0	10.4	5.5
20	8	15	100.0	0.0	22.2	6.7
30	12	15	100.0	0.0	8.2	24.3

[z] Calculated from number of fruit with at least one locule showing moderate or severe internal bruising.

[y] Calculated using the number of locules for each severity rating divided by the total number of locules with seeds for that fruit.

In controlled laboratory studies we have found that tomatoes are quite sensitive to a physiological disorder known as internal bruising. Internal bruising is a latent disorder, which means that it only becomes apparent after the tomato reaches the full-red ripeness stage. It develops when a tomato receives an impact above the locule during harvest or handling. The impact disrupts normal ripening in the locular gel, and at full ripeness stage, the gel is a cloudy, yellowish-green color instead of a clear and red color. Round-type tomatoes dropped at breaker ripeness stage (<10% red color) developed more internal bruising than those dropped at green stage. Of breaker stage tomatoes dropped once from 10 cm (4 inches) onto an unpadded surface, 73% later showed internal bruising, whereas only 5% of tomatoes dropped at green stage developed the disorder (Table 1). This information should be applied to the design of packing lines since tomatoes typically receive multiple drops in excess of this height during handling and packing operations.

Mechanical injuries hasten senescence and ripening as well as provide infection sites for decay organisms (Fig. 18-1). Therefore, vegetables must be carefully handled during harvest, packing and shipping operations to minimize bruising, cuts, punctures and abrasions. Sorting and grading operations are also critical; workers must be thoroughly trained and supervised to ensure removal of injured vegetables, which could later develop decay during shipping. Sources of mechanical injury in several handling operations follow.

Harvest Operations

Harvest operations require the use of appropriate harvest containers and constant management of labor. Workers should be instructed to use appropriate harvest techniques according to the crop, and be constantly monitored to verify proper handling. There should be a system to reward workers for careful handling. Harvest containers, bulk bins and/or gondola wagons should have smooth sides and be kept free of debris, being cleaned and sanitized prior to each reuse. Farm lanes should be kept level and field trucks should be equipped with air suspension instead of spring suspension to dampen vibrations and reduce impacts during transport.

Packing Operations

Methods of transferring product from one component to another on a packing line also influence the incidence of mechanical injury. Minimizing drops and rolls at these transfer points is one of the most effective means for avoiding unnecessary injuries. To achieve this, packing lines should be designed to be straight and have minimal changes in height between components. Overhead brushes or hanging curtains slow crop speed at transfer points; installation of suspended curtains over conveyor belts on sorting tables can reduce impact forces by 50%. Container filling is also a critical operation. Produce can be crushed during closure of an overfilled container and punctured during stapling of cartons, while under-filling of the container can result in severe abrasion or bruising due to jostling during shipping and handling. Packing line workers should trim fingernails and wear disposable gloves during sorting/grading operations, and should be properly supervised to ensure that they practice gentle handling.

The following checklist can be used to inspect packing lines for potential causes of mechanical injuries. Look for:

- drops onto unpadded surfaces
- protrusions at impact surfaces
- directional changes in product flow
- unmatched speeds of adjoining packing line components
- steep angles on transfer plates
- excessive rotational velocities of brushes and rollers that propel product

- excessive packing line speed needed to run over original capacity

Decay

Fresh vegetables are grown in a hostile world with decay causing microorganisms everywhere. The good news is that fresh vegetables are normally very resistant to infection and decay; infection usually occurs only when commodities are injured, infiltrated with water or are late in their storage life. Postharvest decay is also more prevalent when vegetables experience harsh or wet weather conditions in the field. When handling vegetables, it is always important to 1) avoid harming the product's natural defenses, 2) minimize opportunities for pathogens to contact the product, 3) create and maintain conditions that prevent or inhibit pathogen growth, and 4) prevent rapid senescence of the plant organ. Rigorous attention to these details will help keep product decay below customer and USDA grade standard limits and help prevent financial losses.

Decay is caused when pathogenic microorganisms (e.g., decay causing fungi and bacteria) grow on the tissues of the commodity which leads to off-odors and visible changes in the product's texture or appearance. At advanced stages of the microbial attack, mold or bacterial development will be clearly evident on the product. Decaying vegetables also reduce the quality of neighboring product by:

- producing spores that discolor or infect nearby product
- promoting ethylene production that accelerates aging or ripening or the development of physiological disorders (e.g., russet spotting in lettuce)
- allowing the decay organism to spread through direct contact with adjacent product (nesting) or with juices released from infected tissues.

In addition, decaying vegetables may harbor human pathogens. For instance, Salmonella is much more prevalent and grows much faster on vegetables infected with bacterial soft rot (*Erwinia carotovora*).

Methods to reduce postharvest decay:

- Practice good sanitation in the field and throughout the entire harvest and postharvest handling chain. There is a direct relationship between the population of decay pathogens in the field and on the equipment and decay development. Thus, the presence of decaying plant material in the field (e.g., leaf litter, rotting vegetables, dead plants, etc.) and dirty harvesting and handling equipment results in higher rates of decay. Frequently clean and sanitize harvest and hauling equipment, packing areas and equipment, shipping containers, etc. Sanitize and frequently monitor the quality of all recirculated water systems and assure fresh water is free of pathogens (see below for further information).
- As mentioned previously, always harvest and handle commodities carefully to minimize wounds and injury. The epidermis or skin is a commodity's first line of defense. Punctures, cuts, etc. not only break these natural physical barriers, but also rupture cells, which release their contents (water and nutrients), promoting pathogen growth. Even injuries from bruises that do not rupture the epidermis, or exposure to injurious chemicals or atmospheres encourage decay because stressed tissues are generally less able to resist pathogen attack.
- Use synthetic or biological agents that eradicate or suppress the growth and development of decay pathogens.
- Rapid cooling greatly reduces decay development in most vegetables. Pathogenic microorganisms grow best at warmer temperatures, whereas certain commodities are injured when stored at cooler (chilling) temperatures. However, even for chilling-sensitive commodities such as tomatoes, it is essential to remove excessive field heat quickly after harvesting. Certain rapidly developing decays such as bacterial soft rot can develop within a few hours after harvest if the pulp temperature is 30 C (86°F) but at 16 to 20°C (61 to 68°F) the same decay will not appear for several days. An additional benefit to forced-air or vacuum cooling immediately after harvest is that these methods tend to dry wounds, which decreases the chances for a decay growth.
- Properly cure crops such as onions and potatoes after harvest by holding at relatively warm temperatures (e.g., 10 to 32°C/50 to 90°F depending on the commodity) for 2 to 7 days at high (~95%) relative humidity (RH). Curing promotes wound healing and inhibits the invasion of decay causing organisms. New chemicals are becoming available that do not affect pathogens directly, but rather stimulate natural production of these antifungal compounds. In some situations, hot water treatment can be used to physically reduce surface pathogen levels and stimulate product resistance.
- Store and transport vegetables at their lowest safe temperature. Storing and/or handling chilling-sensitive crops below recommended temperatures will lead to development of chilling injury that greatly promotes decay and causes off-flavors and off-aromas.
- Maintain temperatures and humidity levels so that condensation does not form on the product. Fungal spores germinate under high humidity (i.e., >95% RH) or in the presence of free water (i.e., condensation on the product). Wet potato tubers quickly break down. Moist wounds are quite susceptible to all types of pathogens. Protect the product from rain and splashing water (i.e., from melting ice from a nearby load). For commodities that tolerate storage while wet, water quality and effective sanitation of wash water and/or hydrocooling water is critical.

- Use controlled or modified atmospheres for commodities that benefit from their use. Maintaining tissue vitality longer delays decay development.
- For some vegetables, wraps, coatings (including those with fungicides) help prevent decay organisms from "nesting" (i.e., spreading to adjacent product).

Sanitation of Recirculated Water

Pathogens present on freshly harvested vegetables accumulate in water handling systems such as dump tanks, flumes, and hydrocoolers in which the water is recirculated. Even healthy looking products coming in from the field can harbor large populations of pathogens, particularly during warm, rainy weather. When vegetables are immersed in water containing pathogens they can become infected and develop decays during shipping and handling.

Many postharvest decay problems result from the incorrect use of chlorine for sanitizing packinghouse dump tanks and hydrocoolers. In our experience, although many packers routinely add chlorine to their water handling systems, the effectiveness of this treatment in reducing postharvest decay can be decreased or even nonexistent through failure to follow the UF/IFAS guidelines for packinghouse water sanitation. **The current recommendation is constant maintenance of 100 to 200 parts per million (ppm) of free (available) chlorine and a pH in the range of 6.8 to 7.2 for all recirculated water.** Whenever a product is dumped into water or washed with recirculated water that is not maintained under these conditions there is a good probability that decay problems will arise during handling and shipping. Proper water sanitation will also serve to prevent product contamination by various bacteria responsible for food-borne infections in humans.

The first requirement in maintaining water sanitation is the addition of an approved sanitizer to the water, such as sodium hypochlorite, calcium hypochlorite or liquid chlorine, to prevent the accumulation of pathogens. The effectiveness of chlorinated water as a sanitizer is greatly affected by the pH of the solution. If the pH is too high (above 8.0), the chlorine acts slowly and a higher concentration is necessary to achieve a rapid kill of the pathogens in the water. In contrast, if the pH is too low (below 6.5), then the chlorine is too active; it is more corrosive to equipment and effective chlorine concentrations are difficult to maintain. All recirculated water should be changed on a daily basis, or more frequently if the water becomes extremely dirty due to build up of organic matter. Local environmental codes must be consulted for proper disposal of chlorinated water.

The second and also necessary requirement is that the recommended free chlorine concentration (also called available or unreacted chlorine) must be maintained at all times during use. The chlorine product must be added to the water to replace the chlorine lost to reactions with organic matter, chemicals, microorganisms, as well as the surfaces of vegetables (known as the chlorine demand). There are several ways to maintain adequate chlorine concentrations. Automated systems are commonly used to monitor the oxidation-reduction potential (ORP) of the water and correlate that reading to free chlorine concentration as well as monitor water pH. These systems add a chlorine product to the water to replace that lost to reactions in the water as well as add buffers or acidifiers to maintain the appropriate pH levels. Other less sophisticated systems automatically dispense chlorine products, but require a frequent manual measurement of the free chlorine concentration to know if the proper amount of chlorine is being added. Packinghouse managers must be vigilant with these latter systems because the chlorine demand can change abruptly, such as with the addition of product from a different field, a different grower, or a different field crew. If free chlorine measurements are not taken often enough, free chlorine levels in the water can quickly dissipate, leading potentially to an accumulation of hazardous microorganisms in the water. Manual addition of chlorine products can be practiced, but the manager must be diligent about taking free chlorine and pH measurements and the adding the necessary materials to the water. With all sanitizer additions, managers should make sure that the added chlorine product is well-mixed with the water stream to avoid pockets of extremely low pH (<4.0), which can cause toxic chlorine gas to be released. Samples should be taken at least on an hourly basis.

Other factors that affect chlorine efficacy include the initial level of inoculum present on the vegetable surface, the exposure time of the crop in the water, the temperature of the water and the absence of stagnant areas. In the case of tomato dump tanks, the water should be heated 5.6°C (10°F) above the pulp temperature to reduce infiltration of the water (and pathogens) into the tomatoes. The tomatoes should not be in the tank for more than 2 minutes or submerged more than a few inches to minimize infiltration. Flumes must be designed such that fruit move through the system promptly and do not become caught in eddies.

Packinghouse managers must be vigilant in maintaining water quality in handling systems. By following these simple guidelines, postharvest decay problems should be drastically reduced.

Choice of Sanitizer

Proper sanitation of water (especially recirculated water) used in dump tanks, hydrocoolers, etc. of fresh vegetable packinghouses is important for delivering sound produce to the consumer. Not only do unsanitary conditions promote direct product loss through decay, but also rising food safety concerns about human pathogens are becoming increasingly important to consumers. Because water is one of the best carriers of pathogens, it must be treated (either chemically or physically) to prevent the accumulation of

Table 2. Sanitizing chemicals for packinghouses.

Compound	Advantages	Disadvantages
Chlorine	Relatively inexpensive	Corrosive to equipment
(Most widely used sanitizer for packinghouse water systems.)	Broad spectrum - effective on many different microbes	Sensitive to pH. Below 6.5 or above 7.5 reduces activity or increases noxious odors
	Practically no residue left on the commodity	Can irritate skin and damage mucous membranes
Chlorine dioxide	Activity is much less pH dependent than chlorine	Must be generated on-site
		Greater human exposure risk than chlorine. Off-gassing of noxious gases is common
		Concentrated gases can be explosive
Peroxyacetic acid	No known toxic residues or byproducts	Activity is reduced in the presence of metal ions
	Produces very little off-gassing	Concentrated product is very toxic to humans
	Less affected by organic matter than chlorine	Sensitive to pH. Greatly reduced activity at pH above 7-8
	Low corrosiveness to equipment	
Ozone	Very strong oxidizer/sanitizer	Must be generated on-site
	Can reduce pesticide residues in the water	Ozone gas is toxic to humans. Off-gassing can be problem
	Less sensitive to pH than chlorine (but breaks down much faster above ~ pH 8.5)	Treated water should be filtered to remove particulates and organic matter
	No known toxic residues or byproducts	Very corrosive to equipment (including rubber and some plastics)
		Highly unstable in water (half life ~ 15 minutes; may be less than 1 minute in water with organic matter or soil)

Note: Although quaternary ammonia is an effective sanitizer with useful properties and can be used to sanitize equipment, it is not registered for contact with food.

pathogens in the water and prevent cross-contamination of sound produce. Such treatments are not particularly effective at reducing pathogen levels already on the surface of the produce; it is much more effective to prevent cross-contamination of uninfected items. This means following Good Agricultural Practices regarding water quality, use of manure and municipal biosolids, harvesting practices, and worker, field, and packing facility sanitation.

Although chlorine is currently the sanitizer of choice for most vegetable packinghouses, other chemicals have been approved by the Environmental Protection Agency (EPA) for contact with food products. The following are some of the approved antimicrobial chemicals and a discussion of advantages and disadvantages of using each (Table 2).

Chlorine. Chlorination is currently the predominant method used by packinghouses to sanitize water systems. The main advantages to using chlorine are that it is effective at killing a broad range of pathogens, it acts relatively quickly and it is relatively inexpensive. It also leaves very little residue or film on surfaces. However, chlorine is corrosive to equipment and unstable during use. The solution pH must be monitored and adjusted often to maintain chlorine's activity. Continual addition of chlorine without changing the water can result in the accumulation of high salt concentrations that may injure some produce. Certain types of corrosion associated with water chlorination lead to damage of concrete tanks. Chlorine can react with organic matter to form small amounts of different trihalomethanes (THMs) that are thought to be carcinogenic, although the relative risks from chlorine-generated THMs on the surface of fresh horticultural produce is extremely low.

Chlorine dioxide (ClO_2). Chlorine dioxide is a synthetically produced yellowish-green gas with an odor like chlorine. Chlorine dioxide is much more specific for killing microorganisms than is chlorine, with a typical use concentration of between 1 and 5 ppm over a pH range of 6 to 10. Unlike chlorine, however, ClO_2 does not hydrolyze in water. Thus, it remains a gas while in solution. However, with agitated water such as spray washers, ClO_2 readily off-gasses, creating worker and equipment hazards. Chlorine dioxide is usually generated on-site because the concentrated gas can be explosive and will decompose rapidly when exposed to light or temperatures above 122°F (50°C). Chlorine dioxide water treatment does not produce THMs, however the primary breakdown products, chlorite and chlorate, are of interest by the EPA. One additional drawback is that no simple assays to monitor ClO_2 concentration are currently available.

Ozone (0_3). Ozone is a water-soluble gas formed by splitting O_2 (with electricity or UV light) that further reacts with other O_2 to form O_3. Ozone gas is one of the strongest oxidizing agents and sanitizers available and is highly corrosive to equipment including rubber, some plastics, and fiberglass. An expert panel declared O_3 to be Generally Recognized As Safe (GRAS) in 1997 and O_3 is currently legal for food contact applications. Although O_3 is not particularly soluble in water (30 ppm at 68°F/20°C), concentrations of 0.5 to 2 ppm are effective against pathogens in clean water with no soil or organic matter. In practice, even concentrations of 10 ppm are difficult to obtain and concentrations of 5 ppm or less are more common. There have been reports that O_3 may induce resistance to subsequent fungal attacks in some horticultural products.

Ozone decomposes quickly in water with a half-life of 15 to 20 minutes in clean water but less than 1 minute in water containing suspended soil particles and organic matter. Thus, ozonated water should be filtered to remove these particulates. Cooler temperatures of hydrocoolers may also extend ozone's half-life. The antimicrobial activity of O_3 is stable between pH 6 and 8 but decomposes more rapidly at higher pH. Ozone breaks down to O_2 and no other toxic by-products have been reported. Ozone efficacy is diminished when dissolved iron, manganese, copper, nickel, hydrogen sulfide, or ammonia are present in the solution.

Because of its strong oxidizing potential, O_3 is toxic to humans and must be generated on-site. Prolonged exposure to more than 4 ppm O_3 in air can be lethal. Ozone has a pungent odor that can be detected by humans at 0.01 to 0.04 ppm. OSHA has set worker safety limits in air of 0.1 ppm exposure over an 8-hour period and 0.3 ppm over a 15-minute period. At concentrations in water above 1 ppm, off-gassing can result in concentrations in the air that exceed OSHA limits of 0.1 ppm.

Peroxyacetic acid (PAA). Peroxyacetic acid (e.g., Tsunami®, VigorOx®, etc.) is a strong oxidizer formed from hydrogen peroxide and acetic acid. The concentrated product (up to 40% PAA) has a pungent odor and is highly toxic to humans. PAA is very soluble in water with very little off-gassing and it leaves no known toxic breakdown products or residue on the produce. Unlike chlorine and ozone, it has good stability in water containing organic matter, which can greatly increase the longevity of the sanitizer, and it is not corrosive to equipment. PAA is most active in acidic environments with pH between 3.5 and 7, but activity declines rapidly above pH 7-8. High temperatures and metal ion contamination will also reduce its activity. PAA is not as effective against fungal spores as chlorine.

TEMPERATURE MANAGEMENT

Importance

Once harvested, a vegetable continues life processes independent of the plant, and as a result, must utilize its own stored energy reserves. Within hours of harvest, crops held at ambient temperatures can suffer irreversible losses in quality, reducing postharvest life. Additionally, many vegetables such as greens, celery, and lettuce are cut at harvest, and this wounding further increases stress on the tissue. The relative perishability of a crop is reflected in its respiration rate, where respiration is the process of life by which O_2 is combined with stored carbohydrates and other components to produce heat, chemical energy, water, CO_2 and other products. The respiration rate varies by commodity; those commodities with high respiration rates utilize the reserves faster and are more perishable than those with lower respiration rates. Therefore, vegetables with higher respiration rates, such as broccoli and sweetcorn, must be rapidly cooled to the optimal storage temperature to slow metabolism and extend postharvest life during subsequent shipping and handling operations.

Since the introduction of hydrocooling for celery in the 1920s, rapid cooling (precooling) has allowed Florida produce to be shipped to distant markets while maintaining high quality. Commercial cooling is defined as the rapid removal of field heat to temperatures approaching the optimal storage temperature and it is the first line of defense in retarding the biological processes that reduce vegetable quality. Cooling, in conjunction with refrigeration during subsequent handling operations, provides a "cold chain" from packinghouse to supermarket to maximize postharvest life and control disease and pests. (The term "postharvest life" is purposely used in this text, since "shelf life" has the connotation that the commodity "sits on the shelf", implying that the product requires no subsequent refrigeration.) Timeliness during handling is also essential in maintaining produce quality: timely and careful harvest and transport to the packinghouse, rapid packing and cooling, and rapid transport to the market or buyer. Everyone involved at each of the many steps during product handling (e.g., shippers, truckers, receivers) must take care to ensure that the refrigerated cold chain is not broken.

Many Florida shippers are well equipped to rapidly cool their crops, and a growing number are incorporating cooling or upgrading their existing cooling facilities. Simple placement of packed vegetables in a refrigerated cooler is not sufficient to maintain quality for product destined for distant markets. Neither should non-cooled vegetables be loaded directly into refrigerated trailers. In both of these situations the product cools very slowly, at best. Refrigerated trailers are designed to maintain product temperature during transport, and they **do not** have the refrigeration capacity to quickly remove field heat. Therefore, only produce that has been properly cooled should be loaded, and only into trailers that have been cooled prior to loading.

Storage Requirements

Horticultural crops may be grouped into two broad categories based on sensitivity to storage temperatures. The degree of chilling sensitivity, and therefore the lowest safe storage temperature, is crop-specific. Those crops that are chilling sensitive should be held at temperatures generally above 50°F (10°C). Storage below this threshold will give rise to a physiological disorder known as **chilling injury**. Chilling injury symptoms are characterized by development of sunken lesions on the skin, increased susceptibility to decay, increased shrivel, and incomplete ripening as shown by poor flavor, texture, aroma and color. Those crops not as sensitive to chilling injury may be stored at temperatures as low as 32°F (0°C). The severity of chilling symptoms is also dependent on the length of exposure to low temperatures. Short exposure times will result in less injury than longer exposure to chilling temperatures.

In addition to maintaining storage rooms at proper storage temperatures, the relative humidity should also be controlled to reduce water loss from the crop. Optimal storage recommendations and precooling methods are included for a wide range of vegetable commodities (Table 3).

OPTIMIZING COMMERCIAL COOLING

Cooling Concepts

Cooling is a term that is often used quite loosely. In order to be effective and significantly benefit the shipping life of the product, an appropriate definition of commercial cooling for perishable crops is: The rapid removal of at least 7/8 of the field heat from the crop by a compatible cooling method. The time required to remove 7/8 of the field heat is known as the “7/8 Cooling Time.” Removal of 7/8 of the field heat during cooling is strongly recommended to provide adequate shipping life for shipment to distant markets; also, 7/8 of the heat can be removed in a relatively short amount of time. Removal of the remaining 1/8 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 remain in the precooler for **sufficient time** to remove heat. The cooling medium (air, water, crushed ice) must be maintained at **constant temperature** throughout the cooling period. 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.

Cooling Methods

The cooling rate is not only dependent upon time, temperature and contact with the commodity; it is also dependent upon the cooling method being employed. The various cooling media used to cool produce have different capacities to remove heat.

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 existing 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 low respiration rates, such as mature potatoes, dried onions and cured sweetpotatoes. Under certain circumstances even these latter crops may require precooling, such as when harvested under high ambient temperatures.

Forced-Air (Pressure) Cooling

The cooling efficiency of refrigerated rooms can be greatly improved by increasing the airflow 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 (Fig. 18-2, 18-3). 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 air temperature during cooling. Portable systems can be taken to the field (Fig. 18-4).

With either room cooling or forced-air cooling, precautions must be taken to minimize water loss from the product. The refrigeration system actually dehumidifies the cold-room air as water vapor in the air condenses on the evaporator coil. This condensation lowers the RH in the room, creating a greater vapor pressure deficit between the product and the surrounding air. As a result, the product loses moisture to the air. To minimize water loss during cooling and storage, the ambient RH should be maintained at the recommended level for the particular crop (commercial humidification systems are available) and the product

Table 3. Recommended storage conditions and cooling methods for maximum postharvest life of commercially grown vegetables. FA = Forced Air Cooling; HY = Hydrocooling; ICE = Package Ice, Slush Ice; ROOM = Room Cooling; VAC = Vacuum Cooling

	Temperature				
Commodity	**°F**	**°C**	**Relative Humidity (%)**	**Approximate Storage Life**	**Cooling Methods**
Artichoke, globe	32	0	95-100	2-3 weeks	HY, ROOM
Artichoke, Jerusalem	31-32	-0.5-0	90-95	4-5 months	ROOM
Asparagus	32-35	0-2	95-100	2-3 weeks	HY
Bean, dry	40-50	4-10	40-50	6-10 months	ROOM
Bean, green or snap	40-45	4-7	95	7-10 days	HY, FA
Bean, lima	37-41	3-5	95	5-7 days	HY
Bean sprout	32	0	95-100	7-9 days	ROOM
Beet, bunched	32	0	98-100	10-14 days	HY
Beet, topped	32	0	98-100	4-6 months	ROOM
Broccoli	32	0	95-100	10-14 days	HY,ICE
Brussels sprout	32	0	95-100	3-5 weeks	HY,VAC
Cabbage, early	32	0	98-100	3-6 weeks	ROOM
Cabbage, late	32	0	98-100	5-6 months	ROOM
Cabbage, Chinese	32	0	95-100	2-3 months	HY,VAC
Carrot, bunched	32	0	95-100	2 weeks	HY
Carrot, mature, topped	32	0	98-100	7-9 months	HY
Carrot, immature, topped	32	0	98-100	4-6 weeks	HY
Cassava, (yuca)[z]	32-41	0-5	85-90	1-2 months	ROOM
Cauliflower	32	0	95-98	3-4 weeks	HY,VAC
Celeriac	32	0	97-99	6-8 months	ROOM
Celery	32	0	98-100	2-3 months	HY,VAC
Chard	32	0	95-100	10-14 days	HY,ICE,VAC
Chayote	45	7	85-90	4-6 weeks	ROOM
Chicory, witloof, Belgian endive	32	0	95-100	2-4 weeks	HY,ICE,VAC
Collard greens	32	0	95-100	10-14 days	HY,ICE,VAC
Corn, sweet	32	0	95-98	5-8 days	HY,ICE,VAC
Cucumber	50-55	10-13	95	10-14 days	HY
Eggplant	46-54	8-12	90-95	1 week	FA
Endive and escarole	32	0	95-100	2-3 weeks	HY,ICE,VAC
Garlic	32	0	65-70	6-7 months	ROOM
Ginger	55	13	65	6 months	ROOM
Greens, leafy	32	0	95-100	10-14 days	HY,ICE,VAC
Horseradish	30-32	-1.0-0	98-100	10-12 months	ROOM
Jicama	55-65	13-18	65-70	1-2 months	ROOM
Kale	32	0	95-100	2-3 weeks	HY,ICE,VAC
Kohlrabi	32	0	98-100	2-3 months	ROOM
Leek	32	0	95-100	2-3 months	HY,ICE,VAC
Lettuce	32	0	98-100	2-3 weeks	VAC
Malanga[z]	50	10	90-95	4-5 months	ROOM
Melon					
Cantaloupe (3/4-slip)	36-41	2-5	95	15 days	FA,HY
Cantaloupe (full-slip)	32-36	0-2	95	5-14 days	FA,HY,ICE
Casaba	50	10	90-95	3 weeks	ROOM
Crenshaw	45	7	90-95	2 weeks	ROOM
Honey Dew	45	7	90-95	3 weeks	ROOM
Persian	45	7	90-95	2 weeks	ROOM
Watermelon	50-60	10-16	90	2-3 weeks	ROOM

Table 3. Continued.

Commodity	Temperature		Relative Humidity (%)	Approximate Storage Life	Cooling Methods
	°F	°C			
Mushroom	32	0	95	3-4 days	FA,VAC
Okra	45-50	7-10	90-95	7-10 days	FA
Onion, green	32	0	95-100	3-4 weeks	HY,ICE
Onion, dryz	32	0	65-70	1-8 months	ROOM
Onion sets	32	0	65-70	6-8 months	ROOM
Parsley	32	0	95-100	2-2.5 months	HY,ICE
Parsnip	32	0	98-100	4-6 months	ROOM
Pea, green	32	0	95-98	1-2 weeks	HY,ICE
Pea, southern	40-41	4-5	95	6-8 days	HY
Pepper, chili (dry)	32-50	0-10	60-70	6 months	ROOM
Pepper, sweet (bell)	45-55	7-13	90-95	2-3 weeks	FA
Potato, early crop	45-50	7-10	90-95	4-5 months	HY,ROOM
Potato, late crop[z]	40	4	90-95	5-10 months	ROOM
Pumpkin	50-55	10-13	50-70	2-3 months	ROOM
Radish, spring	32	0	95-100	3-4 weeks	HY
Radish, winter	32	0	95-100	2-4 months	ROOM
Rhubarb	32	0	95-100	2-4 weeks	HY,ROOM
Rutabaga	32	0	98-100	4-6 months	ROOM
Salsify	32	0	95-98	2-4 months	ROOM
Spinach	32	0	95-100	10-14 days	ICE,HY,VAC
Squash, summer	41-50	5-10	95	1-2 weeks	FA,HY
Squash, winter	50	10	50-70	2-3 or 6 months (depends on type)	ROOM
Strawberry	32	0	90-95	5-7 days	FA
Sweetpotato, boniatoz	55-60	13-16	85-90	4-7 months	ROOM
Tamarillo	37-40	3-4	85-95	10 weeks	ROOM
Taro (dasheen)[z]	45-50	7-10	85-90	4-5 months	ROOM
Tomato, mature-green	55-70	13-21	90-95	2-3 weeks	FA,ROOM
Tomato, ripening (stages 3-4)	50-70	10-21	90-95	1-2 weeks	FA,ROOM
Tomato, firm red (stage 6)	46-50	8-10	90-95	4-7 days	FA,ROOM
Turnip	32	0	95	4-5 months	ROOM
Turnip greens	32	0	95-100	10-14 days	HY,ICE,VAC
Waterchestnut	32-36	0-2	98-100	1-2 months	ROOM
Watercress	32	0	95-100	2-3 weeks	HY,ICE,VAC
Yam[z]	61	16	70-80	6-7 months	ROOM

[z] Curing required prior to long-term storage. 'Curing' of dry onions actually involves drying the outer bulb scales, reducing the fresh weight by 5 to 6%.

should be promptly removed from the forced-air precooler upon achieving 7/8 Cooling. Forced-air cooling is recommended for most of the fruit-type vegetables and is especially appropriate for vegetables such as peppers and tomatoes that are susceptible to infiltration of water-borne decay organisms.

Hydrocooling

Hydrocooling (Fig. 18-5, 18-6) removes heat at a 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 in order to achieve thorough cooling.

Sanitation of the hydrocooling water is critical, since it is recirculated. Decay organisms present on the vegetables can accumulate in the water, inoculating subsequent product being hydrocooled. 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 sweetcorn, snap beans, cucumbers, and summer squash.

Contact Icing

Contact icing has been used for both cooling and temperature maintenance during shipping, but its use is becoming less common. Heat from the product is absorbed by the ice, causing it 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. Non-uniform distribution of ice reduces the cooling efficiency. There are two types of contact icing: 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 (Fig. 18-7). Prior to shipping, ice is blown on top of containers loaded in truck trailers to aid in cooling and maintenance of higher RH. However, care should be taken to avoid blockage of vent spaces in the load; this restricts airflow, 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 32°F (0°C) to avoid freezing the product.

Package Icing. Crushed ice distributed within the container is known as **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 either bulk or containerized produce or injected into side hand holds. This **“slush ice”** method has been widely adopted for commodities tolerant to direct contact with water and requiring storage at 32°F (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 reduce pulp temperatures to 32^{O}F (0°C) within a reasonable amount of time and maintains a high RH 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 of sufficient strength so as not to deform. Shipping operations must also tolerate water dripping from the melting ice during handling and storage. Package icing is successfully used for leafy crops, sweetcorn, green onions, and cantaloupes.

Vacuum Cooling

Vacuum cooling is a very rapid method of cooling, and is most efficient for commodities with a high surface-to-volume ratio such as leafy crops (Fig. 18-8). This method is based on the principle that, as the atmospheric pressure is reduced, the boiling point of water lowers. Containerized or bulk product is thoroughly wetted, placed in a vacuum chamber (tube) and sealed. The pressure in the chamber is reduced until the water on the product surface evaporates (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 increase cooling efficiency. Any water that evaporates from the vegetable tissue is removed uniformly throughout the product. Therefore, it does not tend to result in visible wilting in most cases even though about 1% of the product weight is lost for each 10°F (5.6°C) of cooling.

Precautions must be taken so as not to cool the products below their chilling temperature threshold. 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 cooled readily by vacuum cooling include leafy crops, such as spinach, lettuce, collards, and celery.

When selecting an appropriate cooling method, several factors must be considered, including: the maximum volume of product requiring precooling on a given day, the compatibility of the method with the commodities to be cooled, subsequent storage and shipping conditions, and fixed/variable costs of the system. (For more information regarding selection of a cooling system, see SSVEC-47, *Evaluating Precooling Methods for Vegetable Packinghouse Operations*.)

MINIMIZING WATER LOSS

Most fresh vegetables are composed of 90-95% water, which is vital for normal biochemical processes, is responsible for many textural qualities (i.e., firmness and crispness), and represents most of the saleable weight of these commodities. Following harvest, vegetables are separated from their source of water and cannot replace lost water. Thus, reducing water loss after harvest is critical for maintaining quality and the saleable weight of the product.

Water escapes from fresh vegetables through evaporation into the surrounding air. Commodities with large surface areas (e.g., leaves) are much more prone to water loss than compact, round commodities (e.g., potatoes). In addition, a commodity's natural barriers to water loss, such as a waxy cuticle, abscission layer, or even pubescent hair, help prevent water loss. The lack of openings such as lenticels or stomata in tomato peel makes them less susceptible to water loss than cucumbers that do have stomata, which is why cucumbers are waxed. Also, cuts or abrasions that break these natural barriers will increase water loss. Thus, careful handling to reduce injury is the first step in reducing commodity water loss.

Even undamaged commodities will lose some water during postharvest handling and storage. The rate of water loss depends on the commodity's contact with the surrounding air and how dry the air is. Air at a given temperature can hold only so much water vapor. If air is holding all the water vapor it can, we say it is saturated. Relative humidity is the ratio of actual water vapor content within the air to the maximum possible water content at a given temperature. Therefore, saturated air is at 100% RH. When the air contains half as much water at the same temperature, the RH is at 50%. The lower the RH of the air, the faster water is lost from fresh vegetables. Therefore, in most instances, maintaining RH between 85% and 95% is recommended. When higher (i.e., 90% to 100%) RH is required, cartons must be constructed of water-resistant materials to prevent carton deterioration. The use of 100% RH is only recommended for commodities (e.g., broccoli) and containers that can tolerate free water from washing or hydrocooling or that which condenses from the air. Adding water to the air through the use of humidifiers to maintain optimum RH levels keeps commodity water loss to a minimum. Steam and atomizing humidifiers allow higher RH to be maintained because less liquid water settles on the product to favor decay development. Wetting the floor in storage rooms also adds moisture to the air as it evaporates.

Another important fact to consider is that warmer air holds much more water vapor than colder air. Thus, air at 32°F (0°C) with 100% RH will be at only about 50% RH after warming to 50°F (10°C). Conversely, when warm, saturated air is allowed to contact cold product (e.g., when product is moved from a cold room to a warm dock) the warmer air at the surface cools. And, because the now cooler air cannot hold as much water, the vapor condenses on the commodity surface. Once the commodity is cool, minimizing air movement around the commodity allows a layer of saturated air (known as a boundary layer) to form around the commodity, creating a barrier to water loss. Water loss can be minimized by quickly cooling the product, keeping the commodity and surrounding air as cool as possible, and by minimizing fluctuations in commodity and air temperatures during handling and shipping operations.

Methods to reduce water loss:

- Handle fresh vegetables carefully.
- Cure/dry certain root, bulb, and tuber vegetables to allow natural tissues that restrict water loss to develop at the site of wounds.
- Use waxes and other surface coatings to further restrict water loss.
- Quickly cool commodities and maintain temperatures at the lowest safe temperature (i.e., non-chilling or freezing temperatures).
- Minimize fluctuations in commodity and air temperatures.
- Reduce fan speeds after the commodity has cooled. Use of wraps, plastic liners, and other packaging also slows water loss.
- Add moisture to the air through the use of humidifiers and maintain RH at the highest recommended level without causing commodity or container deterioration.
- Design cooling systems so that the evaporator coils run within 2°F (1°C) of the air temperature.
- Use crushed ice in shipping containers and mist systems in retail displays of commodities that tolerate direct contact with water. (e.g., leafy vegetables, snap beans, peas, sweetcorn, etc.)
- When the CO_2 tolerance of a commodity is known, it is often possible to leave the fresh-air exchange opening on trailers and containers closed or partially closed, which allows higher RH to be maintained.

SHIPPING CONTAINERS AND PALLETIZATION

The selection and use of appropriately designed shipping containers have long been a concern to fresh produce shippers. In addition to serving as a uniform measure of quantity, a properly designed container must protect the product during handling, allow sufficient ventilation during cooling and storage, and facilitate palletization.

A common mistake is to purchase containers on the basis of cost rather than stacking strength, resulting in failure during shipping and storage. The container must be constructed of material with sufficient strength so that the package, rather than the product, bears the weight of the stacked pallet. Corrugated fiberboard cartons must be protected from direct contact with water during handling, shipping, and warehousing. While providing excellent protection from wet environments, waxing makes the cartons difficult to recycle. Wirebound wooden crates work well under wet conditions, such as hydrocooling, but must be carefully stacked so as to use the sturdy end panels. Stacking on the side panels should be avoided since these have little strength. Inner surfaces of the container should be smooth and free of sharp, protruding, and abrasive edges.

Ventilation is critical for efficient removal of field heat during cooling and for maintenance of product temperature during handling and storage. Containers should be designed with vent holes large enough to maximize airflow.

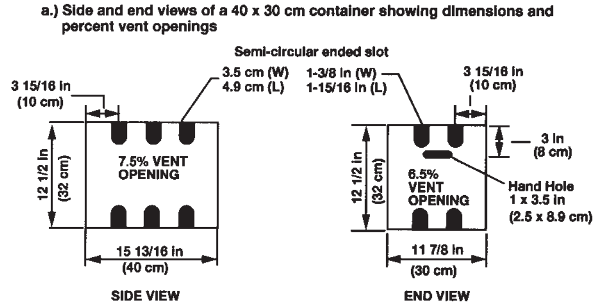
Unitizing (i.e., palletizing) produce shipping containers promotes efficiency in the distribution system – mechanical injury is reduced by eliminating transfers and by reducing the number of shipping container sizes. The movement toward palletization led to the development of standardized container sizes by European, and later American and Canadian, produce associations. The result was container sizes designed to cover 100% of the surface area of a standard-sized pallet measuring 100 by 120 centimeters, or approximately 40 by 48 inches. During the past 10 years, the 40 x 48-inch pallet has become the standard pallet used in the North American produce industry. The footprint (base dimensions) of these standardized containers accommodate 5, 6, 8 or 10 containers per layer on the standard pallet (Table 4). Recently, shippers are being encouraged to use only two shipping containers sizes, 5 or 10 containers per layer. In all of these standardized container footprints, the volume for the specific crop is determined by adjusting the carton height.

Several years ago the Florida tomato and strawberry industries led the way by adopting standardized shipping cartons and palletization. Beginning in the mid-1990s Florida vegetable shippers began incorporating standardized dimensions and other vent-alignment design features recommended by UF/IFAS into their shipping containers (Fig. 18-9A and Fig. 18-9B).

With increasing emphasis on reduction of the waste stream, shippers should consider packing their vegetables in containers that are returnable or recyclable by receivers. For example, some markets refuse to accept produce packed in waxed, corrugated cartons. Similarly, wooden wirebound crates are not easily recyclable but are often reused by smaller produce handlers at destination markets. Recyclable containers can be fabricated from fiberboard or plastic with the cost included in the selling price of the

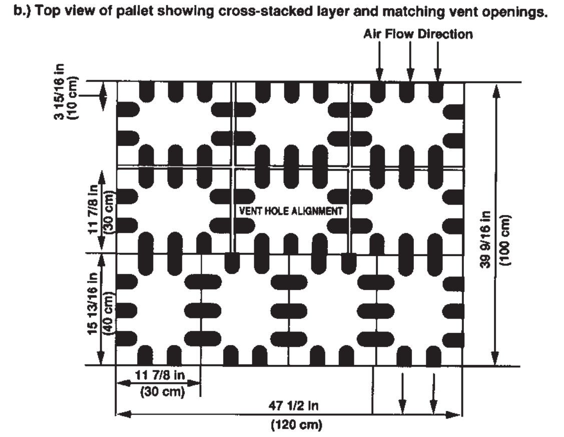
Table 4. Standardized shipping container dimensions designed for a 40 x 48-inch pallet.

Outside Base Dimensions		Containers	Layers Can Be
S.I. units	English units	Per Layer	Cross-stacked
40×30 cm	15 ¾ × 11 ¾ in	10	Yes
50×30 cm	19 ¾ × 11 ¾ in	8	No
50×40 cm	19 ¾ × 15 ¾ in	6	No
60×40 cm	23 ¾ × 15 ¾ in	5	Yes



The authors thank Dr. Michael T. Talbot, Department of Agricultural & Biological Engineering, Univ. of Florida, for providing this Schematic

Fig. 18-9a. Dimensions of a standardized produce shipping container (40×30 cm base) showing alignment of vertical openings for optimal cooling.



The authors thank Dr. Michael T. Talbot, Department of Agricultural & Biological Engineering, Univ. of Florida, for providing this Schematic

Fig. 18-9b. Dimensions of a standardized produce shipping container (40×30 cm base) showing alignment of vertical openings for optimal cooling.

product. Returnable containers are in wide use in Europe, and there is increasing interest on the part of shippers and receivers in North America. These containers are constructed of rigid plastic, have exceptionally long useful life, can be sanitized, and can be designed for excellent ventilation. Return is facilitated through a collapsible design feature. Returnable containers are leased. Recently, leased pallets have become widely available throughout the U.S. and Canada and are competitively priced with purchased pallets. Leased pallets have many advantages in that the supplier maintains a pool of pallets that are clean and in excellent repair.

SUMMARY

Through careful attention to postharvest handling, high quality vegetables can be successfully shipped to distant markets. Principal means for extending postharvest life are:

- minimizing mechanical injury during handling
- maintaining sanitary conditions
- rapidly removing field heat within a few hours of harvest, and
- minimizing water loss from the commodity.

Standardized shipping containers made from sturdy materials should be used to facilitate cooling and palletization. Successful implementation of the above recommended procedures into an operation requires thorough evaluation of each of the components in the handling system.

ADDITIONAL RESOURCES

Mahovic, M., S. A. Sargent, and J. A. Bartz. 2004. Guide to Identifying and Controlling Postharvest Tomato Diseases in Florida. EDIS Publication HS866. Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/HS131

Ritenour, M. A., S. A. Sargent, and J. A. Bartz. 2001. Chlorine Use in Produce Packing Lines. EDIS publication HS761. Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/CH160

Talbot, M. T. and J. H. Fletcher. 2002. A Portable Demonstration Forced- Air Cooler. Document CIR1166. Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/AE096

FOOTNOTES

1. This document is HS719, one of a series of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Date first printed: June, 1995. Date revised: July 2007. Please visit the EDIS Web site at http://edis.ifas.ufl.edu.

2. S.A. Sargent, professor, Horticultural Sciences Department; M.A. Ritenour, associate professor, IRREC-Ft. Pierce; J.K. Brecht, professor, Horticultural Sciences Department; J. A. Bartz, associate professor, Plant Pathology Department, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611. The Vegetable Production Guide for Florida is edited by D.N. Maynard, professor, GCREC-Bradenton, S.M. Olson, professor, NFREC-Quincy, Institute of Food and Agricultural Sciences, University of Florida. The use of trade names in this publication is solely for the purpose of providing specific information. It is not a guarantee or warranty of the products named, and does not signify that they are approved to the exclusion of others of suitable composition. Use pesticides safely. Read and follow directions on the manufacturer's label.

Florida Cooperative Extension Service / Institute of Food and Agricultural Sciences / University of Florida / Larry R. Arrington, Dean

COPYRIGHT INFORMATION