Section 4: Cooling and Curing

Fresh Produce Is Alive[1,2]

Fresh produce, both on the plant and after it has been harvested, is alive. After it has been removed from the plant, it continues the metabolic activity that allowed it to grow while on the plant. As such, it is still affected by many of the same factors that affected its growth in the field: heat, water, humidity, and sunlight will continue to impact produce after it has been picked.

If you have walked out into a field on a cool autumn morning, you may have noticed a snake moving slowly through the field. Reptiles move slowly when the environment is cold because they require heat from their surroundings to increase their internal temperature and thus their metabolism. Once their internal body temperature has warmed, they can metabolize foods more quickly and produce the energy through the process of respiration.

Similarly, the metabolic rates of plants both in the field and in the postharvest environment are affected by temperature. Like the snake in the field, the rate of metabolic reactions of produce slows in lower temperatures. Over the range of temperatures from 32 – 86° F, every 18° F rise in temperature increases the rate of all metabolic reactions, including respiration, by two or three times.

As respiration occurs in plants, carbohydrates – the stored sugar and starch in harvested plant parts that contribute to the desirable taste and textures of produce – are broken down to provide energy to drive other metabolic processes. This process requires oxygen and releases heat. Water is also lost through this process, as well as lost through transpiration due to the difference between the water vapor pressure inside the plant versus in the surrounding air.

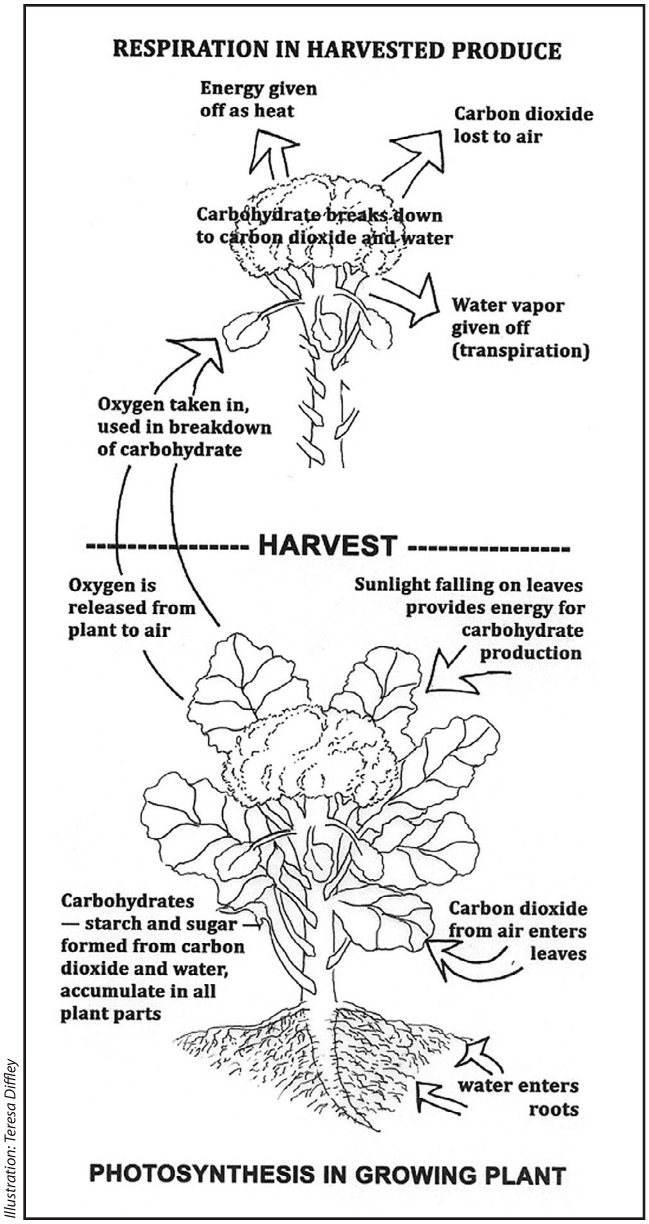


Illustration: Teresa Diffley

The instant a crop is removed from the ground or separated from its parent plant, it begins to deteriorate.

While fruits and vegetables are still attached to the plant, the carbohydrates and water that are lost during metabolism and transpiration can be replaced through photosynthesis and water uptake by roots. Once harvested, they cannot be replaced. Water uptake and photosynthesis stop. Stored food reserves are lost during respiration, which means loss of nutritional value, flavor, salable weight, and a general loss of quality.

Once produce is harvested, postharvest handling practices cannot improve quality. They only slow the rate of deterioration.

Respiration and Produce Quality

Different crops and plant parts respire at different rates during the postharvest period. The different rates of respiration directly affect the rate at which carbohydrates and other materials are metabolized. The respiration rate of a product directly impacts postharvest life with respect to transit and shelf life.

The higher the respiration rate, the more perishable a crop is.

Respiration rates of commodities can be slowed at lower temperatures, while higher temperatures increase respiration rates. To ensure high quality and proper shelf life, rapid cooling to the commodity's lowest safe temperature is particularly critical for those fruits and vegetables with inherently higher respiration rates. (See the table at right for examples. For respiration rates of all crops included in this manual, see the crop profiles).

Rate of Water and Energy Loss

To extend the usable shelf life of produce, the rate of water and energy loss must be slowed as much as possible. Factors that affect the rate of loss include:

1. Temperature

For every 18° F increase in internal produce temperature the rate of deterioration increases two to three times.[4] Immediately removing field heat is the single most important step you can take in extending shelf life and maintaining a product suitable for buyers. Prompt and thorough cooling to the core of the produce will slow the respiration rate, and the rate of deterioration.

Classification of Sample Horticultural Commodities According to Respiration Rates[3]

Class	Commodity
Very Low	Dates, dried fruits and vegetables, nuts
Low	Apple, beet, celery, cranberry, garlic, grapes, honeydew melon, onion, papaya, potato (mature), sweet potato, watermelon
Moderate	Apricot, banana, blueberry, cabbage, cantaloupe, carrot, (topped), celeriac, cherry, cucumber, fig (fresh), gooseberry, lettuce (head), nectarine, olive, peach, pear, pepper, plum, potato (immature), radish (topped), summer squash, tomato
High	Blackberry, carrot (with tops), cauliflower, leeks, lettuce (leaf), lima beans, radish (with tops), raspberry, strawberry
Very High	Artichoke, bean sprouts, broccoli, Brussels sprouts, endive, green onions, kale, okra, snap bean, watercress
Extremely High	Asparagus, mushroom, parsley, peas, spinach, sweet corn

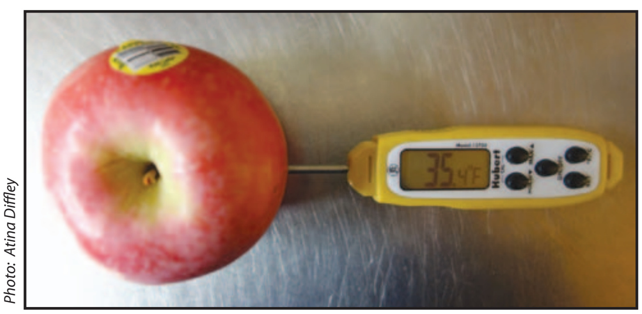


Photo: Atina Diffley

Monitor internal produce temperature with a probe thermometer. Some probe thermometers can be programmed to give an alarm once a set temperature is reached. Look for a thermometer that can be recalibrated by simply submerging the tip in ice water and holding down a button.

This makes a difference of days, weeks, or even months – depending on the crop.

Crops with extremely high respiration rates, such as sweet corn and broccoli, require cooling treatments within one hour of harvest. Even crops with lower respiration levels, such as celery, beet and watermelon should be cooled within a few hours. A general rule of thumb for moderate and high respirators is that a one-hour delay in cooling reduces a product's shelf life by one day or more.[5]

This cooling step needs to happen on the farm, and quickly. If produce is shipped without removing field heat, its quality and shelf life will be negatively affected. Also, if warm produce is brought into grocery stores and wholesale operations, the heat and humidity released from the produce can warm up and affect the humidity of their storage facilities, and cause damage to the other stored products.

Lower temperatures can also reduce sensitivity of produce to ethylene, a gaseous plant hormone that can speed respiration and cause earlier than desired ripening.

Growers who do not own or have access to cooling facilities, refrigerated storage, or refrigerated trucks will have to carefully select which crops they grow for wholesale markets. In these circumstances, the best-suited crops are low respirators such as gourds, some melons, and certain root crops; or chilling sensitive produce such as basil, snap beans, cucumbers, eggplants, muskmelons, peppers, potatoes, pumpkins, squash, sweet potatoes, tomatoes, and watermelons that require storage between 45° F and 70° F. Check the crop profiles in the back of this manual for specifics on each crop. High-respiration crops such as broccoli, greens, or sweet corn will not hold quality without a way to quickly remove the field heat and store them cold.

Postharvest Temperature Management

- Harvest during the coolest times of the day; mornings are usually best.
- Keep harvested produce and loaded vehicles in the shade to minimize heating.
- Bring harvested produce into the packing shed frequently.
- During transport, use covered vehicles, or cover loaded vehicles with tarps to minimize heating and sun injury.
- Thoroughly cool as soon as possible.
- If grower has no ability to cool produce and is sending product to a cooling service or aggregation hub for cooling, product should not be allowed to accumulate for long or critical moisture and quality will be lost.
- Maintain proper storage and/or transit temperature.
- Ship as soon as possible

2. Humidity and Air Movement: Cooling and Water Loss[6]

Fresh fruits and vegetables are full of water; freshness is water, and freshness sells! Water loss is one of the main causes of deterioration that affects the shelf life and marketability of fresh fruits and vegetables.

Effects of water loss: Many fruits and vegetables are negatively affected by losing even a small percentage of their original weight due to water loss. For example, leafy green vegetables quickly wilt, and then shelf life and quality are reduced. Visibly shriveled fruits, vegetables, and flowers are unmarketable and must be discarded.

Factors that affect water loss: Relative humidity in storage, the temperature of the product and its surrounding atmosphere, and air velocity around the product all affect the amount of water lost from fresh fruits, vegetables, and flowers. Water loss from warm products to warm air is particularly serious under windy conditions or during transport in an open vehicle.

The influence of the type of produce on water loss: The rate at which water is lost varies with the type of produce. Leafy green vegetables, especially spinach, lose water quickly because they have a thin waxy skin with many pores. Others, such as potatoes, which have a thick corky skin with few pores, have a much lower rate of water loss.

Water loss and cooling: The faster the surrounding air moves over fresh produce the quicker it cools, and the more water is lost. Air movement through produce is essential to cool and remove the heat of respiration, but the type of produce, and the desired postharvest process – cooling or storage – must be taken into consideration in designing the rate of air movement. During cooling, high rates of airflow are often used to speed the removal of heat. Sensitive crops such as berries must be carefully monitored to prevent dehydration and moved into storage as soon as they are cooled. During storage, airflow is necessary to remove respiration heat, but the rate of movement must be kept as low as possible. Well-designed packaging materials and suitable stacking patterns for crates and boxes can contribute to controlled airflow through produce.

Generally, Produce Is Cleaned Before Cooling – But Not Always!

Cleaning of most produce happens before cooling. Exceptions are crops that are stored before washing, which is generally recommended for root crops, onions, and winter squash.

At Harmony Valley Farm, parsnips are harvested into plastic-lined bins and moved into a room cooler for cooling and storage. The bags will be kept open until the roots are cooled, then closed to maintain a humid environment. The roots stay whiter when the bags are closed.

Some crops, such as baby greens, are cleaned and cooled during the same process with a temperature step-down system for food safety. For more information see Section 5: Cleaning and Cooling, in this manual.

Photos: Atina Diffley

Maintaining the Cold Chain[7]

Despite the paramount importance of removing field heat immediately, it is only the first step in a long chain of handling, packing, shipping, and delivery. Below, Lisa Kitinoja and Adel Kader from the University of California-Davis discuss the "cold chain" from field to wholesaler. Farmers should measure and record produce and storage area temperatures at each stage until the wholesaler has picked up or received it.

Harvest

- Protect the product from the sun.
- Transport quickly to the packinghouse.

Cooling

- Minimize delays before cooling.
- Cool the product thoroughly as soon as possible.

Storage

- Store the product at optimum temperature.
- Practice first-in, first-out rotation.
- Ship to market as soon as possible.

Transport to Market

- Use refrigerated loading area, if possible.
- Cool truck before loading.
- Load pallets toward the center of the truck to minimize cool air loss through the walls.
- Put insulating plastic strips inside door if the truck makes multiple stops.
- Avoid delays during transportation.
- Monitor product temperature during transport.

Handling at Destination

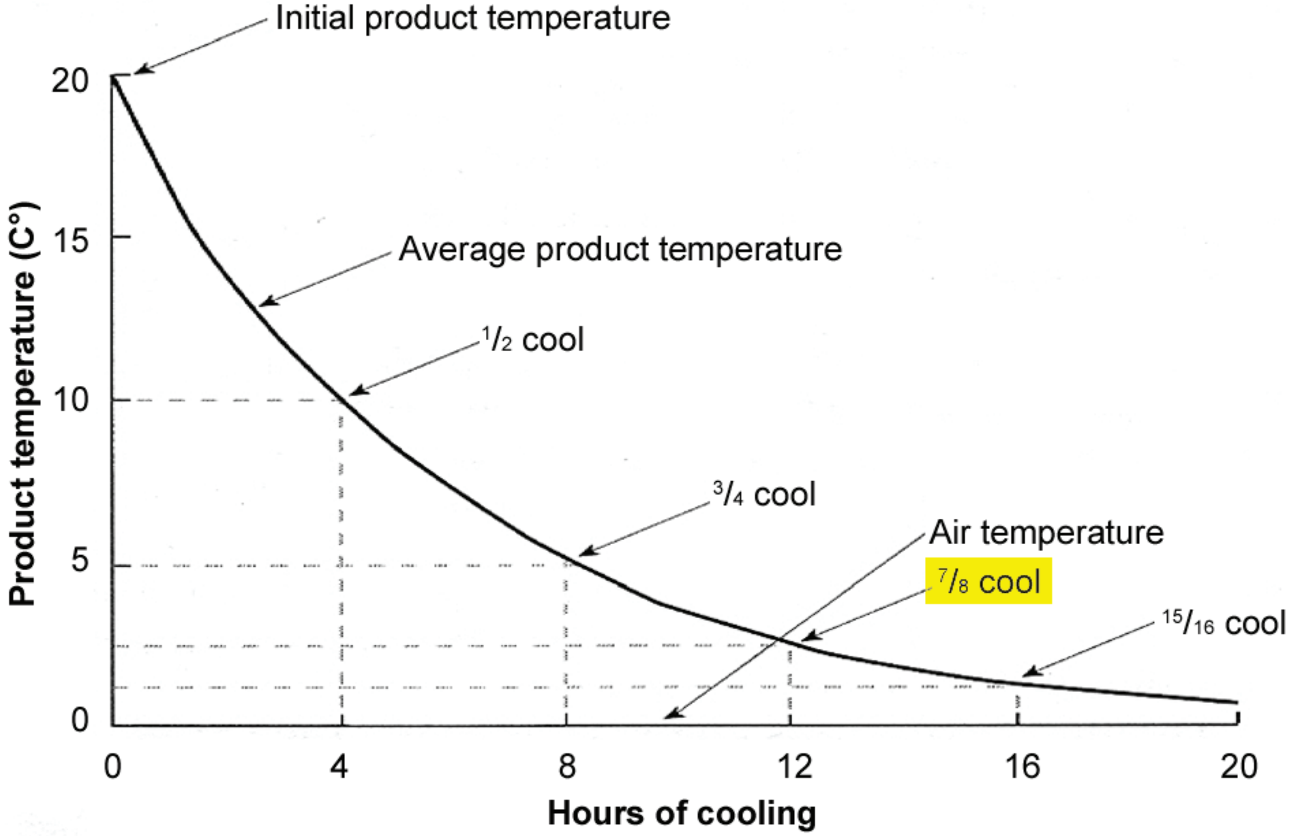
- Use a refrigerated unloading area.
- Measure product temperature.
- Move product quickly to the proper storage area.
- Transport to retail markets or foodservice operations in refrigerated trucks.
- Display at proper temperature range.

Shaded areas should be available for harvested produce, cooling facilities, packing and storage areas, and transport vehicles. Trees not only provide shade in the field, but also can drastically reduce ambient temperatures around packinghouses and storehouses. Also, lighting options should be evaluated; incandescent bulbs are in fact better suited for small-scale heating purposes than for lighting a cooled storage room. Look for fluorescent or high-pressure sodium lights, which produce far less heat and require less energy to provide the same amount of light as incandescent bulbs. Higher up-front costs will save money over the medium- and long-term. Make sure to shield bulbs so that if they break, glass shards will not contaminate any produce.

Comparison of Five Common Cooling Methods[8]

	Room cooling	Forced-air	Hydrocool	Water spray	Ice
Typical Cooling Time (hours)	20 to 100	1 to 10	0.1 to 1.0	0.3 to 2.0	0.1 to 0.3
Product Moisture Loss (%)	0.1 to 2.0	0.1 to 2.0	0 to 0.5	No data	No data
Water Contact with Product	No	No	Yes	Yes	Yes
Potential for Decay Contamination	Low	Low	High	High	Low

Typical cooling time for room cooling of large fruit (e.g., peaches) exposed to moderate amounts of airflow.[11]



Cooling Methods

Before transporting produce into refrigerated storage, it is important to remove field heat as quickly as possible. Several methods are available to do so, depending on the item's characteristics. It is important to use the proper cooling method for each type of produce. The chart on page 57 and Section 11: Crop Profiles provide specific cooling options for each produce type.

Cooling methods

1. Room cooling
2. Forced-air cooling
3. Hydrocooling
4. Water spray cooling
5. Icing

Prompt cooling to required temperatures inhibits growth of decay-producing microorganisms, restricts enzymatic and respiratory activity, inhibits water loss, and reduces ethylene production by the product.[9]

Half-Cooling Time

One of the most important concepts to understand the speed of cooling in postharvest handling is half-cooling time. This is the time required for the field temperature to drop halfway to the desired storage temperature. For example, corn harvested with an internal temperature of 95° F should be cooled to 32° F. The half-cooling time would be the time required to reach 63.5° F, which is halfway between 95° F and 32° F. Experts agree that 7/8 cooled (87.5%) is the appropriate time to remove the produce from pre-cooling and place in cold storage.

Getting to 7/8 cooled generally takes three times longer than the half-cooling time. Knowing the half-cooling time of a cooling process will enable you to calculate how long cooling to 7/8 temperature will take and if your cooling process is quick enough to achieve the desired shelf life.

The illustration on page 49 shows the half-cooling time in a typical room cooler for large fruit. In this scenario, it would take 12 hours to reach 7/8 cool. A quicker method would be needed for high-respiration crops or shelf life will be shortened. Small and mid-sized growers often use hydrocooling, icing, or forced-air cooling, which have much quicker half-cooling times than room cooling to bring high respiration produce quickly out of the high temperature range, and then finish cooling in room coolers. This method will not reach the ideal of 7/8 cooled before being placed in a room cooler.[10]

Room Cooling

Room cooling is not a true pre-cooling method, but uses the ambient temperature

Photo: Atina Diffley

At Harmony Valley Farm, unwashed root crops – low respirators – are cooled and stored in a room cooler. Space is left between bins to allow airflow. For food safety, unwashed produce and clean produce are kept in different parts of the cooler.

Photo: Atina Diffley

Featherstone Farm uses multiple cold rooms. One has been designed with high airflow and is kept at 33° F for rapid cooling. After produce reaches its ideal storage temperature it is moved to a second cold room with lower airflow to prevent dehydration. Chilling-sensitive crops, such as peppers and eggplants, that need to be stored at warmer temperatures, can be cooled in the cooling room, and then moved to a warmer cold room when they reach their ideal storage temperature.

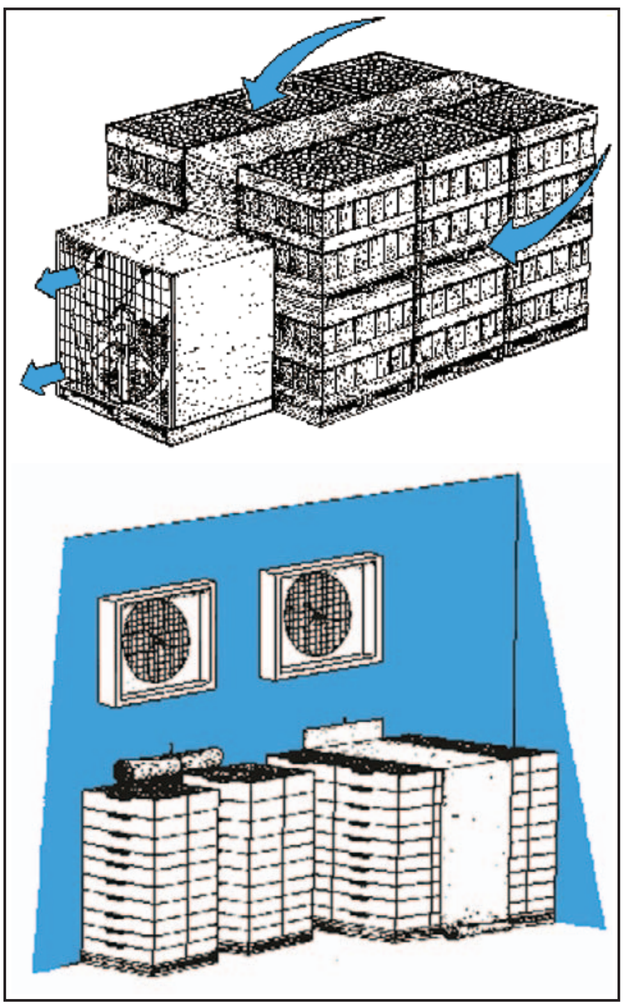
of a refrigerated storage facility to act as the cooling process. The University of Maryland Extension office defines room cooling as a cold room where air movement equals 200-400 feet (60-120 m) per minute or less through the containers.[12]

Cooling times in room coolers are too slow for moderate or high-respiration produce.

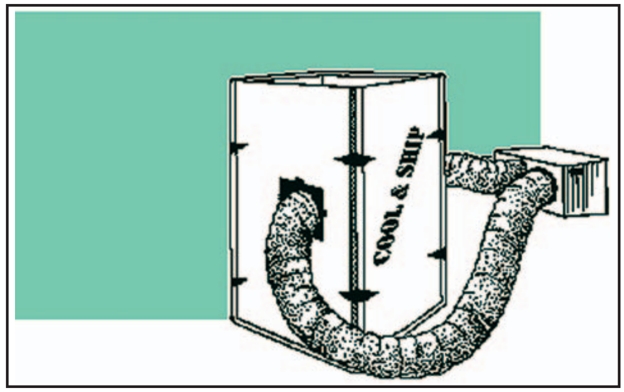
Room cooling can be an effective method for cooling less perishable items such as potatoes, gourds, onions, and some citrus fruits; and chilling-sensitive crops, such as peppers, eggplant, watermelon, or cucumbers.

To ensure equal cooling, leave space between stacks of boxes for good airflow; about 1 to 2 inches is sufficient to allow cold air to circulate around individual boxes. Produce in vented boxes will cool much faster than produce packed in unvented containers. If produce is loaded into the room tightly, cooling cannot take place at all. In small coolers, stacks of produce inside the cold room should be narrow, about one pallet width in depth. Rooms with high airflow rates can accommodate more depth than one pallet. Fans should be installed to move the cold air throughout the room. You'll want to monitor the temperature of the produce within the packages at various locations in the room to determine that the produce is being cooled as desired. Rearrange the stacks and measure the rate of cooling until you find the right pattern for your cold room.[13]

Room cooling systems should be well designed to maximize effectiveness. The cooling system should be large enough to handle the maximum heat load expected, but not so large that the extra capacity is wasted. There should be an air circulation system to mix the cooled air with the room air, but precautions are needed to prevent circulation drying out the produce. Cooling systems should be specially designed to work with high humidity levels, or problems with condensers freezing up can cause frequent shutting down of the system. Working with a refrigeration and cooling specialist to meet your farm's specific cooling and storage needs is recommended for designing cooling and storage systems.



Forced-air systems15



COOL AND SHIP: A LOW-COST, PORTABLE FORCED-AIR COOLING UNIT

(The North Carolina Agricultural Extension Service provides online plans for building and using a forced-air cooling system that also serves as a cold shipping unit. The Cool and Ship system provides rapid cooling for modest amounts of small fruit and is versatile, portable, reusable, and inexpensive. The system uses an air-conditioning system and common building materials. http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ag-414-7/index.html

Forced-Air Cooling

Forced-air units are ideal for berries, stone fruits, fruit-like vegetables, tubers, and cole crops, though most fruit and vegetables can be cooled using forced-air.[14]

Forced-air cooling is similar to room cooling but adds fans to direct air movement through pallets of produce. This method is much faster and more consistent than standard room cooling. Half-cooling times are often less than one hour. Forced-air units are also generally inexpensive and fairly easy to construct on site.

In a typical forced-air cooling setup, pallets are stacked and lined up in front of a pressure fan and covered with a tarp or other airtight covering. The tarp creates a tunnel and cold air is pulled through the pallets and through the containers. An effective and efficient forced-air system requires packaging with vents and a fan system capable of moving enough air to rapidly cool the produce (usually 1-2 cubic feet per minute per pound).

Because moving air also facilitates moisture evaporation, the amount of time produce is in a forced-air unit must be carefully managed or wilting, shriveling, and shrinkage can result.

Photos: Atina Diffley

The Harvest Cooler, a forced-air tunnel available from onfarmstorage.com, has two commercial Heatcraft cooling units. It's designed to cool 1,800 lbs. of carrots from 85° to 35° F in 6 to 8 hours. It is semi-portable and can be moved by a roll-off truck. Growers can use it to cool produce and then move the product into a different room cooler for storage. Or it can cool produce, and then be set with less air movement for storage.

During forced-air cooling the humidity of the air is not crucial for produce quality, except for some products such as mushrooms. Humid air actually slows the rate of forced-air cooling. However, the amount of time produce is in a forced-air unit must be carefully managed or dehydration can result. As soon as the product is cooled, it should be moved to a storage area that has the recommended relative humidity.

Do not blow air at the storage containers, but orient the fans so that they pull air over the produce and through the boxes of produce. Blowing air at the produce can "short-circuit" the airflow, with air going immediately back out the fan without reaching the containers. Ideally, there should be a separate room dedicated to forced-air cooling, but you can integrate it into a storage room by hanging a tarp from the ceiling or installing a second wall.

The formula for how much refrigeration is needed at any given moment can be calculated as follows: $(\text{Btu/hr}) = 2.1 \times (A - B) \times C \times D \div E$
Where:

A = Temperature of produce, ° F (° C)
B = Temperature of cooling air, ° F (° C)
C = Weight of produce being cooled, in lb. (kg)
D = Specific heat of produce, usually about 0.9 Btu/lb./° F (3.77 kJ/kg/° C)
E = 7/8 cooling time (hr)

For the initial stages of refrigeration, this equation will produce very high refrigeration

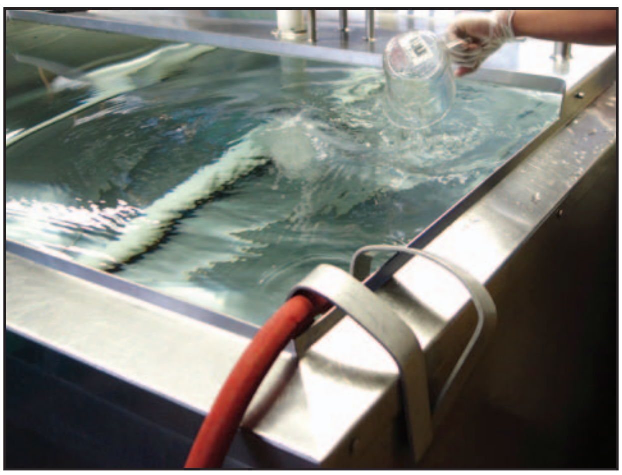
Photos: Atina Diffley

Plastic Blocks Air Flow *Produce should be fully cooled before blocking airflow with shrink film or cooling will be slowed. There are times where growers need to wrap before produce is cooled. In that case shrink film can be twisted to allow some air spaces.*

amounts, often over 20 tons. One ton of refrigeration equals 12,000 Btu. A general rule of thumb is to design for 2/3 of the amount of refrigeration required at the beginning of pre-cooling.

Cooling and refrigeration design are beyond the scope of this manual. *Commercial Cooling of Fruits, Vegetables and Flowers,* Revised Edition, 2008, from UC Davis, includes a complete discussion on design for hydrocooler and forced-air cooler systems. http://postharvest.ucdavis.edu/files/93530.pdf

These spray-washed, green-top, bunched carrots are now ready for hydrocooling at Loon Organics farm.



Photos: Atina Diffley

Tsunami sanitizer is measured and added to fresh and potable water before produce is added for cooling at Harmony Valley Farm. Below, staff monitors the sanitizer concentration with a test strip for a second time after mini-peppers have been added.

Another good book is *Refrigeration and Controlled Atmosphere Storage for Horticultural Crops*, NRAES-22 bulletin, by James A. Bartsch and G. David Blanpied. http://web2.msue.msu.edu/Bulletins/Bulletin/PDF/Historical/finished_pubs/e1914/e1914-ND.pdf

Hydrocooling

Hydrocooling takes advantage of water's ability to rapidly transport heat away from an object. While hydrocooling is one of the fastest and most uniform pre-cooling methods available, it is not appropriate for all crops, and can quickly distribute and internalize pathogens if the produce or worker's hands are not clean, if the water is not potable (safe to drink), or if it hasn't been properly sanitized.

Hydrocooling is generally best suited for leafy greens, brassica crops (except cabbage), asparagus, sweet corn, cucumbers, some fruit-like vegetables, stone fruits, and bunched root crops. Immersion in water should be avoided for crops that cannot tolerate exposure to high levels of water and crops that are very dirty.

A simple form of hydrocooling that is commonly used on small farms in northern areas is immersing produce in a tank of cool, ground-temperature water. To hydrocool produce to a colder temperature, a refrigerated unit could be used or ice can be added to the water, though refrigerated hydrocooling or adding ice is not a standard hydrocooling practice on small farms.

In the southeastern United States, ground water temperatures are generally 60° F or higher; and in Florida, they are 70° F or higher. That is not cold enough to cool produce and refrigeration or ice would be needed for this to be a viable cooling method.

Combining Hydrocooling and Room Cooling

Small growers in northern areas often combine hydrocooling and room cooling for a two-step cooling process. The first step of hydrocooling with cool ground-temperature water has a much quicker half-cooling time than room cooling and can quickly bring produce temperatures down. However, without a refrigeration unit or ice, the groundwater will not be cold enough to bring produce down to the ideal 7/8-cooled temperature before storage. The produce is then placed in a cold room to finish cooling to storage temperature. This combination can be a viable, reasonable, and realistic system for a small producer and is significantly better than only room cooling.

In southern states, groundwater temperatures are not cool enough for this system to work unless ice or refrigeration is used.

Produce Must Be Clean Before Immersion Hydrocooling

Immersing fresh produce in water creates a pressure differential that causes water to be pulled into the produce. The difference between the water temperature and the produce is very important. When the water temperature is colder than the produce, the amount of water absorbed increases.

If there are pathogens present on the produce surface or in the water they can become internalized. Subsequent washing will not reduce pathogen levels once they are inside the produce. It is crucial to practice good food safety procedures when immersing produce in water.

Slightly dirty produce must be cleaned in water that is no more than 10° F colder than the produce before cooling. Very dirty produce should be spray washed before hydrocooling. For more information see Section 5: Cleaning and Drying. Highly sensitive crops such as baby greens are often hydrocooled in a step-down approach. See "baby greens" on page 66 in Section 5: Cleaning and Drying for details.

Sanitation During Hydrocooling (and Washing)

The quality of the water used for washing and chilling the produce after it is harvested is critical for food safety. Using water that is not clean can contaminate many boxes of produce.

Hydrocooling also creates an opportunity for water-borne pathogens to reproduce readily. Additionally, because postharvest pathogens travel quickly in water and can be internalized, there is the potential for contamination of an entire load of produce.

Several important points should be considered when hydro- cooling:

1. Produce should always be cleaned before hydrocooling.
2. Water must be potable (safe to drink.)
3. Sanitizing agents should always be added to the water.
4. Good food safety practices must be used. Read more in Section 10: Food Safety.

Sanitizers

Peroxyacetic acid (PAA) is an increasingly popular sanitizer for use on produce, particularly for organic producers. PAA can be used to reduce fruit and vegetable surface microbial activity, thus reducing product spoilage by microorganisms and reducing

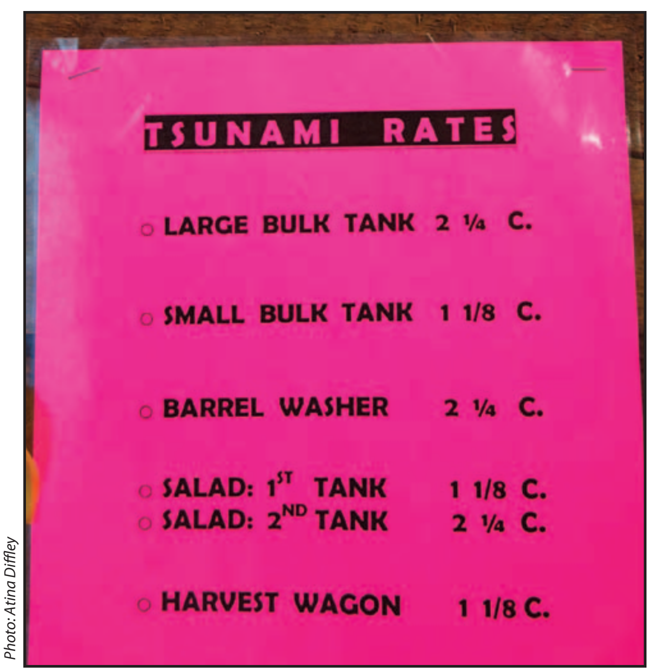


Photo: Atina Diffley

Tsunami sanitizer mix rates are posted on the wall next to the dispenser at Harmony Valley Farm.

the risk of foodborne illness. Peroxyacetic acid sanitizers are made by mixing hydrogen peroxide and acetic acid; the active ingredient's mode of action is through oxidation. The ingredients decompose into acetic acid, water, and oxygen, thus creating a safe sanitizing product. PAA is particularly appropriate for use in hydrocooling as it has low reactivity with organic matter and soils, thus providing more consistent microbial control. Also, it is effective across the wide pH ranges found in local water sources, allowing for effective microbial control in both acidic to slightly alkaline conditions.

PAA is available under several trade names. SaniDate 5.0 (www.biosafesystems.com) and Tsunami 100 (www.ecolab.com) are two popular brands of PAA. Tsunami 100 is used for pathogen reduction in fruit and vegetable processing water and is appropriate for the sanitation of produce. It can be used in both batch and continuous operations. Tsunami 100 reduces levels of the pathogens causing foodborne illness (including *Escherichia coli O157:H7*, *Listeria monocytogenes* and *Salmonella enterica*), as well as microbes causing decay or spoilage on the surface of produce. Alternatively, SaniDate 5.0 is a peroxyacetic acid-based sanitizer/disinfectant that can be used directly on produce as well as on pre-cleaned, hard, non-porous, food contact surfaces and equipment. It is effective against fungus, mold, and bacteria such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Salmonella choleraesuis*, *Salmonella enteriditis*, *Salmonella typhimurium*, *Proteus vulgaris*, *Streptococcus pyogenes*, *Enterobacter aerogenes*, *Lactobacillus maefermentans*, *Pediococcus damnosus*, *Listeria monocytogenes*, *Klebsiella pneumoniae*, and *Escherichia coli*.

When using either of these products, read the label and follow the instructions for proper use. They are strong oxidants, so use of personal protection is advised when handling them. Product concentrations must be maintained at the appropriate concentrations as outlined on the labels; appropriate test kits and equipment are available from the manufacturers for use in monitoring product concentrations.

Chlorine is an accepted disinfectant for hydrocooling water, but is subject to federal law and must be carefully monitored. Many farmers consider chlorine hazardous because of its toxic fumes and bioproducts formed in reaction with organic matter. Also some crops do not tolerate exposure to chlorine. As a result, more farmers are using peroxyacetic acid. Any farmer discharging water, such as from a hydrocooler, must comply with the Safe Drinking Water Act. Chlorine concentrations at the discharge/effluent point may not exceed the Maximum Residual Disinfectant Limit (MRDL) of 4mg/L for chlorine and 0.8mg/L for chlorine dioxide. Chlorine is allowed in organic production, as long as it remains within these limits. However, individual certification agencies may have more stringent regulations regarding the use of chlorine. Contact your certifier to ensure that you do not accidentally jeopardize your organic status. Chlorine materials may also be used to sanitize food contact surfaces but, again, the residual chlorine levels in the discharge water may not exceed the MRDL.

When using chlorine, measure the pH of the water before and after adding it. Chlorine is most effective in neutral water (pH = 7.0). When water is either acidic (pH < 6.5) or alkaline (pH > 7.5), much more chlorine is needed to act as a disinfectant. In water with a pH of 8.5, seven times as much chlorine must be added as for water with a pH of 7.0. Common acids such as lemon juice or vinegar can be added to increase acidity. However, making the water too acidic can result in the formation of chlorine gas, which is toxic. Certified organic operations should check the approved materials list to make sure that the particular acid is allowed. Use of personal protection is advised when handling chlorine. See Section 9: Postharvest Sanitation for more information on sanitizing.

Photo: Atina Diffley

Hydro spray cooling often involves produce being sprayed in a tote or on a conveyor belt, but here Cate, at Ridgeland Harvest Farm, sprays produce just in from the field with potable water as it waits for its turn in the water cooler. This can provide some cooling and helps prevent water loss until product can be cooled.

Water Spray Cooling

Produce can also be watercooled by spraying or moving the produce through running water. Because the produce is not immersed when sprayed there is less risk of water being imbibed into the produce. Also, sanitizers can be injected directly into spray-cooling water. Cleaning dirty produce with cold sprayed water combines cooling with cleaning. After the produce is cleaned, if further cooling is needed, it can be sprayed more, cooled in a hydrocooling water tank, or placed in a room cooler.

Icing

Using ice to cool produce and maintain the cold chain in storage, transportation, and sales is quick, simple, and uniform. While ice machines can seem expensive at first, this is a tool that can pay for itself in quality, shelf life, and farm reputation. If you can't afford an ice machine right now, purchasing ice when needed can be a viable option.

Icing is limited to produce that can withstand water-ice contact. Some crops should be iced, some can be iced, and some should never be iced. For information on each crop see the chart at the end of this chapter or Section 11: Crop Profiles.

Package icing is ideal for sweet corn and broccoli, and is frequently used for dark leafy greens such as kale, spinach, and collards, root crops such as radishes and carrots, cantaloupe, and green onions.

Bringing a high-respiration crop like broccoli down to storage temperature can be accomplished quickly with crushed ice.

Use water-tolerant shipping containers, such as waxed boxes or plastic totes, as ice will melt.

Crushed ice can also be used at farmers' markets and roadside stands to maintain cold produce when displayed without refrigeration.

Some Crops Should Never Be Iced

- Berries
- Green Beans
- Cucumbers
- Garlic
- Basil
- Okra
- Onions
- Romaine
- Potatoes
- Peppers
- Summer Squash
- Tomatoes

Photos: Atina Diffley

Above, field-packed broccoli is brought into the packing shed where it is iced, and then placed in a room cooler at the Diffley's Gardens of Eagan Farm. Below, Dehn's Produce uses ice to keep carrots fresh and crisp for farmers' market sales.

Cooling Information Chart[17,18]

CROP	Harvest Quality	Cooling Method	Respiration Rate	ICED	Cool To Store Temp
Apple		R, F, H	low	NO	32-38
Asparagus	bracts at tip closed	H, I	extremely high	YES	35
Basil	fresh, tender leaves		high	NO	50
Beans, snap	seeds developed, plump	R, F, H	very high	NO	41-46
Beans, lima	crisp pods, seeds immature	R, F, H	high	NO	41-43
Beets, bunched	crisp fresh leaves	H, I	high	YES	32
Beets, root	firm, deep red roots	R	moderate	Can	33-36
Blackberries	full color, sweet	R, F	high	NO	32
Blueberries	full color, sweet	R, F	moderate	NO	32
Broccoli	firm head, buds not open	I, F, H	very high	YES	32
Brussel sprouts	firm sprouts	H, V, I	very high	YES	32
Cabbage	crisp, firm, compact head	R, F	moderate	NO	32
Cantaloupe	full slip, rind color	H, F	moderate	NO	36-41
Carrots, topped	tender, sweet roots	I, R	moderate	YES	32
Cauliflower	compact, white curds	H, V	high	YES	32
Celery	crisp, tender	I	moderate	YES	32
Corn, sweet	plump tender kernels	H, I, V	extremely high	YES	32
Cucumbers	crisp, green, firm	F, H	moderate	NO	50-55
Eggplant	seeds immature; shiny, firm	R, F		NO	50-54
Endive	fresh, crisp, tender leaves	H, I	very high	YES	32
Garlic		N	low	NO	32
Leafy Greens	crisp, dark green leaves	H, I	very high	YES	32
Herbs	fresh, crisp, tender leaves			NO	32-41
Leeks	size, crisp	H, I	high	YES	32
Lettuce	compact head, crisp, tender	H, I	moderate	YES	32
Mushrooms	size, firm		very high	NO	32
Onions, bulb	firm bulbs, tight necks	N	low	NO	32
Onions, green	crisp stalks, firm white bulbs	H, I	very high	YES	32
Parsley	crisp, dark green leaves	H, I	extremely high	YES	32
Pear		F, R, H	moderate	NO	32
Peas, in pods	tender, green, sweet pods	F, H, I	extremely high	CAN	32
Peppers, bell	firm, shiny, thick walls	R, F	moderate	NO	45-50
Peppers, hot	firm, shiny, thick walls	R, F	moderate	NO	41-50
Potatoes, early	well shaped, defect free	R, F	moderate	NO	50-59
Potatoes, late	well shaped, defect free	R, F	very low	NO	40-54
Pumpkins	hard rind, good color, heavy	N	moderate	NO	54-59
Radishes	firm, crisp, dark green leaves	H, I	high	YES	32
Raspberries	full color, sweet	R, F	high	NO	32
Rutabagas	roots firm with smooth surface	R	low	NO	32
Spinach	dark green, fresh, crisp leaves	H, I	extremely high	YES	32
Squash, summer	firm, shiny, right size	R,F	moderate	NO	41-50
Squash, winter	hard rind, heavy, good color	N	moderate	NO	50-55
Strawberries	full color, sweet	R, F	high	NO	32
Sweet potatoes		N	low	NO	55-59
Tomatoes	firm, uniform coloration	R, F	moderate	NO	45-55
Turnips	firm, heavy roots	R, H, V, I	low	YES	32
Watermelon	crisp, good flesh color, not mushy	N	low	NO	50-59

F = forced-air cooling, H = hydrocooling, I = package icing, R = room cooling, V = vacuum cooling, N = no precooling needed.

Sources: USDA Agricultural Marketing Service, Kansas State University Extension, and Jim Waltrip at PetoSeed

2012 Production Guide for Storage of Organic Fruits and Vegetables NYS IPM Publication No. 10 Cornell University

While icing and liquid-ice cooling is effective to maintain quality, and can be a very useful tool for small and mid-sized growers who may not have consistent storage or delivery refrigeration, the national produce industry is moving away from its use because it requires waxed boxes or plastic crates, adds extra cost to transport, and is messy at a distribution center as it melts.

Finally, packing ice, like any water-based cooling system, can spread pathogens. To minimize food safety concerns, ensure that ice is made from potable water sources only and that ice making equipment and scoops are cleaned and sanitized regularly to prevent the spread of bacteria.

Curing

Onions, Garlic, and Shallots

If onions, garlic and shallots are sold for fresh market consumption they can be harvested, trimmed, cleaned, and packed without curing. For long-term storage, curing after harvest is necessary.

Alliums intended for storage should be harvested after the stalks have flagged and before the top is fully dry. The plant has stopped growing at that point and is beginning to go dormant. Spread bulbs out in a single layer, taking care not to bump or bruise them. Garlic and shallots are often bunched while pulling and hung in a shed. Dry greenhouses – with a shade cloth and good airflow – can be a good location for curing. Fans are used to circulate air and promote drying. Heated air can be forced under drying benches with a squirrel cage fan to speed the curing process.

After curing, roots and stems are cut off. Sharp pruners work well. Then the soil and loose skin are removed by rubbing the bulbs between gloved hands. Wearing cotton gloves with vinyl dots can speed the task. Large operations use mechanical roller toppers to speed this task, but they can cause bruising and only very hard varieties should be cleaned in them.

Sweet Potatoes

Although sweet potatoes can be eaten right away, their flavor and storage quality are greatly improved by curing at warm temperatures.

Photo: Atina Diffley

Onions curing on screen benches in the greenhouse at Grinnell Heritage Farm.

Photo: Atina Diffley

After harvest, sweet potatoes at Grinnell Heritage Farm will be cured before marketing.

Cure sweet potatoes by holding for about 10 days at 80° F - 85° F and high relative humidity (85 - 90%). If the temperature is 65° F - 75° F, they should be cured for 2-3 weeks. To maintain the required high humidity, stack storage racks or boxes and cover them with paper or heavy cloth, or pack in perforated plastic bags.

Winter Squash and Pie Pumpkins

Winter squash do not need to be cured before eating. For long term storage it is generally believed that if the rinds are soft, winter squash will keep better if cured for 7-10 days at 70° F to 80° F with good air movement. (With the exception of some varieties of acorn squash, which lose quality during curing).

A greenhouse can be a good place for curing. There is, however, limited information on the value of a curing period. Likewise, there is limited information regarding washing before storage. Some farms wash winter squash before storage. Others store unwashed and clean right before shipping.

After curing, winter squash and pie pumpkins should be held from 50° to 55° and at 50 to 75% humidity. Hubbard squash need more moisture and should ideally be held at 70 - 75% relative humidity.

Photo: Atina Diffley

At Small Family CSA Farm, winter squash is cured and stored unwashed on screen tables in a dry and well-ventilated greenhouse. If cold weather threatens, the house can be heated with wood.

Photos: Atina Diffley

At Harmony Valley Farm, winter squash is washed right in the field in a water tank on a moving wagon as part of the harvest process. Sanitizer is used in the wash water at a higher concentration. After washing, squash is packed in wooden bins and then stored in a dry greenhouse with good airflow.