Keeping Produce Fresh

Postharvest Handling for Market Growers and Farm-to-Institution Sales

PennState Extension

Carrots with bacterial soft rot and pythium. *Beth Gugino, Penn State Plant Pathology*

The canopy in well-weeded carrots will dry out faster compared to weedy carrots, reducing the propagation of bacterial disease. *Tianna DuPont, Penn State Extension*

Thrips can vector bacteria-causing soft rot in onions. *Ruth Hazzard, UMass*

One example of a cultural management which reduces post-harvest disease is the use of biodegradable mulches for onions. In this system the soil stays cooler and is less conducive to bacterial soft rot diseases. *Beth Gugino, Penn State Plant Pathology*

Consumers tell us that appearance and freshness drive their food purchases. How can we as producers keep produce quality high? As producers, it is our job to maintain quality from the field to the shelf through our handling, cooling, and storage.

Good Storage Starts with Growing a Healthy Crop

Storage can only prolong the life of the crop; it cannot improve its quality. Many storage problems start in the field.

Diseases

Plant disease infection will reduce produce storage and shelf life. For example, bacterial soft rot of carrots, caused by *Erwinia carotovora* or *Pseudomonas* spp., starts in the field with lack of rotation, and shows up later in storage. This bacteria enters crops from infected crop residue in the soil. Sufficient crop rotation allows time for plant tissue to degrade. Without a host, the pathogen dies and cannot infect the next crop.

Cultural controls to minimize disease such as a three-year rotation away from host crops, using resistant cultivars, and increasing air circulation by controlling weeds will help reduce plant disease and associated storage losses.

Insects

Insects can cause visible blemishes on produce, directly reducing consumer appeal. Additionally, these blemishes are holes in the protective layer of the produce that allow easier entry for the plant diseases that cause postharvest rots. Some insects can also vector diseases. For example, thrips can carry and transfer bacteria in their mouthparts to onions when they feed on the greens. These bacteria lead to bacterial soft rot in storage.

Fertility

Proper fertility is critical not only for yield but also quality. For example, calcium-deficient strawberries can be small, hard, and seedy. Phosphorus-deficient strawberries can be soft with insipid flavor. High-nitrogen fertilization is related to water loss in storage for sweet potato, decreased flavor in celery, and hollow stem in broccoli. Calcium deficiency can lead to blossom end rot in tomatoes, blackheart in celery, and tip burn in lettuce. Make sure to maintain fertility levels based on soil test recommendations. Often tissue tests can further help growers avoid nutrient deficiencies.

Irrigation

Adequate moisture is critical to maintaining quality. Water stress may reduce the overall yield as well as the size of the harvested produce. On the other hand, too much moisture can spread plant pathogens and increase the risk of infection from postharvest decays. Too much water and too much fertilizer also produce more succulent but weaker leafy greens.

Good Cultural Management

Selection of disease-resistant varieties is important for postharvest success. Additionally, practices that promote crop health such as staking and pruning tomatoes and using row covers to exclude plant pests will help produce high-quality vegetables and berries. Another example of a cultural management practice is the use of biodegradable mulches to reduce postharvest disease. In this system the soil stays cooler and is less conducive to bacterial soft rot diseases.

Harvest

How you handle produce during harvest directly affects produce quality. Injuries such as bruising, surface abrasion, and cuts leave produce open to disease-causing organisms, accelerate loss of nutrients such as vitamin C, and reduce consumer appeal.

- Pick produce with high transpiration early in morning when the produce is the coolest and fully hydrated.
- Shade harvested produce.
- Keep humidity high around most produce.
- Maintain air circulation.
- Harvest at the correct stage of maturity.
- Practice gentle and sanitary picking.
- Discard damaged produce.
- Pick clean (some crops).
- Don't overfill containers.
- Remove tomato stems and pack fruit shoulder side down.

Prevent Bruising and Scraping

Worker training is important to ensure that delicate produce is not bruised. This can be difficult. Farmer Atina Diffley, Gardens of Eagan, has a strategy to show instead of just tell her crew. She has a new worker pick one box of tomatoes and put it in the cooler with his/her name on it. The next day she has him/her sort the box. Just like human bruises, bruises on produce take some time to develop, and by the next day the new worker can clearly see his/her fingerprints where he/she squeezed ripe fruit too tightly. Hopefully next time he/she is more careful.

Minimize Hauling

Bumping and scraping produce during hauling can damage produce and provide entry points for disease.

- Harvest produce into bins and remove the bins with pallet jacks.
- Use roller tables to unload the pallets into sheds.
- Consider using harvest conveyors. (A new harvest conveyor may cost only $1,200. When it allows harvest of ½ mile of sweet corn in 20 minutes the returns are noticeable!)
- Use loading docks.

Use Systems to Keep the Produce Clean

Minimizing dirt on the produce reduces your labor to clean it and the potential to contaminate produce with human and plant pathogens.

- Straw, plastic, and living mulch reduce splash onto produce.
- Harvest in nonmuddy conditions when possible.
- Use clean and sanitized tools, knives, and harvest containers.
- Trim produce in the field, leaving the dirt in the field instead of bringing it into the packhouse.

When to Harvest

Harvest crops when they are at the appropriate maturity (Table 1). Keep in mind that the appropriate ripeness will depend on your buyer. For example, wholesalers generally want "turners," tomatoes with just a blush versus full ripe. Also consider whether the produce is best harvested wet or dry. For example, potatoes, eggplants, tomatoes, summer squash, and green beans are best harvested dry. Storage onions, garlic, and winter squash need to be dry before storage and are better harvested dry.

Additional detailed maturity indices for fruits, vegetables, and cut flowers can be found online at **postharvest.ucdavis.edu**.

Canopies on harvest trailers help keep produce cool and keep birds from contaminating produce. *Tianna DuPont, Penn State Extension*

Mechanical injury can impact the interior as well as exterior of fruit. *UC Davis*

Delicate zucchini should be placed in bins with stems all facing one direction to reduce scratching. *Andrew Puglia, Hillside Farm*
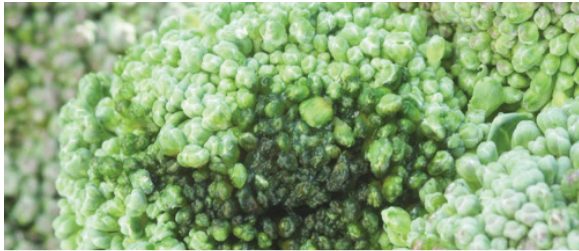

Cup zucchini with your hand as you remove from the plant to protect fruit from scratching by vines. *Andrew Puglia, Hillside Farm*

Trimming stems reduces scratching. *Andrew Puglia, Hillside Farm*

Does your produce look like this in the store? Minimize abrasion of produce while harvesting to increase consumer appeal on the shelf. *Tianna DuPont, Penn State Extension*

Rots such as this bacterial soft rot are usually associated with physical injury. *UC Davis*

Harvest conveyors are one way to minimize handling and promote efficiency. *Tricia Borneman, Blooming Glen Farm*

Annual ryegrass and clover planted between rows keeps harvest bins out of the mud and reduces splash. *Tianna DuPont, Penn State Extension*

Table 1. Recommended maturity for harvest.

Produce	Maturity
Broccoli	Bud cluster compact (overmature if loose)
Cabbage	Head compact (overmature if head cracks)
Cauliflower	Curd compact (overmature if flower cluster elongates and becomes loose)
Celery	Big enough before it becomes pithy
Eggplant, cucumber	Desirable size reached but still tender (overmature if color dulls or changes and seeds are tough)
Green onion	Leaves at their broadest and longest
Honeydew melon	Change in fruit color from a slight greenish white to cream; slight aroma noticeable
Lettuce	Big enough before flowering; firm, but not hard
Lima bean, pigeon pea	Well-filled pods that are beginning to lose their greenness
Muskmelon	Easily separated from vine with a slight twist, leaving clean cavity
Okra	Desirable size reached and the tips can be snapped
Potato, onion, and garlic	Tops beginning to dry out and topple down
Radish and carrot	Large enough and crispy (overmature if pithy)
Snap bean	Well-filled pods that snap readily
Sweet corn	Exudes milky sap from kernel if cut
Sweet pepper	Deep green color turning dull or red
Tomato	Seeds are not cut when fruit is sliced, or green color turning pink
Watermelon	Color of lower part turning creamy yellow; dull hollow sound when thumped

Source: Bautista and Mabesa (1977).

Slowing the Produce Aging Process

A one-hour delay in cooling can reduce the shelf life of produce by a day or more.

Produce is alive. Even after we harvest it from the plant, produce continues the metabolic activity that allowed it to grow while on the plant. But after harvest, produce cannot photosynthesize, or take up water to replace the water and energy it is expending. Learning the basics about these metabolic processes can help us learn how to slow them down and prolong the life of our harvested produce.

Respiration

Fresh produce respires to produce energy. It uses stored carbohydrates, proteins, and fat, and releases CO_2 (carbon dioxide) and heat (Figure 1). As produce loses carbohydrates to the air as CO_2, consumers lose flavor and shelf life, and the produce appears shriveled.

Plants need oxygen in order to respire (Table 2). If there is not enough oxygen available, the produce will ferment. Some crops respire at higher rates than others (Table 2). Make sure you know which crops have higher respiration and how to manage them.
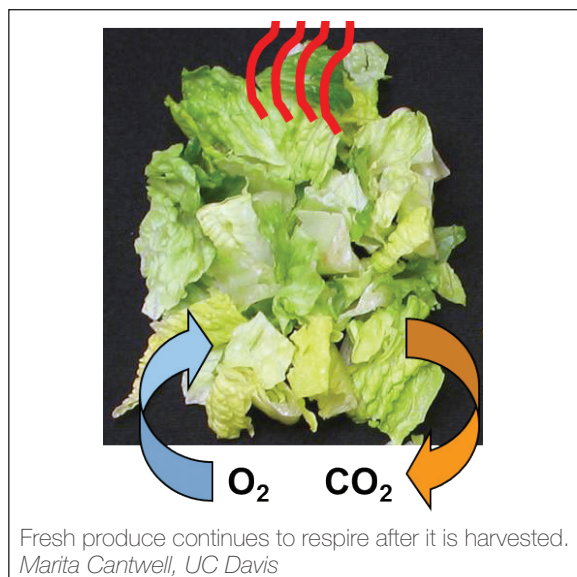
Ethylene

Ethylene (C_2H_4) is a natural hormone that plants produce and use to regulate growth and development. Generally, ethylene rates increase with maturity and when produce is injured.

During storage ethylene can damage sensitive crops. For example, exposure to ethylene causes russet spotting on lettuce and yellowing in broccoli. Ethylene damage generally does not occur in less than 24 hours of exposure. Exposures are cumulative.
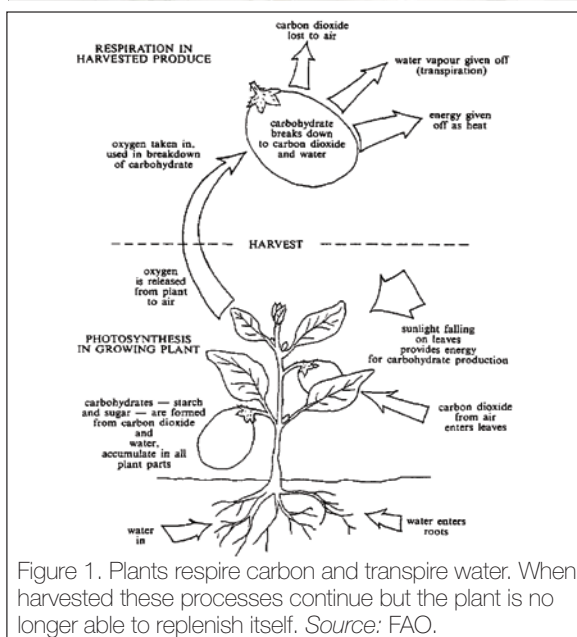
Rapid and efficient cooling help prevent damage. Eliminate internal combustion engines that generate ethylene from storage rooms, and periodically vent the storage area. Producers can also place ethylene-absorbing filters in storage rooms.
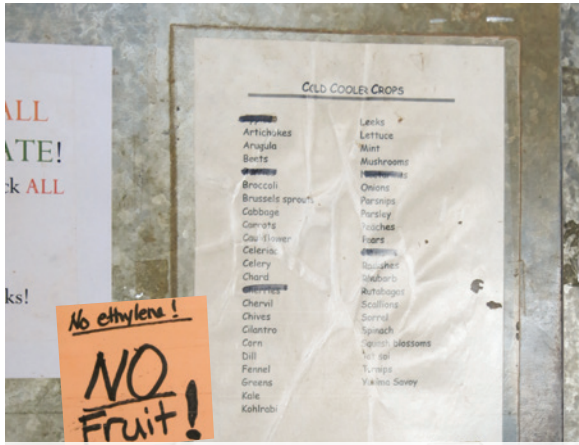
Market growers often see ethylene damage when they store apples, which release high ethylene levels, with sensitive crops like broccoli.

Fresh produce continues to respire after it is harvested. *Marita Cantwell, UC Davis*

Ethylene damage in collards. *Marita Cantwell, UC Davis*

Ethylene filter. *Tianna DuPont, Penn State Extension*

Table 2. Respiration rates of common produce.

Respiration Rate	Commodity
Very low	Nuts, dried fruit
Low	Apple, beet, celery, garlic, onion, potato, sweet potato, watermelon
Moderate	Cabbage, cantaloupe, cucumber, lettuce, peach, pear, pepper, plum, potato (immature), radish (topped), summer squash, tomato
High	Blackberry, carrot (w/tops), cauliflower, leeks, leaf lettuce, radish (w/tops), raspberry
Very high	Bean sprouts, broccoli, Brussels sprouts, endive, green onions, kale, okra, snap beans
Extremely high	Asparagus, mushroom, parsley, peas, spinach, sweet corn

Figure 1. Plants respire carbon and transpire water. When harvested these processes continue but the plant is no longer able to replenish itself. *Source:* FAO.

Keep ethylene-producing crops in separate coolers, especially for long-term storage. *Tianna DuPont, Penn State Extension*

Bin liners can reduce transpiration losses. *Andy Andrews, Pennypack Farm, courstesy of Spiral Path Farm*

Water loss symptoms. The tomato on the far left shows no loss, while the one to the right exhibits high loss. *Marita Cantwell, UC Davis*

After six days of refrigeration without protective packaging, lettuce to the left has lost much of its water due to transpiration. *Tianna DuPont, Penn State Extension*

Polyethylene liners keep humidity high and reduce water transpiration losses. *Tianna DuPont, Penn State Extension*

Transpiration and Water Loss

Each hour of exposure to warm, dry air results in over twice as much water loss as holding produce in high-humidity cold storage for one week.

Most fresh produce is 85 to 95 percent water when harvested. Within growing plants there is a constant flow of water. Liquid water is absorbed from the soil by the roots, then passed up through the stems, and finally lost from the aerial parts, especially leaves, as water vapor.

The passage of water through the plants is called the transpiration stream. It maintains the high water content of the plant. A lack of water will cause plants to wilt and perhaps die.

Fresh produce continues to lose water after harvest, but unlike in the growing plant, it can no longer replace lost water with water from the soil. Instead it uses up water in the harvested produce. This loss of water from fresh produce after harvest is a serious problem that causes wilting and shriveling as well as loss of weight.

When harvested produce loses 5 or 10 percent of its fresh weight, it begins to wilt and shrivel and becomes unusable. To extend the usable life of produce, its rate of water loss must be as low as possible.

The rate of water loss varies with the type of produce. Leafy green vegetables, especially spinach, lose water quickly because they have a thin skin (epidermis) with many pores. Others, such as potatoes, which have a thick corky skin with few pores, have a much lower rate of water loss.

A significant factor controlling water loss is the ratio of produce surface area to its volume. The greater the surface area in relation to the volume, the more rapid the loss of water will be.

Main ways to slow transpiration:
- Lower the temperature.
- Increase the humidity.
- Reduce air movement.
- Protect the produce with packaging.

The faster the surrounding air moves over fresh produce, the quicker water is lost. Air movement through produce is essential to remove the heat of respiration, but the rate of movement must be kept as low as possible during storage. Well-designed packaging materials and suitable stacking patterns for crates and boxes can contribute to controlled airflow through produce (Table 3).

Table 3. Percent weight loss per day of sample crops at lower and higher relative humidity.

Crop	Storage Temperature (°F)	Relative Humidity (%)			
		95	90	85	80
Brussels sprouts	32	1.6	3.2	4.8	6.4
Cabbage	32	0.06	0.12	0.18	0.23
Carrots	32	0.315	0.63	0.95	1.3

Chilling Injury

Freezing injury occurs when produce is held below its freezing temperature. Generally, collapse of the tissues and total loss of the commodity occur when it is rewarmed.

Chilling injury is a different problem. Certain types of produce are also injured when they are held at temperatures above their freezing point but below their critical point of 41 to 59°F, depending on the produce (Table 4). Common symptoms are internal browning, pitting, water-soaked areas, failure to ripen, and accelerated decay.

Shelf life of chilling sensitive to active produce decreases at excessively cold temperatures. For example, cucumbers could be stored for 90 days at 55°F but only 20 days at 32°F.

Chilling injury on eggplant includes pitting, large sunken areas, and internal browning. *Tianna DuPont, Penn State Extension*

Chilling injury can cause seed browning in peppers. *Tianna DuPont, Penn State Extension*

Sweet potato chilling injury. *UC Davis*

Table 4. Typical chilling injury symptoms on fruits/vegetables.

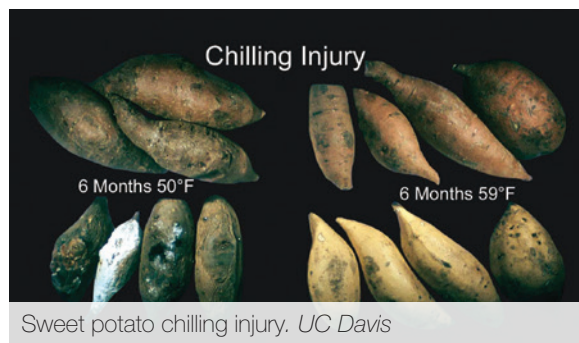| Commodity	Symptoms
Beans	Darkening or dullness if stored below 41°F; rusty brown lesions if stored at 41 to 46°F; discoloration of seeds, increased susceptibility to decay, surface pitting
Cantaloupe	Only sensitive to chilling injury if stored below 36°F for extended periods; fruit can show surface browning and decay after removal from storage
Eggplant	Brown, discolored areas; surface pitting leading to large sunken areas; calyx discoloration; seed and flesh browning
Melons	Failure to ripen normally; water-soaked areas; increased susceptibility to decay; dull or bronzed surface
Okra	Darkening and discoloration; pitting; water-soaked areas; increased susceptibility to decay
Peppers	Surface pitting leading to large sunken areas; seed browning; calyx discoloration; water-soaked tissue; increased susceptibility to decay, especially Alternaria rot
Summer squash/cucumber	Surface pitting followed by brown or black lesions; water-soaked areas; increased susceptibility to decay
Tomatoes	Short exposure (4 to 6 days at less than 50°F) results in poor flavor; longer exposure causes failure to ripen normally, pitting, shriveling, and softening, and increased susceptibility to decay with Alternaria rot a diagnostic symptom
Watermelon	Surface pitting and sunken areas that dehydrate upon removal from storage; off-flavors; internal brown discolored areas on rind
Winter squash	Weakening of tissue, especially on the stem with increased susceptibility to decay, particularly Alternaria rot

Source: Dris, Niskanen, and Jain (2001).

On this moderate summer day with a high of 85°F at 8:00 a.m., the produce temperature was 61°F. At 11:00 a.m., it was 74°F. *Tianna DuPont, Penn State Extension*

Insulated reflective covers can keep produce cool during harvest and transport. *Andy Andrews, Spiral Path Farm*

Room cooler. *Andrew Puglia, Hillside Farm*

Large shared cooler. *Tuscarora Organic Growers*

Cooling

Crops harvested earlier in the day will have a lower internal temperature, which means less energy and time to cool them. A one-hour delay in cooling reduces produce shelf life by one day or more.

It is critical to promptly cool produce to slow down carbohydrate and vitamin loss from respiration, reduce water loss from transpiration, and decrease decay. For example, a six-hour delay in strawberry cooling can result in 50 percent more water loss. Prompt cooling is especially critical for crops with high respiration rates and high surface area. For example, the respiration rate of salad greens at 50°F is four times higher than it is at 32°F (Table 2).

Cooling delays can also reduce quality due to physiological changes in the produce. For example even a four-hour delay in cooling asparagus can allow it to create more lignin and result in 50 percent tougher spears.

- Minimize the delay between harvest and the start of cooling.
- Start harvest early to protect produce from temperatures above 70 to 75°F.
- Shade produce after harvest to prevent excess temperature rise, sunburn, and sunscald damage.
- Use shaded receiving areas.
- Even placing an empty picking box on top of a filled box protects produce from temperature gain.
- Protect produce from moisture loss during cooling by using vented plastic liners, bin covers, or plastic containers.
- Some produce, like carrots, can be sprinkled with water to reduce moisture loss during temporary holding at warm temperatures before cooling.

Shaded fruit temperature is usually within a few degrees of air temperature, but produce exposed to sunlight can be 7 to 11°F (4 to 6°C) warmer than air temperature.

Room Cooling

Room cooling is a standard cooling practice on small and medium farms. It has the advantage of providing storage and cooling in the same place and a simple design. However, room cooling has several disadvantages:

- Cooling can be slow, requiring 24 hours to several days.
- Produce is often shipped without adequate cooling.
- Sensitive produce can deteriorate measurably in the time required for cooling.
- Significant moisture is lost.
- Produce containers without sufficient venting or stacked too close together are particularly slow to cool.
- Moisture released by the warm-interior produce may condense and cause moisture on colder outside produce, causing decay growth.

Design your room cooler correctly. Talk to your local cooling engineer for a design. Your cooler should have:

- A fan capacity of 100 cubic feet per minute (cfm) per ton of maximum produce capacity to use during cooling
- An air-handling system that distributes air uniformly throughout the room
- The ability to reduce airflow rate to 20 to 40 cfm per ton after produce is fully cool for storage

Forced-air Cooling

Forced-air cooling uses fans in conjunction with a cooling room to pull cool air through packages of produce. Although the cooling rate depends on the air temperature and the rate of airflow, this method is usually 75 to 90 percent

faster than room cooling. Fans should be equipped with a thermostat that automatically shuts them off as soon as the desired produce temperature is reached.

A tunnel cooler (Figure 2) is the most common design for forced-air cooling. Pallet loads of produce are placed in two lanes on either side of an open channel in a cold room. A tarp is placed over the produce, covering the open channel. A fan is placed at the end of the tunnel and situated to suck cold air through the tunnel and back to the cooling unit to cool produce down as rapidly as possible.

- Bins and packaging must have openings to allow cold air to pass over individual pieces of produce.
- Packaging/bin vents should comprise 5 percent of the side area.

Hydrocooling

Dunking produce into cold water or running cold water over produce is an efficient way to remove field heat and can serve as a means of cleaning at the same time. In addition, hydrocooling reduces water loss and wilting. Using an appropriately labeled disinfectant in the water is recommended to reduce the spread of foodborne pathogens and postharvest diseases. Due to food safety concerns, hydrocooling is becoming less widely used because of the potential for water to move pathogens among produce.

Hydrocooling is not appropriate for berries, potatoes to be stored, sweet potatoes, bulb onions, garlic, or other commodities that cannot tolerate wetting.

Water removes heat about five times faster than air but is less energy efficient. Well water is a good option. However, it usually comes out of the ground with temperatures in the 50 to 60°F range. If you are cooling with well water, you will need to create a multistep system that cools the rest of the way with room or forced-air cooling.

Mechanical refrigeration is the most efficient method for cooling water. A thermal storage immersion hydrocooler system can be fabricated economically to suit various volume requirements.

Used stainless steel bulk farm milk coolers may be an option. If hydrocooling water is recirculated, it should be chlorinated (or other approved sanitizer) to minimize disease problems.

For large volumes of produce, shower hydrocooling over boxes/bins may not reach the center of the stack of bins.

In shower-type hydrocoolers, produce moves slowly through a continuous shower of cold water. Smaller diameter produce will cool more quickly than larger diameter

Clean baby greens are cooled by forced-air cooling inside a larger walk-in. *Andy Andrews, Spiral Path Farm*

Berries move on a conveyor through a chilling room. *Sand Hill Berries Farm*

In this hydrocooling system, lettuce on a conveyor goes through chilled (34°F) water in order to quickly cool. *Andy Andrews, Spiral Path Farm*

Large bulk tanks can be used to hydrocool produce. *Sandy Arnold, Pleasant Valley Farm*

Most well water is 55 to 60°F and will not bring all produce down to optimum temperature. *Tianna DuPont, Penn State Extension*
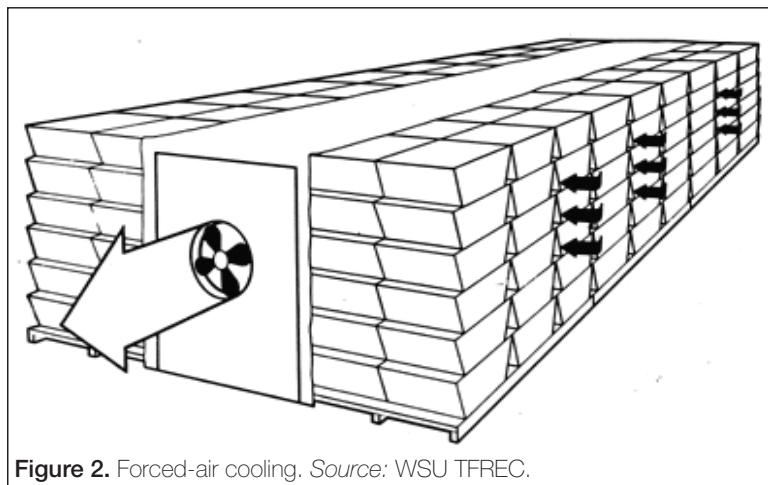

Figure 2. Forced-air cooling. *Source:* WSU TFREC.

Green onions are cooled and rinsed as they are un-loaded from the truck onto roller tables, which convey produce into the pack area. *Andy Andrews, Pennypack Farm, courtesy of Spiral Path Farm*

Table 5. Cooling methods for different crops.

Crop	Cooling Method
Asparagus	H, I
Basil	R
Beans, snap	R, F, H
Beets, bunched	H, I
Beets, no tops	R
Blackberries	R, F
Blueberries	R, F
Broccoli	I, F, H
Cabbage	R, F
Cantaloupe	H, F
Carrots, topped	I, R
Corn, sweet	H, I, V
Cucumbers	F, H
Eggplant	R, F
Endive	H, I
Garlic	N
Leeks	H, I
Lettuce	H, I
Onions, green	H, I
Onions, storage	N
Peas	R, H, I
Peppers	R, F
Potatoes, early	R, F
Potatoes, late	R, F
Potatoes, sweet	N
Pumpkins	N
Radishes	H, I
Rutabagas	R
Spinach	H, I
Squash, summer	R, F
Squash, winter	N
Strawberries	R, F
Tomatoes	R, F
Turnips	R, H, V, I
Watermelon	N

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

Source: Kitinoja and Thompson (2010).

produce. You need a large amount of water, about 10 gallons per minute per square foot of cooling area, to rapidly cool produce. It is also important that the distance between the spray nozzles and the produce never exceeds 6–8 inches. Water pressure can cause surface pitting and water–soaked damage on sensitive leaves and fruit.

Icing

In top icing, crushed ice is added to the container over the top of the produce by hand or machine. For liquid icing, a slurry of water and ice is injected into produce packages through vents or handholds without removing the packages from pallets and open-ing their tops. Icing methods work well with high-respiring com-modities such as sweet corn and broccoli. One pound of ice will cool about 3 pounds of produce from 85°F to 40°F. See Table 5 for which produces can be iced and what produce is harmed by icing. However, dripping water from iced containers can be a liability issue and the ice adds to produce weight and transport costs.

Other Options

Explore options for cooling if appropriate, including vacuum cooling. Vacuum coolers can accommodate a truckload of lettuce, and small vacuum coolers are available for one or two pallets. Tables 5 shows which cooling method is preferred for different produce, and Table 6 provides a comparison of cooling methods.

Table 6. Comparison of cooling techniques.

	Room Cooling	Forced-air Cooling	Hydrocooling	Package Ice
Typical Cooling Time (hours)	20–100	1–10	0.1–1.0	0.1–0.3
Produce Moisture Loss (%)	0.1–2.0	0.1–2.0	0–0.5	No data
Water Contact with Pro-duce	No	No	Yes	Yes
Potential for Decay Contami-nation	Low	Low	High	Low
Capital Cost	Low to medium	Low	Low	High
Portability	No	Sometimes	Rare	Yes

Source: Kitinoja and Thompson (2010).

Storage

The most efficient way to extend the shelf life of your produce is to quickly remove field heat and then maintain your produce at the correct temperature (Table 7). For example, in one trial, broccoli stored at 55°F started yellowing in just 6 days compared to 35 days at 32°F.

Good cold-storage facilities contain:

- Adequate insulation
- A vapor barrier on the warm side of insulation to prevent moisture condensation
- Effective distribution of refrigerated air
- Sensitive and properly located controls
- Enough refrigerated coil surface to minimize the difference between coil and air temperatures
- Adequate capacity

Keeping High Relative Humidity in Cold Storage

In order to minimize water loss, keep relative humidity at 85 to 95 percent for fruit, and 90 to 98 percent for vegetables except for garlic, dry onions, and pumpkins (70 to 75 percent).

To maintain relative humidity:

- Add moisture with misters (not recommended for food safety).
- Regulate air movement and ventilation.
- Maintain refrigeration coils within 2°F of the air temperature.
- Use polyethylene liners (polyliners) in containers.

Tips for Cold Storage

- Stack bins in cold rooms with spaces between pallets and room walls to ensure that cold air can circulate and cool produce.
- Use plastic curtains on doors to reduce loss of cold air.

Examples of Storage Facilities

The most common produce storage is a refrigerated cooler or insulated room. Coolers should be sized appropriately to handle the maximum volume of produce expected.

For some growers (e.g., those on rented ground), buying a used, insulated marine shipping container and adding a refrigeration unit may prove cost effective.

CoolBot-equipped Cold Room

Another option for providing refrigeration is to use a modified air conditioner. The control system of the unit is modified to allow it to produce low air temperatures without building up ice on the evaporator coil. Without this unit, the ice buildup restricts airflow and stops cooling. Recently a company developed an easily installed controller that prevents ice buildup but does not require modifying the control system of the air condition;er (CoolBot, Store It Cold, LLC, **storeitcold.com**). Assuming prices in U.S. dollars, a room air conditioner with a CoolBot control system costs about 90 percent less than a commercial refrigeration system of equivalent capacity. However, keep in mind that while the air conditioner/CoolBot system has the capacity to keep the air temperature at 36°F, it does not have the capacity to cool large volumes of produce quickly, which is important for produce quality.

Liners help reduce transpiration loss during cooling and storage. *Andy Andrews, Spiral Path Farm*

Exposed lettuce produce on the left will have high water loss, while produce on the right is protected from drying. *Tianna DuPont, Penn State Extension*

Bins should have spaces between them to allow for good airflow. *Andy Andrews, Pennypack Farm*

Plastic curtains on doors help retain cold air and save energy. *Tuscarora Organic Growers*

Insulated shipping container retrofitted with a cooling unit to provide produce storage. *Roots to River Farm*


CoolBot control system and air conditioner for a small cold room. *Roots to River Farm*

A carport serves as protection for workers and produce. Bathroom facilities and walk-in coolers are located in barn directly to the rear. *Tianna DuPont, Penn State Extension*

Barn converted to a packhouse with food-grade-painted walls, covered ceilings, and cement floors to allow for easy cleaning. *Penn State Extension*
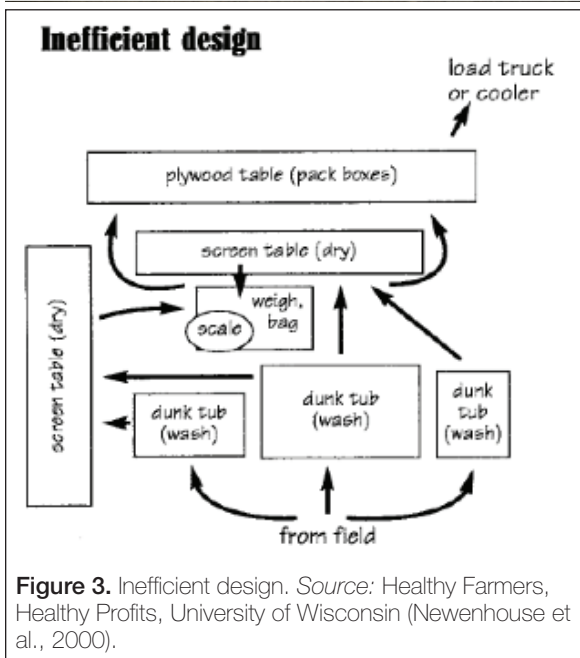
Figure 3. Inefficient design. *Source:* Healthy Farmers, Healthy Profits, University of Wisconsin (Newenhouse et al., 2000).

Convenient storage of bags, twist ties, and other packing materials increases worker efficiency. *Barefoot Gardens*

Packing Shed

Why Update Your Packhouse Design?

Every extra movement equals time and money. One Pennsylvania farm shared that packhouse labor is one-quarter the labor on their farm, which is second only to harvest labor. Making workers in the packhouse comfortable, happy, and efficient by creating a healthy and efficient working environment will make you money. For high-quality produce your packhouse must be designed with postharvest science and food safety in mind.

Minimum Packhouse Requirements

- A roof with sidewalls will protect workers and produce from the sun, wind, and rain.
- A walk-in cooler allows you to preharvest crops and deliver them chilled to the buyer.
- A supply of potable water and drains to move the water away. This could be as simple as a set of hoses or a deep gravel bed.
- Bathrooms and handwashing facilities are necessities. Workers handling produce must be able to take care of sanitation needs easily. The handwashing station does not have to have warm water, but warm water will encourage workers to wash for the recommended 20 seconds. Soap and single-use towels are a must.
- To address other food safety concerns, protocols should be made for sanitizing equipment and facilities, and pests should be excluded. Open-air packing facilities can't exclude pests, but they can make the packing area less inviting to rodents, flies, and birds by keeping the area clean of debris, installing bird netting over open rafters,

and moving pallets regularly. For more information, go to **extension.psu.edu/food/ safety/farm/gaps**.

Packhouse Location

Centralized access to the packhouse on the farm can be helpful. Also think about how produce will enter the area. Doors that open to the level of your produce wagons and/or delivery trucks can improve efficiency.

Design and Flow

Have you ever taken the time to watch how produce moves through your pack area from the field/truck to the cooler and back out to delivery? Does it look like this (Figure 3)?

In order to see your packhouse with new eyes, enlist the help of a fellow farmer or other person new to your farm, or video record the packhouse in action. Think about how you can reduce the number of movements (steps, bending over, etc.) by creating a step-by-step task line.

Consider the following:
- Is your space large enough for your packing needs?
- Is there a clear, uncluttered path for produce and workers to follow?
- Is there plenty of light?
- Does some produce need to be sprayed and others dunked?
- Could you run two lines into a shared workstation that has water and electricity?
- Is the scale handy and easy to use?
- Are supplies such as bags and rubber bands kept where needed?

Packhouse at New Morning Farm

Jim Crawford wants to ensure efficient flow in the packhouse (Figure 4). Produce comes in on trucks or carts that back up to the correct height so workers can unload with pallet jacks and move directly into the cooler for cooling without having to lift boxes. For produce that must be spray washed after cooling, the crew washes at spray tables that can be adjusted to an ergonomic height for each worker. Directly after spray tables are the spinner for greens and dry pack area. Convenient shelves contain bags, twist ties, knives, and other postharvest tools.

Packhouse Worker Health

Washing and packing involve a lot of repetitive labor. Think about ways to make workers more comfortable.

- Are workstation heights adjusted to individual workers?
- For lightweight items, efficient work height is halfway between wrist and elbow measured when the arm is held down at the worker's side (slightly lower for heavier items).
- Do electrical cords have ground fault circuit interrupters? They are easy to install and can prevent electrocution.

Variations on Basic Components

- **Dunk tanks.** Greens are often triple-rinsed to remove soil and freshen them. Depending on the volume of produce you are working with, you may want to have larger or smaller basins.

- **Spray tables.** Tables can be of different materials, such as stainless steel; however, wood is not recommended for surfaces that contact produce. Spray tables may also have screens, plastic liners, floor tiles, and other components to aid in keeping the area clean and produce safe.

Labor Savings and Efficiencies

Washing and packing can consume a quarter of the labor on a farm. A well-designed packhouse can pay for itself quickly in reduced labor costs. Here are a few examples of potential labor saving components to include in your packhouse where appropriate:

- Pallets and pallet jacks
- Roller tables
- Conveyors
- Sorting tables
- Barrel washers
- Brush washers
- Foldable bins

Barrel washers make washing root crops quick. For example, 160 pounds of turnips can be washed in 10 minutes. The barrel is at a slight angle. It rotates at various speeds driven by a small motor and a belt. Crops are fed into one end. As crops proceed down the barrel they are sprayed by a series of small jets from the metal pipe bracketed inside the barrel. A worker on the other end monitors the vegetables entering a bin placed at the exit. Roots that are not clean enough are tossed back in for another washing. Quickly spraying bins with a hose before they are poured into the washer helps remove larger clumps of soil and reduce the number of roots that have to be thrown back in for a second washing.

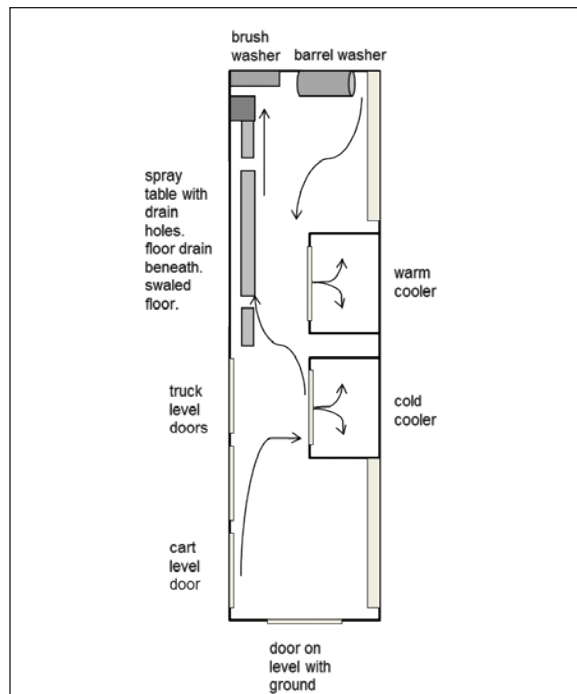Brush washers can be used for many types of produce. Be careful to have a thorough and

Figure 4. Packhouse. *Source:* New Morning Farm.

Triple-basin stainless steel sinks often can be acquired from restaurants going out of business. *Luna Farms*

Plastic laundry basins (right) can be plumbed to function as triple-rinse sinks that can be sanitized easily. *Penn State Extension*

One-hundred-gallon and 150-gallon horse troughs are often used for washing medium-scale amounts of greens. *Penn State Extension*

Spray tables made with floor tiles provide an easily cleanable surface that is also smooth and less likely to nick produce. *Tianna DuPont, Penn State Extension*

Stainless steel spray tables like this one with a channel for spray water to drain off are sometimes available when restaurants go out of business. *Tianna DuPont, Penn State Extension*

This screen table for spraying greens is fitted with a plastic liner for catching spills when produce is shipped and plumbed to allow water to drain away. *Tianna DuPont, Penn State Extension*

Pallets and pallet jacks save time and your workers' backs. *Tianna DuPont, Penn State Extension*

frequent cleaning and sanitizing schedule for brushes that can hold foodborne-illness-causing pathogens. Because most cannot be taken apart to be cleaned they can be a food safety concern. Gears will eventually wear on these machines.

Food Safety in the Packhouse

- Do you have a handwashing station?
- An enclosed packing area is preferred.
- Open walls are okay if measures are taken to keep pests out.
- Keep the area clean and uncluttered.
- Check the roof and walls for signs of water entry.
- Water should drain away.
- Glass fixtures should be shatterproof or covered.
- Have a regular cleaning schedule for all areas.
- Avoid using water-absorbing materials (e.g., wood) where produce comes in contact with the surface.
- Avoid surfaces that are difficult to clean.
- Water must be potable.
- Use a sanitizing agent in wash water.
- Use a test strip or ORP (oxidation-reduction potential) meter to check the concentration of wash water sanitizer.
- Change the water when it's dirty.
- Clean/sanitize the tank between uses.
- Monitor the temperature.
- Do not wash overly dirty produce; prewash it.
- Clean your hands and equipment!
- Be sure sanitizers used are approved for food contact.

For more detailed information, visit **extension.psu.edu/food/ safety/farm/gaps**.

This spray table uses a cement mixing pan to catch spray water; the screen is on hinges for easy access to clean the basin; and the overhead piping of water keeps hoses off the floor. *Andy Andrews*

Small pallets with wheels can allow one person to move six bins in one trip and fit easily in smaller walk-in coolers. *Sandy Arnold Pleasant Valley Farm*

These bins collapse flat so that they take up less storage space and are easy to wash/sanitize. *Andy Andrews*

EZ-tilt pallet jacks and mini pallets make it easy to move large amounts of produce into tight spaces in coolers. *Sisters Hill Farm*

Barrel washer. *Blooming Glen Farm*

Brush washer. *Scholl Orchards*

Crates on wheels, knife racks, automatic front doors, and a cement floor in the cooler all help improve efficiency in the pack area. *Sandy Arnold, Pleasant Valley Farm*
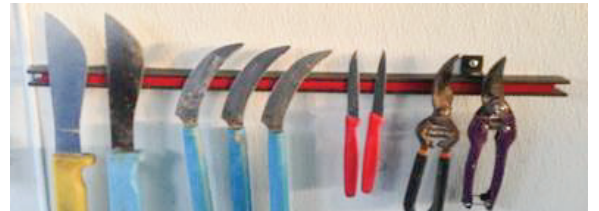
Knife racks keep harvest knives organized and clean. *Pleasant Valley Farm*

Sorting tables allow workers to efficiently size produce and check for quality. *Scholl Orchards*

This wash area has stainless steel spray table and triple-basin sinks as well as dry-pack tables. Shelving conveniently houses waxed boxes. Lights are covered with shatter proof plastic. The painted concrete floor is easy to clean and contains a floor drain. Mats make standing for long periods easier on workers. The handwashing sink is located to the rear. *Tianna DuPont, Penn State Extension*

This packhouse is covered to protect produce. All clean produce-contact surfaces are stainless steel or washable hard plastic. A sanitizer is used to clean all surfaces before each wash-pack. Potable well water is used for triple-rinsing produce with a food-safe sanitizer in the first and last washes. *Tianna DuPont, Penn State Extension*

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Table 7. Compatible fresh fruits and vegetables during seven-day storage.

Group 1A: Vegetables, 32–36°F, 0–2°C, 90–98% relative humidity

Alfalfa Sprouts	Artichoke	Arugula*	Asparagus*	Beans: Fava, Lima
Bean Sprouts	Beet	Belgian Endive*	Bok Choy	Broccoli*
Brussels Sprouts	Cabbage*	Carrot*	Cauliflower*	Celeriac
Celery*	Chard*	Chinese Cabbage	Chinese Turnip	Collard*
Corn: Sweet, Baby	Cut Vegetables	Daikon*	Endive* - Chickory	Escarole*
Fennel	Garlic	Green onion*	Herbs* (not Basil)	Horseradish
Jerusalem Artichoke	Kale	Kohlrabi	Leek*	Lettuce*
Mint	Mustard Greens*	Parsley*	Parsnip	Radicchio
Radish	Rutabaga	Rhubarb	Salsify	Shallot
Snow Pea*	Spinach*	Sweet Pea*	Swiss Chard	Turnip
Turnip Greens*	Water Chestnut	Watercress*		

Group 2: Vegetables, 45–50°F, 7–10°C, 85–95% relative humidity

Basil	Beans: Green, Wax	Cactus Leaves (Nopales)	Calabasa	Chayote*
Cowpea	Cucumber*	Eggplant*	Long Bean	Okra*
Pepper: Bell	Pepper: Chili	Summer Squash*	Tomatillo	

Group 2: Fruits, 45–50°F, 7–10°C, 85–95% relative humidity

Grapefruit*	Lemon*	Lime*	Orange	Passion Fruit
Pummelo	Tamarillo	Tamarind	Tangelo	Tangerine
Ugli Fruit	Watermelon			

Group 3: Vegetables, 55–65°F, 13–18°C, 85–95% relative humidity

Cassava	Dry Onion	Ginger	Potato	Pumpkin
Squash: Winter, Hard Rind*	Sweet Potato*	Tomato	Yam*	

Group 3: Fruits, 55–65°F, 13–18°C, 85–95% relative humidity

Crenshaw Melon	Honeydew Melon			

*Ethylene level should be kept below 1 ppm in storage area.

For More Information

- Fruit Growers News Buyers' Guide: read.uberflip.com/i/404935-fgn-2015-buyers-guide/2
- Leopold Center for Sustainable Agriculture Post-Harvest Handling Decision Tool: **www.leopold.iastate.edu/cool_tools/post_harvest_handling_decision_tool**
- Penn State Extension Farm Food Safety: **extension.psu.edu/food/safety/farm**
- UC Davis Postharvest Yellow Pages: **postharvest.ucdavis.edu/yellowpages**
- Vegetable Growers News Buyers' Guide: **read.uberflip.com/i/417108-vgn-2015-buyers-guide**

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Thompson, J. F., et al. *Commercial Cooling of Fruits, Vegetables, and Flowers*. Oakland: University of California Division of Agriculture and Natural Resources, 2008.

Thompson, J. F., et al. "Effect of cooling delays on fruit and vegetable quality." *Perishables Handling Quarterly* 105 (2001): 2–5.

For more information on farm food safety, visit **extension.psu.edu/food-safety-and-quality/farm-food-safety.**

extension.psu.edu