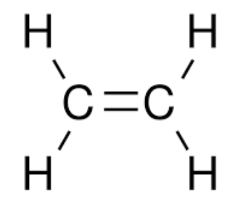
Ethylene



Ethylene (C_2H_4) is a simple gaseous organic molecule.

As a plant hormone, it is involved in regulation of growth, ripening, senescence and abscission processes.

Ethylene is naturally synthesized in plants, but also evolves from engines and fires. It is biologically active at very low concentrations in the range of ppm levels.

Ethylene

- Ethylene is a simple hydrocarbon gas (C_2H_4); produced when organic materials are burned with too little oxygen.
  - Poorly adjusted forklifts, gas or wood heaters
- It is also a ripening hormone for plants.
- Ethylene in a storage area can cause serious produce quality problems.
- High ethylene producing produce stored with ethylene sensitive items can cause premature or over-ripening and quality loss.
  - Can cause yellowing or browning, softening, spotting, sprouting in potatoes, flavor degradation, etc.

Ethylene Producers

- • Apple
- • Apricot
- • Avocado
- • Banana
- Berries
- Cherries
- Grapefruit
- • Kiwi, ripe
- Lemon
- Lime
- • Mango
- • Melons
- • Nectarine
- Orange
- • Papaya
- • Passion Fruit
- • Peach
- • Pear
- Pineapple
- Plantain
- • Plum
- Prune
- • Quince
- Tangerine
- • Tomato

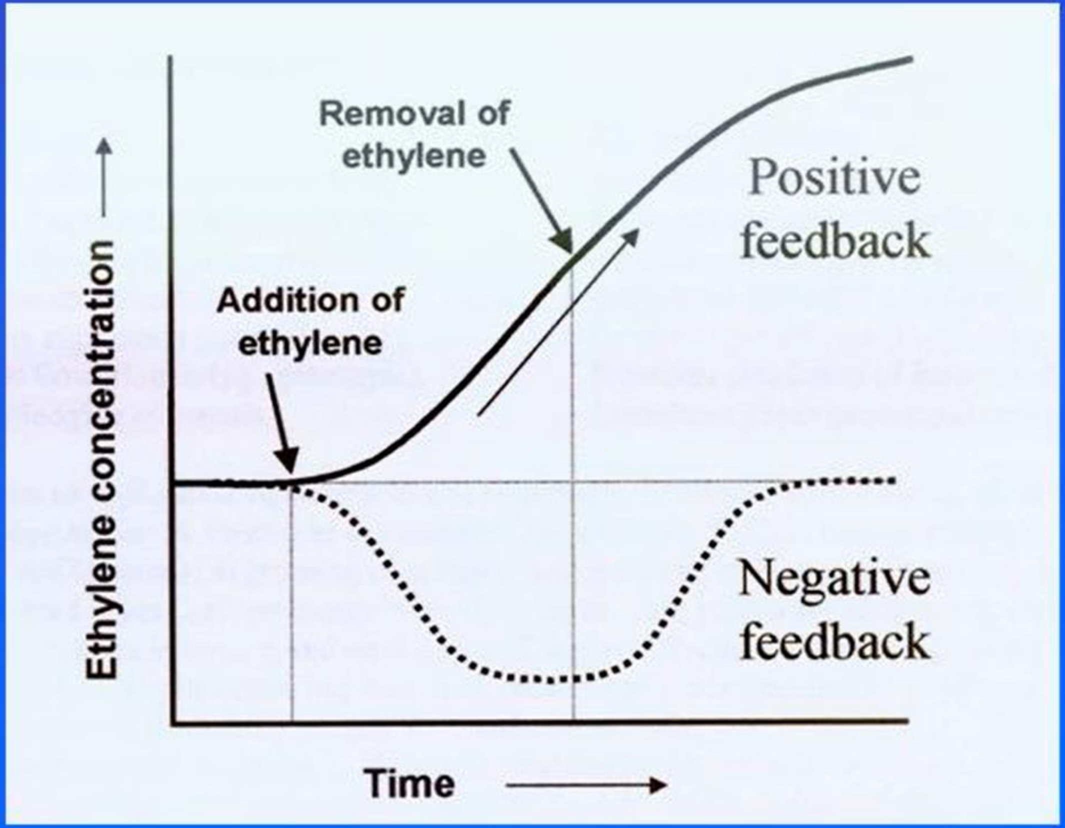
Ethylene Sensitive

- Asparagus
- Beans, snap
- Bok Choy
- • Broccoli
- • Brussels Sprouts
- • Cabbage
- Carrots
- • Cauliflower
- • Celery
- Chili Pepper
- • Cucumber
- Daikon
- Eggplant
- • Endive
- Escarole
- • Fresh Herbs
- Grapes
- • Green Onion
- • Leafy Greens
- Leek
- • Lettuce
- Okra
- • Parsley
- Peas
- • Persimmon
- Potato
- Spinach
- Sprouts

• Varieties that are both high ethylene producers and are highly sensitive to its effects. • Exceptionally sensitive

Autocatalytic production of ethylene

In climacteric fruit, the natural increase in ethylene production during ripening stimulates its own synthesis – a phenomenon called "autocatalytic production of ethylene".



In some climacteric fruits, such as avocado, banana, melons, pears and tomatoes, the autocatalytic positive feedback may increase ethylene production rates by 1,000 x fold during ripening.

Exposure to external ethylene also enhances autocatalytic production of ethylene and ripening!

Regulation of ethylene biosynthesis

Generally, ethylene production increases:

- with maturity at harvest
- after physical damage (dropping, wounding)
- in decayed fruit
- at increasing temperatures up to 30°C
- during stresses (water stress, chilling, etc.)

On the other hand, ethylene is reduced by:

- low storage temperatures
- reduced O_2 levels (below 8%)
- elevated CO_2 levels (above 2%)

Atmospheric ethylene

Beside its own biosynthesis, harvested produce may be exposed to atmospheric ethylene.

Sources for atmospheric ethylene include exhaust from trucks and forklifts, pollution from industrial activity and burning of fuels, fires, and from nearby ripening climacteric fruit.

Beneficial uses of ethylene in postharvest

Commercial postharvest applications of ethylene are used to:

1. Promote full and uniform ripening of bananas, avocado, mango and green-harvested tomatoes.
2. Promote color change (degreening) in citrus fruit.

Optimal conditions to promote ripening

Considerations to achieve uniform ripening:

- Temperature between 18-25°C
- RH about 90-95%
- Ethylene concentration between 1-100 ppm
- Duration of treatment between 1-5 days
- Adequate air circulation in ripening room
- Ventilation and air exchange to prevent excess accumulation of CO_2

Sources of ethylene

Ethylene could be applied to ripening rooms from:

- **Industrial gas cylinders** (including explosive-proof ethylene mixtures in inert gases without presence of oxygen)
- **Ethylene generators** (produce ethylene from dehydration of ethanol by heating)

$$C_2H_5OH - H_20 \rightarrow C_2H_4$$

- **Ethylene releasing agents** ('Ethepon')
- **Use of ripen fruit**

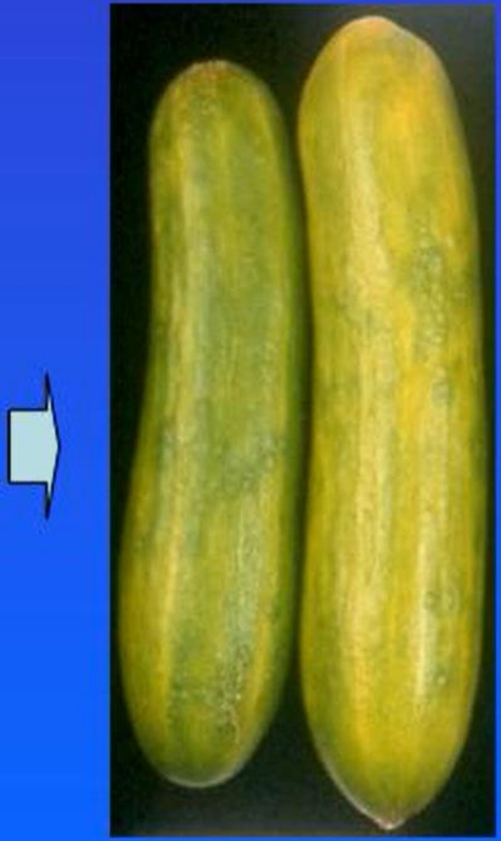
- **It is also produced by heating either natural gas, especially its ethane and propane components, or petroleum to 800–900 °C, giving a mixture of gases from which the ethylene is separated**

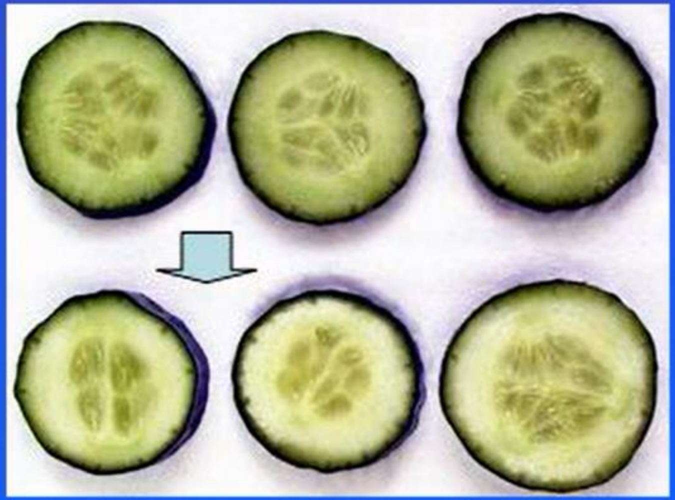
Undesirable effects of ethylene

As the main ‘ripening’ and ‘senescence’ hormone, ethylene has detrimental effects on postharvest storage and quality.

1. Accelerates leaf senescence.
2. Accelerates ripening and fruit softening.
3. Accelerates flower wilting
4. Accelerates abscission
5. Stimulates sprouting of tomato
6. Stimulates lignification and toughening of asparagus
7. Causes leaf and peel disorders

Yellowing and change in texture





Peel disorders caused by ethylene

Preventing the deteriorative effects of ethylene

Measures to reduce ethylene effects:

1. <u>Eliminate the sources of ethylene</u>:

- Do not hold stocks of ripen fruit near ethylene sensitive commodities
- Use electric powered forklifts
- The truck loading area should be isolated from handling and storage areas.
- Remove decayed pellets of fruit
- Do not smoke or burn fires in the packinghouse area

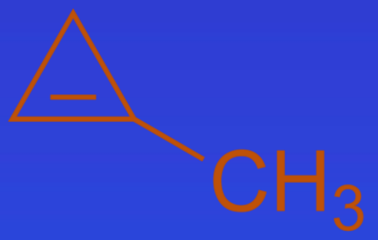
2. Ventilation: harvested produce synthesize ethylene. Therefore, simple ventilation (using an intake fan and a passive exhaust) can effectively remove excess ethylene.

3. Ethylene absorbers: ethylene may be absorbed from storage rooms by using chemical scavengers, such as potassium permanganate and charcoal.

4. Inhibition of ethylene action: use of 1-MCP.

1-MCP was discovered in the early 1990s and is a very effective inhibitor of ethylene. It is now being licensed for use in fruit and vegetables.

Commercial products of 1-MCP



EthyBlock® – for use with ornamentals

SmartFresh® – for use with fruit and vegetables

- 1-Methylcyclopropene (1-MCP) is cyclopropene derivative used as a synthetic plant growth regulator. It is structurally related to the natural plant hormone ethylene and it is used commercially to slow down the ripening of fruit and to help maintain the freshness of cut flowers

Compositional changes

Compositional changes that occur during ripening and continue after harvest:

- **<u>Changes in pigments</u>:**

<u>Loss of chlorophyll</u> (green color) – is desirable in fruit but not in vegetables.

<u>Development of carotenoids</u> (yellow and orange colors) – desirable in various fruits, such as apricots, peaches, citrus, tomatoes, etc.

<u>Development of antocyanins</u> (red and blue colors) - desirable in various fruits, such as cherries, strawberries, etc.

Loss of chlorophyll after harvest

- **Changes in metabolites**:

Loss of sugars

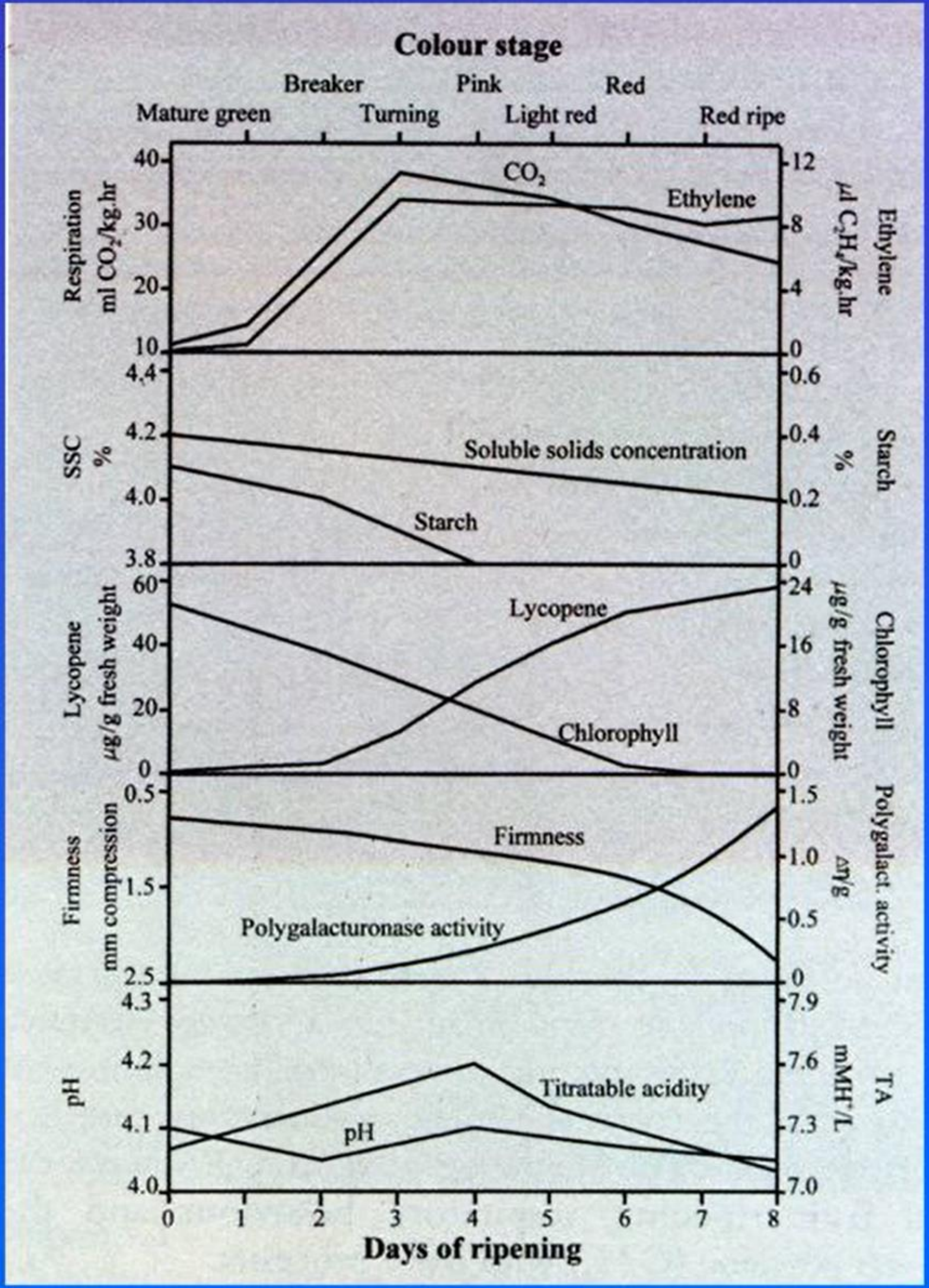
Loss of acids

Loss of amino acids

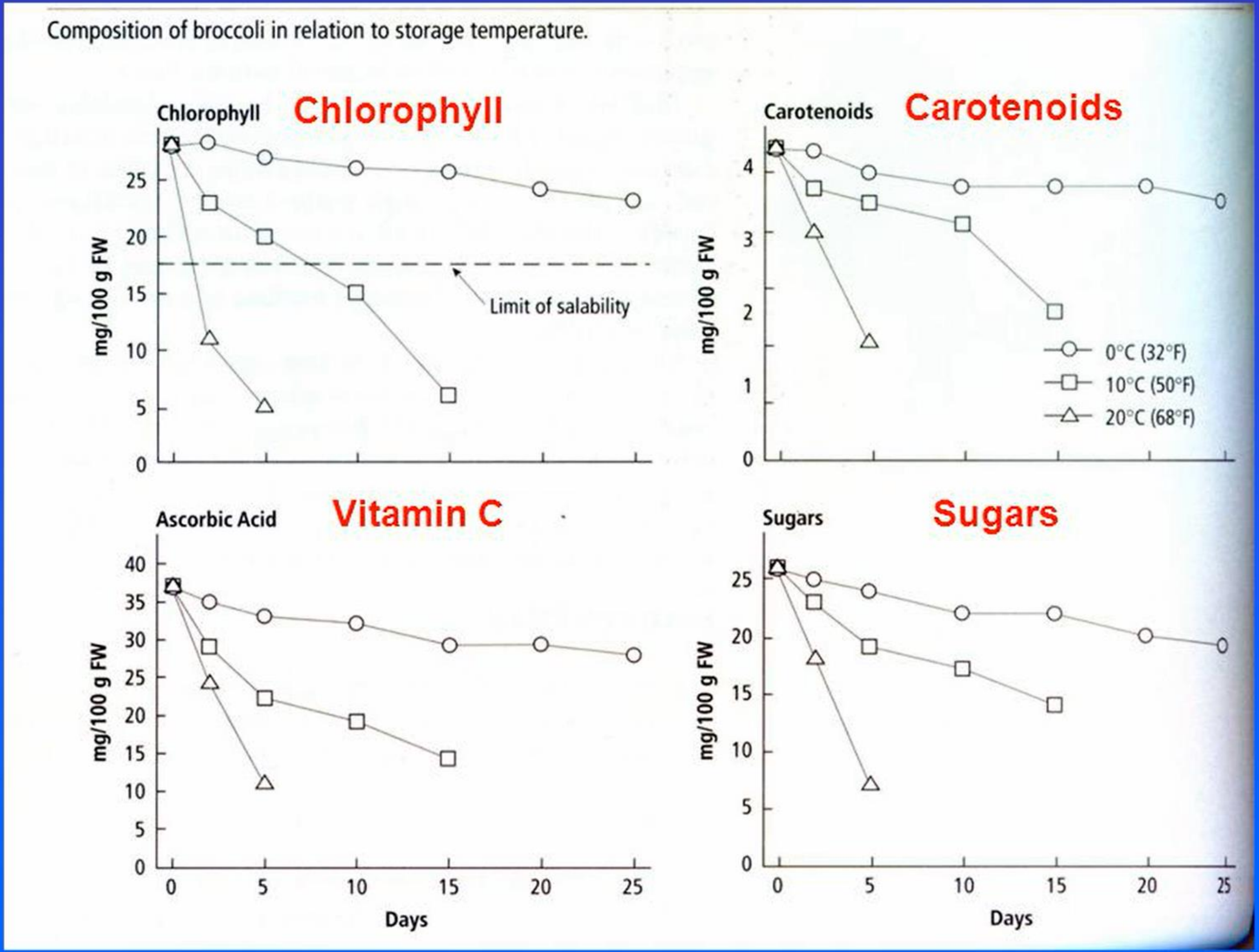
Loss of lipids

Loss of vitamin content

Metabolic changes during ripening of tomato



Metabolic changes in broccoli after harvest



Water loss

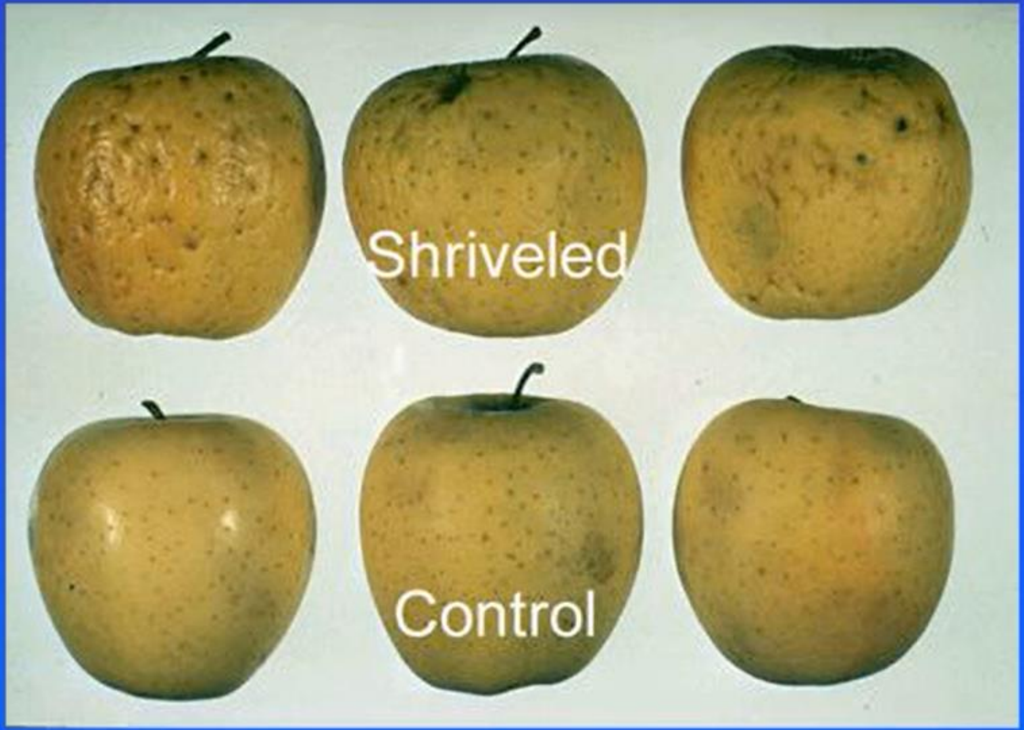
Water loss is a main cause of deterioration because it results in:

- Direct loss of salable weight
- Loss in appearance (wilting and shriveling)
- Loss of textural quality (softening, crispness)

Small fruit have large surface-to-volume ratios, and especially suffer from water loss!

Water loss and shriveling

Apple



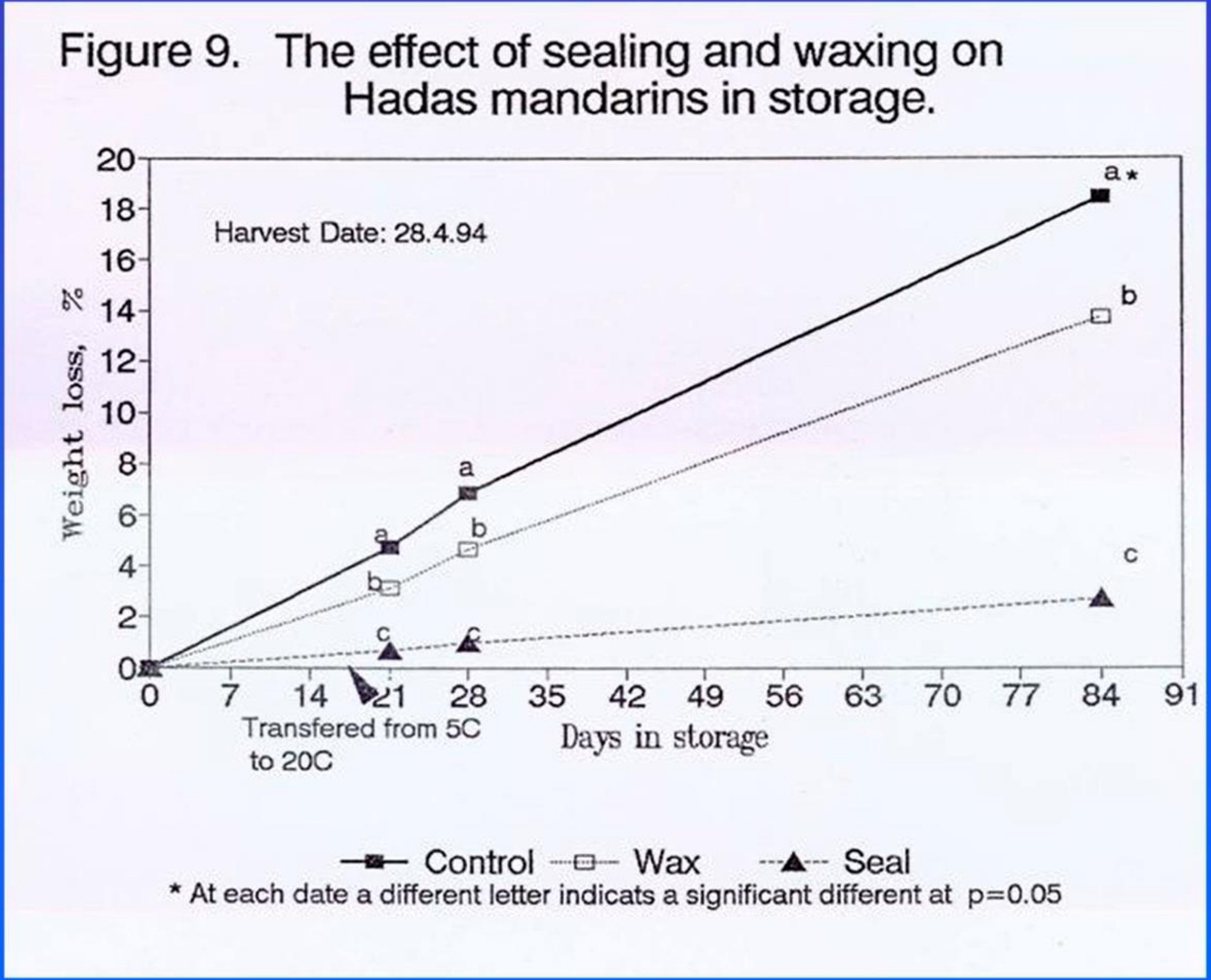
Peach

Ways to reduce water loss after harvest:

1. Low temperatures
2. High RH
3. Prevent surface injuries
4. Application of waxes or other coatings
5. Wrapping with plastic films

Reduction of water loss and shrinkage using plastic liners

Effects of wax and seal packaging on weight loss of mandarins

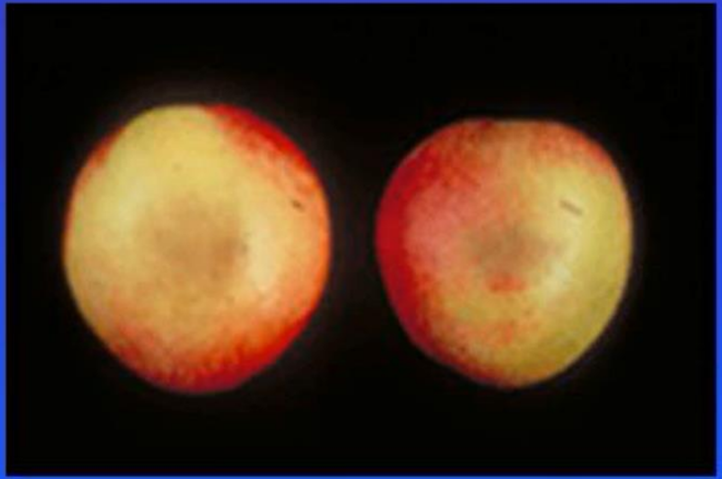


Physical damage

Physical damage (surface injuries, bruising, vibration damage) is a main contributor to deterioration.

The damaged areas become brown (because leakage of phenolic compounds), accelerate water loss, stimulate ethylene production, and provide sites for pathogen invasion.

Bruising damage in apple, nectarine and cherry



Bruising and skin abrasion in guava and banana

Skin Abrasions

Physiological breakdown

Physiological disorders may develop following storage under undesirable conditions or as a result of improper preharvest management leading to ‘weak’ fruit with nutritional imbalances.

Physiological disorders caused by improper storage conditions:

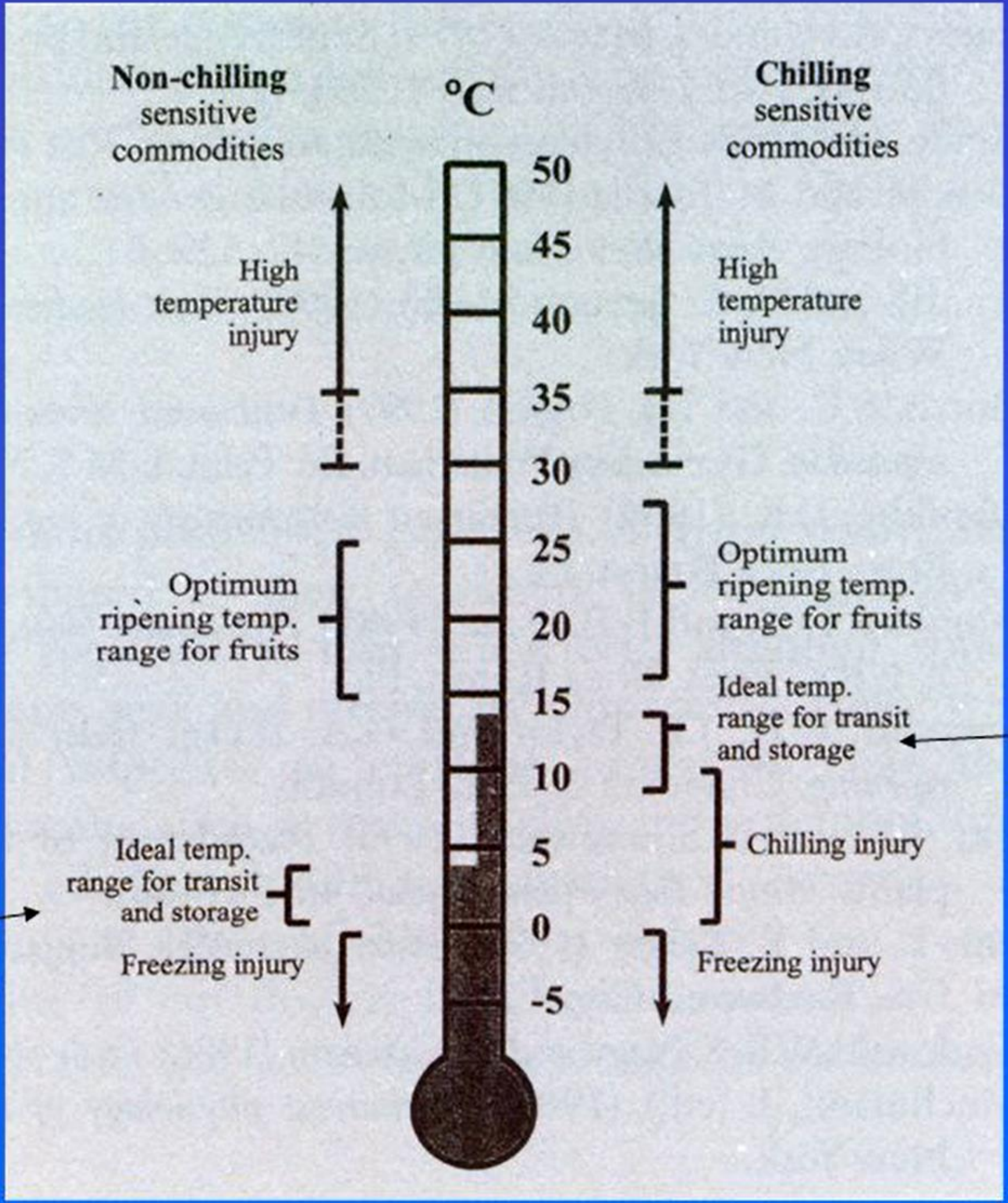
- Chilling injuries
- Freezing injuries
- Heat damage
- Low humidity
- Low O_2 injuries
- High CO_2 injuries

Chilling injuries

Tropical and subtropical fruits are sensitive to low non-freezing temperatures below 15°C.

The most common symptoms of chilling injuries include surface and internal browning, pitting, water soaked areas, uneven ripening or failure to ripen, development of off flavors, and increased decay incidence.

Cold storage chart



Chilling sensitive commodities are stored at 8-13°C

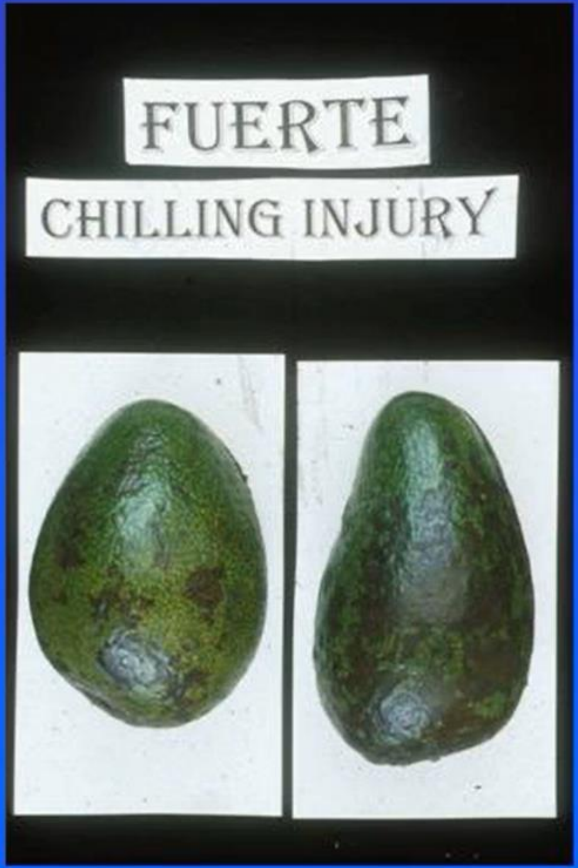
Non-chilling sensitive commodities are stored at 0-3°C

List of fruit and vegetables tolerant or sensitive to chilling

GROUP I (chilling tolerant)		GROUP II (chilling sensitive)	
Fruits	Vegetables	Fruits	Vegetables
Apple*	Artichoke	Avocado	Beans, snap
Apricot	Asparagus	Banana	Cassava
Blackberry	Beans, lima	Breadfruit	Cucumber
Blueberry	Beet	Carambola	Eggplant
Cherry	Broccoli	Cherimoya	Ginger
Currant	Brussels sprouts	Citrus	Muskmelon
Date	Cabbage	Cranberry	Okra
Fig	Carrot	Durian	Peppers
Grape	Cauliflower	Feijoa	Potato
Kiwifruit	Celery	Guava	Pumpkin
Loquat	Corn, sweet	Jackfruit	Squash
Nectarine*	Endive	Jujube	Sweet potato
Peach*	Garlic	Longan	Taro
Pear	Lettuce	Lychee	Tomato
Persimmon*	Mushrooms	Mango	Watermelon
Plum*	Onion	Mangosteen	Yam
Prune	Parsley	Olive	
Raspberry	Parsnip	Papaya	
Strawberry	Peas	Passion fruit	
	Radish	Pepino	
	Spinach	Pineapple	
	Turnip	Plantain	
		Pomegranate	
		Prickly pear	
		Rambutan	
		Sapodilla	
		Sapote	
		Tamarillo	

Note: *Some cultivars are chilling sensitive.

Chilling injuries in citrus and avocado

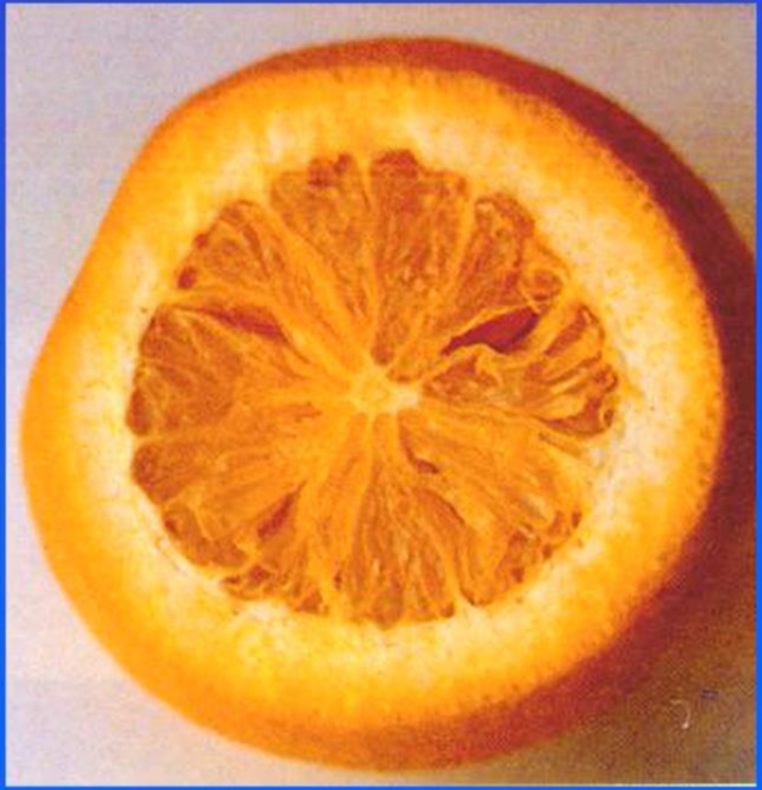


Chilling injuries in yam, peach and mango

Chilling injuries in banana

Freezing injuries

Storing produce below their freezing point causes immediate collapse of the tissue and complete loss.



Heat injury

Caused by exposure to direct sun light or excessively high temperatures. The symptoms include bleaching, surface burning, uneven ripening and softening.

Low humidity (desiccation)

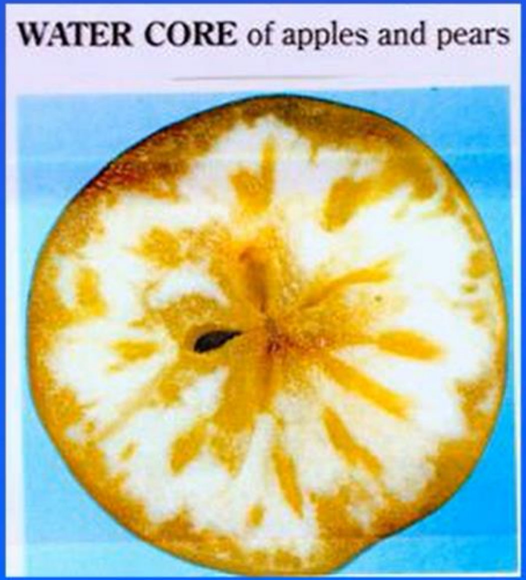
Storage under low humidity conditions may enhance disorders related to desiccation and senescence.

Nutritional imbalances

Certain disorders may develop after harvest because of nutritional deficiencies. For example, bitter pit and water core symptoms in apples are related to deficiency in calcium.

Bitter pit

Water core



Pathological breakdown

One of the most obvious symptoms of deterioration is growth of pathogens.

Healthy fruit are mostly resistant to pathogens, but senesced and damaged fruit become susceptible to infection.

* Infection by pathogens became a very serious problem in postharvest handling in recent years, since health authorities consistently reduced the permitted residue limits (MRL's) for chemical fungicides.

P. expansum

Rhyzopus

Botrytis

Colletotrichum

Phytopthora

P. digitatum

Alternaria

Pre-Cooling crops and carcasses

- Foods require cooling immediately after **harvest** or **slaughter** to reduce both **metabolic activity** and the growth of **microorganisms**, and hence reduce changes to organoleptic and nutritional qualities and maintain product safety
- Cooling of raw materials **slows spoilage** by naturally occurring **enzymes** and contaminating **microorganisms**, and therefore extends their **shelf-life**
- Precooling can significantly extend the storage life of fresh fruits and vegetables, particularly when large quantities of produce **harvested in warm temperatures** are involved
- In many situations, the bulk could take several days to cool to the final storage temperature if alternative means were not used
- **Precooling** may involve a technology separate from that of normal **cooling in a refrigerated environment** **(**refrigerated storage)

- In **crops**, some parts of the plant **respire** more rapidly than others and these should be **cooled quickly** (Table 2.1-107)

- The **rate of deterioration** is proportional to the **respiration rate** of the commodity, which is temperature-dependent.

- For each **10°C reduction** in temperature, the respiration rate of a wide range of produce can be reduced by a factor of **2 to 4**

Table 2.1 Respiration rate and storage life of selected foods

Respiration rate		Examples of foods	Typical storage life (weeks at 2°C)
Class	**Rate of CO_2 emission at 5°C (mg CO_2 kg^{-1} h^{-1})**		
Extremely high	>60	Asparagus, broccoli, mushroom, pea, spinach, sweetcorn	0.2–0.5
Very high	40–60	Artichoke, snap bean, Brussels sprouts	1–2
High	20–40	Strawberry, blackberry, raspberry, cauliflower, lima bean, avocado	2–3
Moderate	10–20	Apricot, banana, cherry, peach, nectarine, pear, plum, fig, cabbage, carrot, lettuce, pepper, tomato	5–20
Low	5–10	Apple, citrus, grape, kiwifruit, onion, potato	25–50
Very low	<5	Nuts, dates	>50

- **There are 5 methods for pre-cooling:**

1) **Room Cooling**
2) **Forced-Air Cooling (Chilled air)**
3) **Hydrocooling (Chilled water)**
   a) Immersion in cold water bath
   b) Shower cooling
4) **Vacuum Cooling**
5) **Contact Icing**

Room Cooling

- ❖ Room cooling is where a bin or carton of produce is simply placed inside a cool room

- ❖ Unless there is rapid air movement, most cooling will occur by **conduction**

Advantages:

1) Minimizes re-handling
2) Cost and labour are minimized

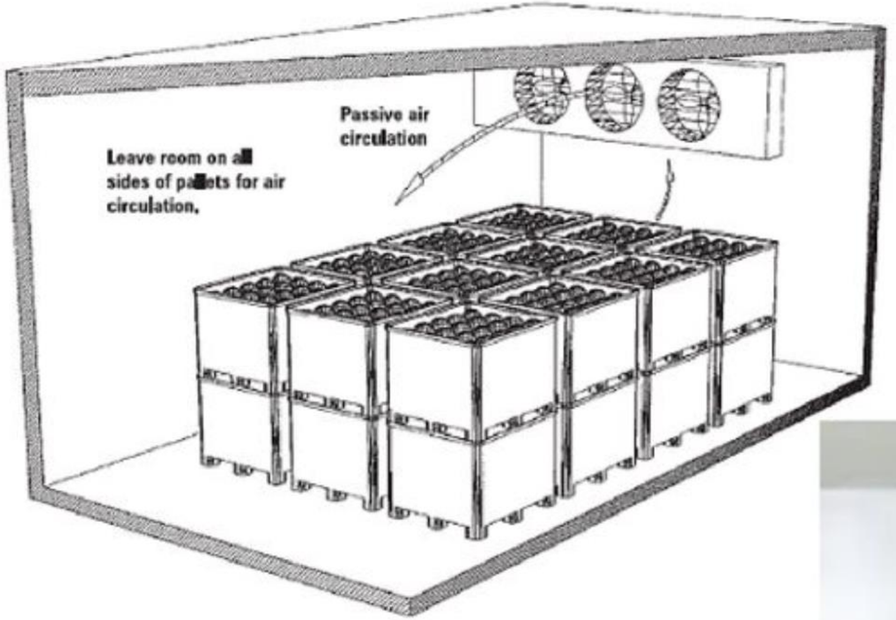
Disadvantages:

1) Temperatures can take **hours or days** to approach the room setpoint

2) Slow cooling rates can increase **weight loss** and cause **condensation** (This can be problematic if products have been harvested while hot, are susceptible to moisture loss and/ or have a fungal or bacterial infection)

3) As products must be widely spaced to allow airflow, room cooling is also **space inefficient**

4) It can increase the **load on the refrigeration system** if warm products are constantly being added to the room


Passive air circulation
Leave room on all sides of pallets for air circulation.

Forced-Air Cooling

- Forced air or '**pressure cooling**' effectively increases the **surface area** being cooled from that of the package to that of the produce inside and can be used on a **wide range of produce**

- It can cool produce **4 to 10 times faster** than **room cooling** and produces a **more uniform** temperature distribution in the pallet

- Cold air is **forced through the product**, rather than just surrounding the produce containers as is done in **room cooling**

- Most forced air systems are designed for **two rows** of stacked pallets (or bins) to be placed against a **central plenum** **(Fig)**

- A **tarpaulin** is draped over the top to block the gaps between the pallets, forcing air through the carton side vents **(Fig)**

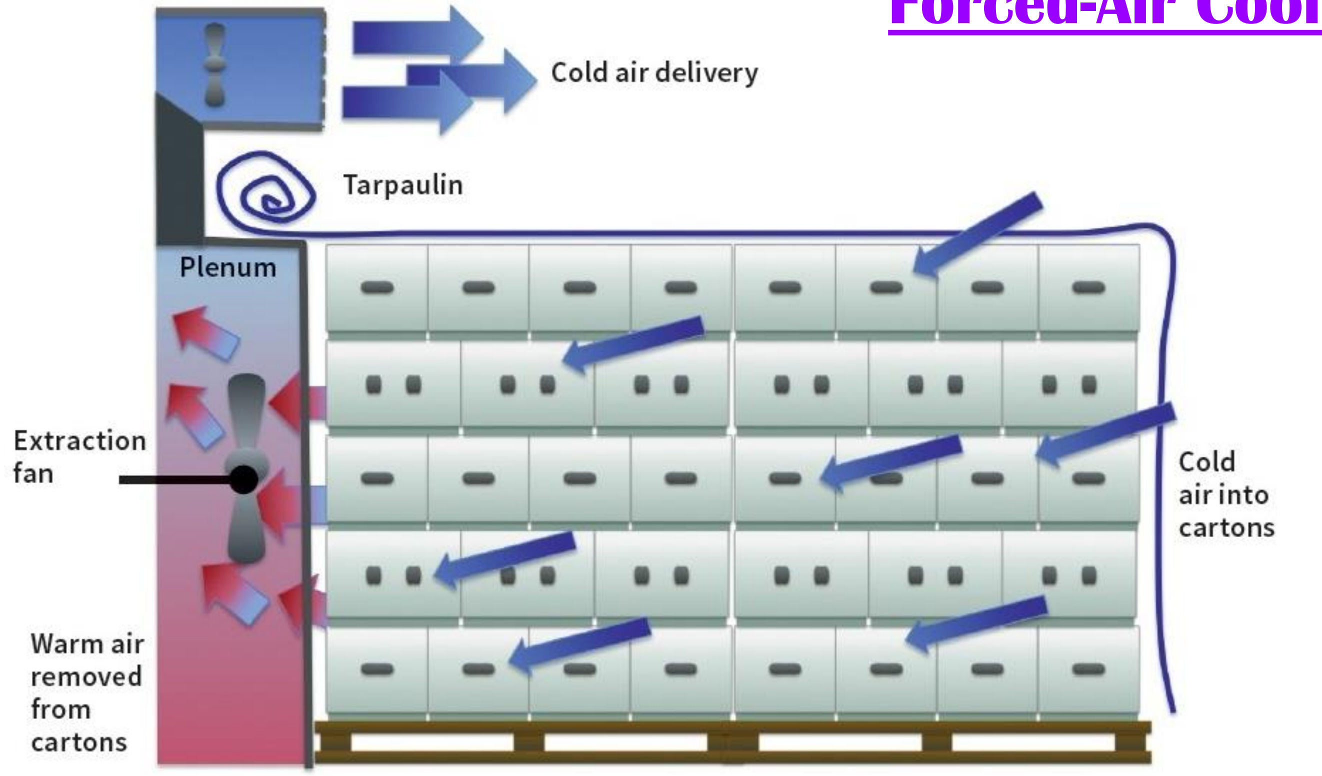
- **Fans** are used to create a **static pressure** difference across the two sides of the product containers

- This results in the air's being pulled through the containers, thus removing the warm air around the produce by **convection**

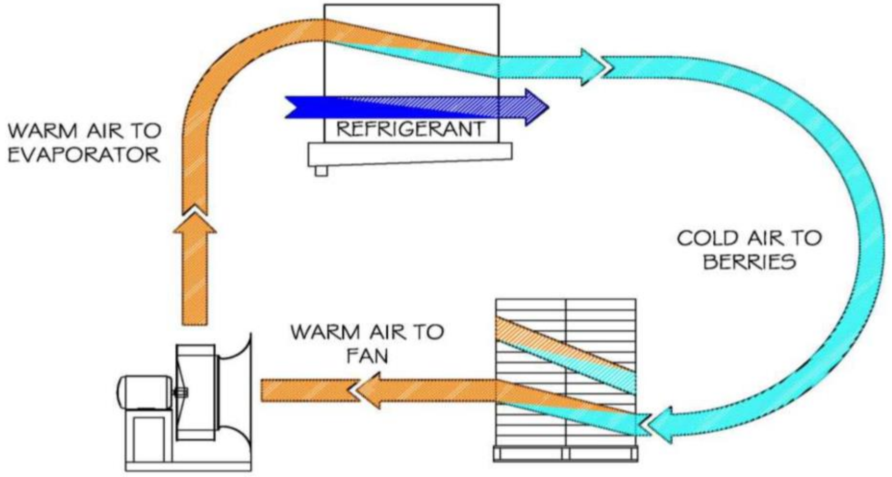
- Cooling is **faster** and **more uniform** as the static pressure used is increased

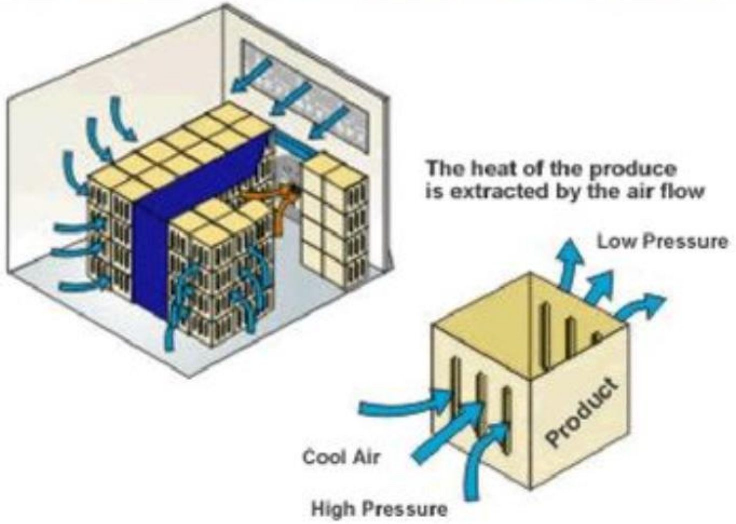
- It is recommended that a **fan** with a wide flow rate range or a fan run by a **variable-speed** motor be purchased, if it is expected that the quantities of produce to cool will vary **over the season** [1]

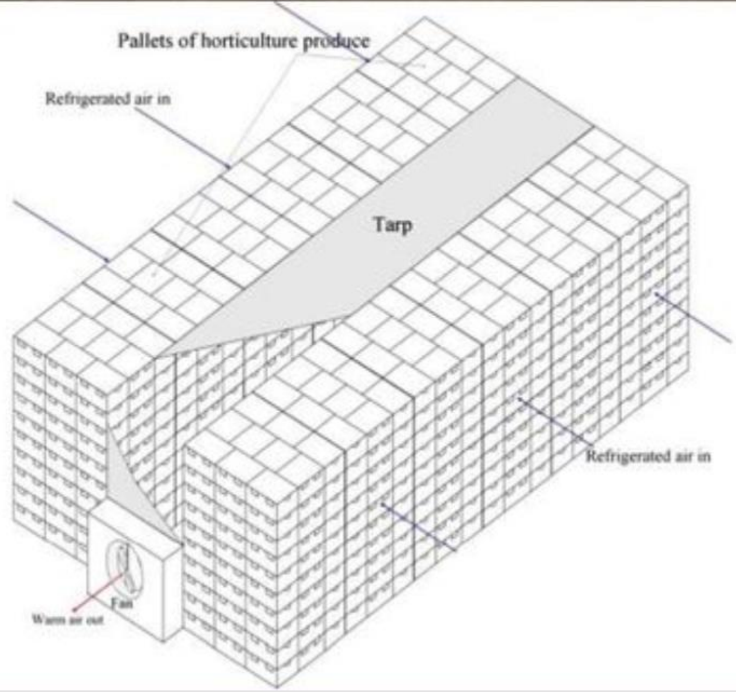
Forced-Air Cooling



The Forced-Air Cooling Cycle




The heat of the produce
is extracted by the air flow
Low Pressure
Product
Cool Air
High Pressure


Pallets of horticulture produce
Refrigerated air in
Tarp
Refrigerated air in
Fan
Warm air out

- It is recommended that the **total area of vents** be at least 5% to 10% of the **surface area of the sides** of the container

- An opening percentage of **25%** seems to be the optimum

- The produce inside the containers must **not** **be wrapped** so that optimal **heat transfer** conditions can be achieved

Disadvantages:

- This method of cooling requires **greater refrigeration capacity** than room cooling because of the higher rate of heat removal

- It also requires **fans** that have the capacity to deliver the required flow rate at the ideal pressure

- It is believed that forced-air cooling can **dry** out some products, such as **lettuce, spinach, mushrooms, and peaches**

  (However, it can be successful if the cooling **is rapid** and the relative **humidity** of the air is kept high)

- Without positive air movement, **water vapour** transpired by warm produce can **condense** on the cold product or packaging closer to the air delivery system

- **Condensation** does not occur with forced air systems (**unlike room cooling**)

- With forced air systems, the air warms as it moves through the produce, increasing its capacity to hold and remove water vapour, thus preventing condensation from occurring

- Condensation can increase **disease** and **reduce strength** of cardboard packaging

Hydrocooling

- Hydrocooling is the cooling of produce with cold water($\approx 1.5°C$), which is very effective for a wide range of products

- Water is a better **conductor of heat** than **air**

- One **advantage** of hydrocooling is that the product loses **no moisture**, and some may even be gained

- Hydrocooling can provide fast cooling so long as the water chiller has enough capacity to remove the heat from the water (the **cooling times** are in the range of **10 minutes to 1 hour**) 1

- There are **two methods** of hydrocooling:

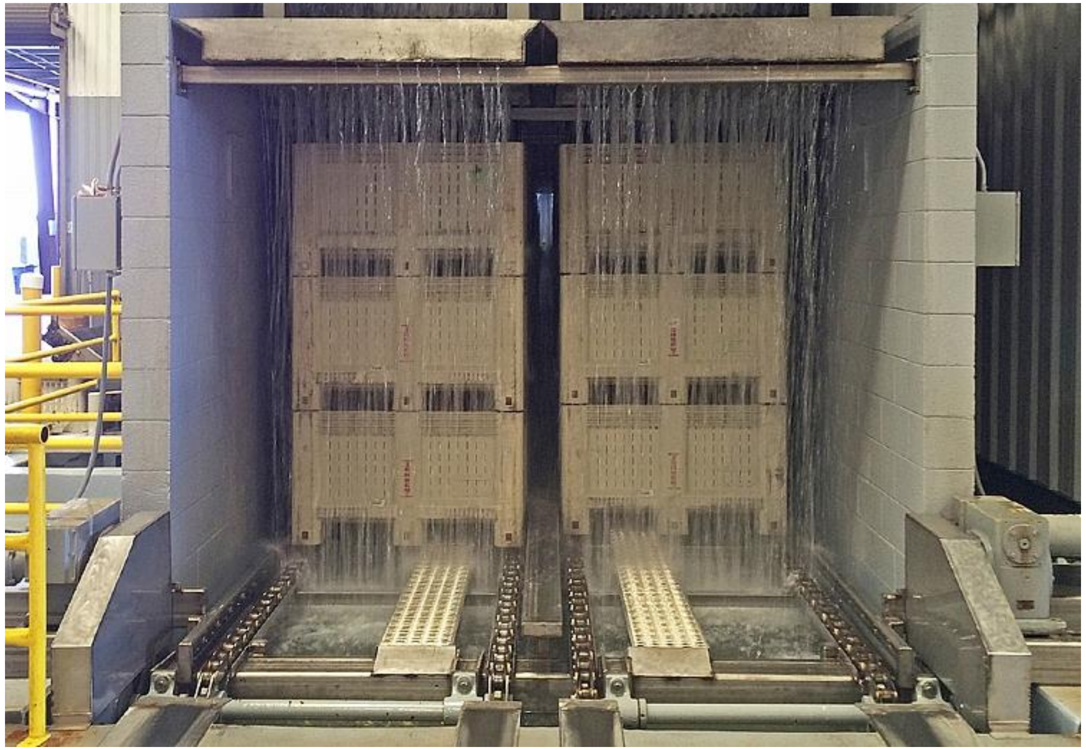
  (a) **immersion** in a cold water bath

  (b) **shower** cooling

- Hydrocooling systems can be either **continuous** feed on a conveyor, or a **batch** treatment.

- Immersion systems are most useful for products that have a **higher density than water** and therefore remain submerged

Shower-type Hydrocooling



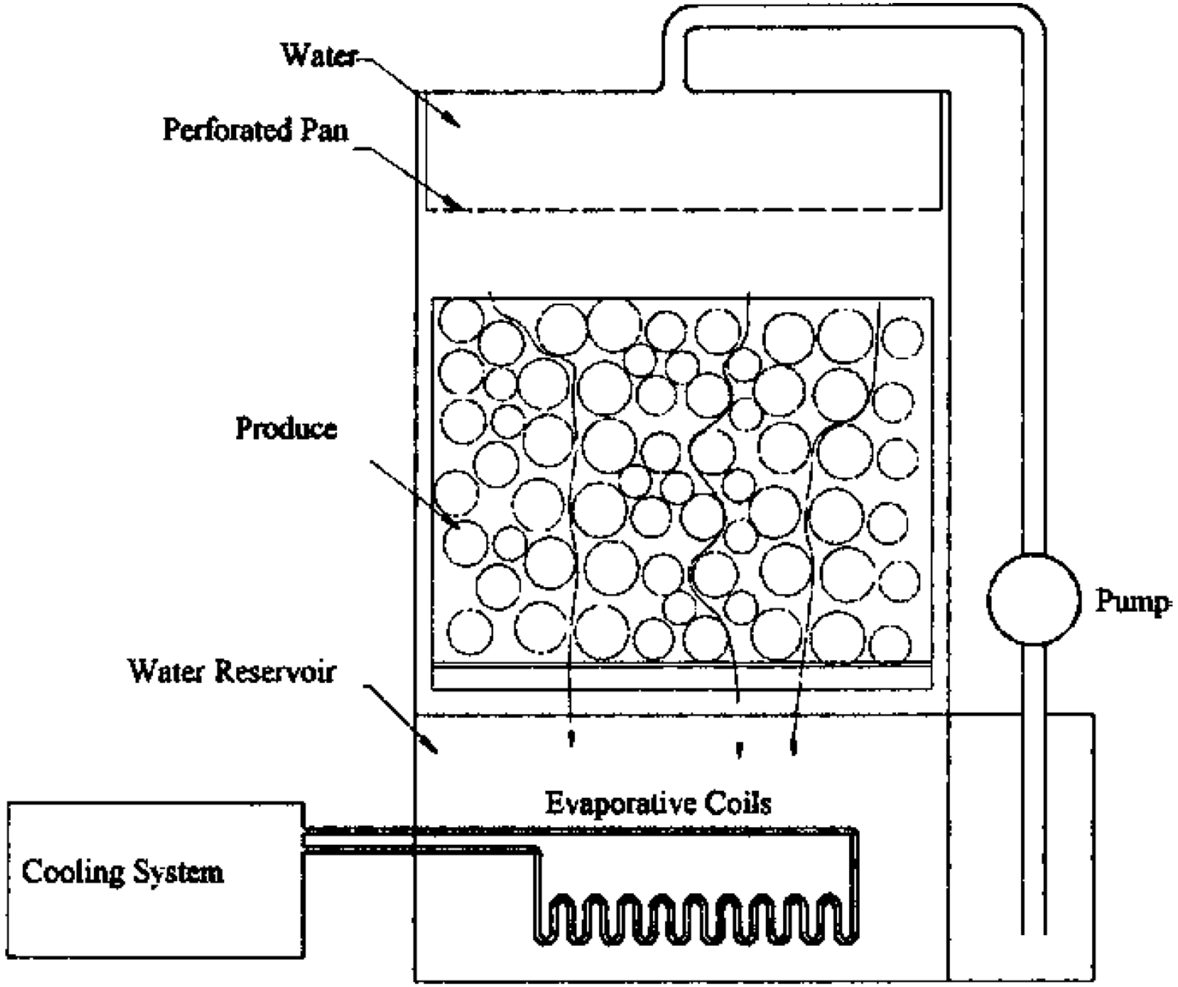


Fig. 1 Schematic view of a shower-type hydrocooler.


GREENS

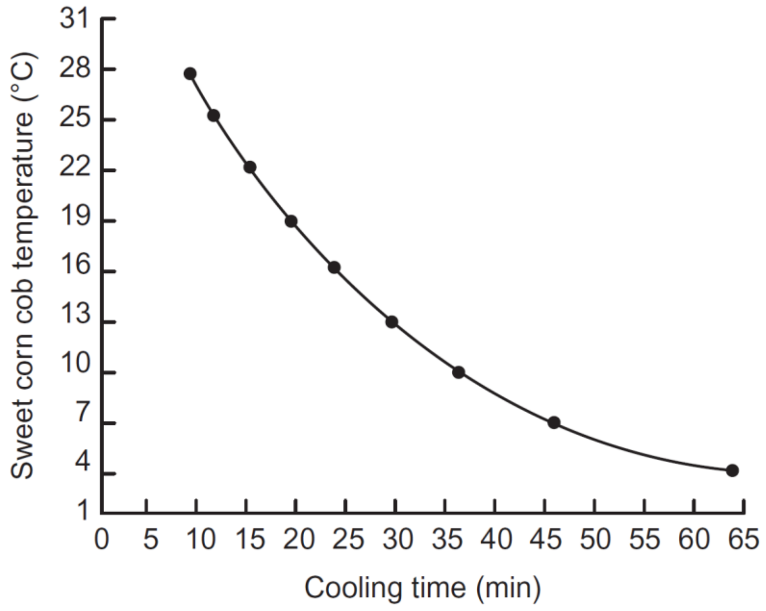

- **Lower-density** produce such as cucumbers, squashes(pumpkin), and tomatoes is cooled by **flotation** in circulating water

- To reduce the risk of **microbial infection** (human or plant pathogens), the recirculated water is chlorinated or treated with **chlorine dioxide** [1] or **ozone** (the free chlorine level in water should be 100 to 150 ppm)

- This is particularly important for **fleshy** products or those containing **internal air spaces**, such as **capsicums** or **pumpkins**.
- As the warm air inside the product cools, it contracts, creating negative pressure. This can draw water into the flesh or cavity

- In hydrocooling, the **cooling rates** of different crops are **measured**

- This information is used to calculate the time taken to cool the interior of a food from the field temperature to the required temperature for distribution



- Hydrocooling is suitable for **bulk and packaged** produce. It is commonly used for **melons**, **root vegetables**, **stem vegetables**, and many types of **tree fruits**

- Commodities that are hydrocooled must be tolerant to contact with water and to the levels of **chlorine** in the sanitized water

- Commodities such as **grapes** and **most berries** must be **ventilated** after hydrocooling to remove surface water, which can otherwise encourage **decay**

- Not all fruits and vegetables can be cooled to low temperatures (Table 2.2):

  - some tropical and subtropical crops suffer from **'chilling injury'** at 3-10 C, which causes a range of defects, including **browning** or **discoloration**, the development of **off-flavors** and excessive **softening**

- **Storage** temperatures should always be above these minimum temperatures

- Low **storage** temperatures, below about 10 C, also cause an increase in the sugar content of **potatoes**, which is undesirable if crops are intended for use in fried products because they darken excessively during frying

Table 2.2 Chilling injury to selected fruits and vegetables

Crop	Lowest safe storage temperature (°C)	Chilling injury symptoms
Avocados	5–13	Grey discolouration of flesh
Bananas, green/ripe	12–14	Dull, grey-brown skin colour
Grapefruit	10	Brown scald, watery breakdown
Lemons	13–15	Pitting, red blotch
Limes	7–10	Pitting
Mangoes	10–13	Grey skin, scald, uneven ripening
Melons, honeydew	7–10	Pitting, failure to ripen, decay
Pineapples	7–10	Dull green colour, poor flavour
Pumpkins	10	Decay
Sweet potato	13	Internal discolouration, decay
Tomatoes, mature green	13	Water-soaked softening, decay
Tomatoes, ripe	7–10	Poor colour, abnormal ripening, rot

- There are **seven groups** of fruit and vegetables that have different requirements for storage temperature and humidity (RH). If mixed crops are to be stored in the same storeroom it is important that they should come from the same group, which has similar temperature and humidity requirements

Group 1: 0-2 C, 90-95% RH (e.g. apples, apricots, beets, leeks, mushrooms, peaches, pears, plums, pomegranates, radishes)

Group 2: 0-2 C, 95-100% RH (e.g. artichokes, asparagus, berries (except cranberries), broccoli, Brussels sprouts, cabbages, carrots, cauliflowers, cherries, grapes, lettuce, parsnips, peas, spinach)

Group 3: 0-2C, 65-75% RH (garlic, onions)

Group 4: 4-5 C, 90-95% RH (e.g. cranberries, lemons, litchis (lychees), oranges, tangerines)

Group 5: 10 C, 85-90% RH (e.g. aubergines (eggplants), okra, olives, peppers, potatoes, cucumbers, squash)

Group 6: 13-15 C, 85-90% RH (e.g. avocados, bananas, coconuts, ginger root, grapefruits, guavas, mangoes, papayas, passionfruits, pineapples, ripe tomatoes)

Group 7: 18-21 C, 85-90% RH (e.g. sweet potatoes, watermelons, yams, mature green, tomatoes).

Products in **groups 5-7** are subject to chilling injury

Hydrocooling Equipment

- There are **4 types** of hydrocoolers that differ in their **cooling rates** and processing **efficiencies**:

(1) Batch (Immersion)-

- Produce is packed into crates, mesh bags or perforated metal bins and loaded into an enclosure or tank filled with chilled water 1
- Relatively **inexpensive** and suitable for growers that have smaller amounts of produce or a short harvest season

(2) Batch **(Hydro-Air cooler)-** a high-capacity **fan** is used to **suck** a fine mist of chilled water through the stack of bins

(3) Conveyor- (shower / immersion)- up to 15 m long and 2.5 m wide, pass produce under a **shower** of chilled water on a **mesh** or **belt** conveyor; the speed of the conveyor is adjusted for different crops

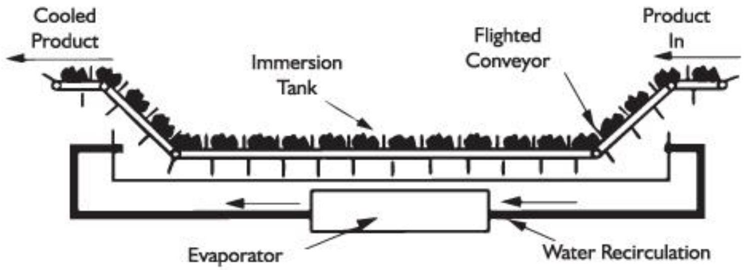
  - Because of their relatively high cost, conveyor coolers must operate for long periods in a year to be economically justified

- **In immersion conveyor** produce is moved by a submerged conveyor through a large tank of chilled water
  - More rapid cooling than other types
  - Nearly twice as fast as a conveyor-shower cooler (water has greater contact with food surfaces and heat transfer rates are higher

Conveyor Hydrocooler

Conveyor shower

Continuous Hydrocooling



Schematic of an immersion hydrocooler.

Immersion conveyor

(4) Truck hydrocoolers- stacked bins of produce are conveyed through a cooling tunnel on a chain conveyor

- Chilled water at up to 4000 L /min from multiple **spray nozzles**
- It has a separate flat-bed **trailer** for the **refrigeration** module and often a **diesel generator** that powers the system

Truck hydrocooler
with refrigeration module

- The **portable hydrocooler** is a self-contained semitrailer that is highway legal and moved by a highway tractor

- It can be used by a **grower at a central location** on a **farm** for a lower cost than a permanently installed hydrocooler

Portable truck hydrocooler

Washing

- Many items must be washed
- Water quality is extremely important - food safety
  - Contamination can quickly be spread to a large amount of product
  - Potable water for all washing, cooling, icing, and processing
- Sanitization of water is often needed
  - Continually used dump tanks
  - Must be chlorinated or otherwise sanitized
- Water temp is important
  - Cold water used for pre-cooling, though some items cannot be immersed in cold water (peppers, cantaloupe)
  - Avoid water temps more than 10ºF cooler than produce
  - Water uptake can occur in blossom and stem scars.

Washing

- For produce that cannot be immersed, brush washing and blow drying is a good alternative (cucumbers, peppers).
- Highly delicate produce should not be washed
  - Water may be trapped under calyx leading to decay
  - strawberries, blackberries
- Some produce should not or may not need to be washed
  - Just brush off dirt or other debris if needed
  - squash, zucchini, onions, okra, grapes, cabbage, tomato



Produce Soak

KSTech-Custom.com


Chlorination of Wash and Cooling Water

- Chlorination reduces transfer of contamination
- Maintain constant chlorine by monitoring.
  - In general 100-150 ppm.
- Monitor pH of water.
  - Optimum range 6.0-7.0
- Be conscious of water temp.
  - High temp results in quicker pathogen kill, but also results in rapid loss of chlorine due to gas formation.
- Water disinfection options:
  - Chlorine gas, sodium hypochlorite, Calcium hypochlorite, Chlorine dioxide, Acidified sodium chlorite, Surfactants, Ozone, Ionizing radicals, Hydrogen peroxide, Peroxyacetic acid, Ultraviolet Illumination.

Vacuum Cooling

- Vacuum cooling involves placing crops in a sealed chamber and reducing the air pressure using a **vacuum pump**
- This reduces the pressure from normal air (1 atm) to a vacuum (<0.01 atm). Under these conditions water boils at <7°C
- The crop is **sprayed with water** and when the pressure is reduced evaporative cooling rapidly lowers the temperature throughout the crop (**hydro-vacuum coolers**)
- It is especially suitable for **leafy vegetables** (e.g. lettuce and spinach) that loose moisture easily and also difficult to cool with **water or air**
- Vacuum cooling is not suitable for products with **waxy skins**, or low surface area compared to their volume, e.g. carrots, potatoes or zucchini
- For suitable products, vacuum cooling is **the fastest** of all cooling methods (only 20 – 40 minutes is needed to reduce temperature of leafy products from 30°C to 4°C)
- Vacuum cooling is also the **most energy efficient** form of cooling, as nearly all the electricity used reduces the temperature of the product (There are no lights, forklifts or workers inside a vacuum cooler that can increase the temperature)


Contact Icing

- One of the oldest and simplest cooling methods and is well suited to products that is **tolerant** to long periods of **cold** (0°C) **wet** conditions (**Fish** and other marine products)

- This involves filling packed containers or pallets with ice or covering pallets with ice

- In general, reduction of product temperature from 35°C to 2°C requires a mass of ice equal to 38% of the product weight

➢ ***Different methods of filling the containers with ice:***

- Individual package **top icing**

  - ✓ Is the **simplest** method but is rather **slow** since the ice is only in contact with the top layer
  - ✓ It is **not** efficient for **large operations** because of the amount of **labor** involved in opening the containers, adding the ice, and then closing the containers
  - ✓ The coating of ice may **block vent spaces** and leaving the center of the load **warm**
  - ✓ It is better and should be used only **after precooling** and before shipping to assist in cooling and in maintaining high relative humidity

- Pallet box **icing by layer**
  - ✓ Crushed ice and produce are **alternately layered** in the pallet box
  - ✓ Is more **labor intensive** than top icing but the cooling is **faster** and more **uniform**

- **Liquid icing**
  - Is **much faster** than individual package top icing
  - A **slurry** of cold water and ice is drenched over the pallet
  - The water slurry causes the produce to **float** until the **water drains** out of the bottom of the container
  - As the water drains out, ice is distributed throughout the container
  - This method creates **very good contact** between the ice and the product, resulting in good **heat removal**
  - The **cold water** of the slurry has a substantial effect on the cooling of the product(40% of the cooling effect on broccoli)
  - Liquid icing can reduce the **pulp temperature** to 0°C in a reasonable amount of time and maintain high **relative humidity**

➢ A greater financial investment is required for liquid icing than for the other methods of contact icing. Equipment includes an ice crusher, a slurry tank with mixer, a pump, and delivery hoses

Comparison of Common Cooling Methods

	Room/Air	Forced Air	Hydrocool	Water Spray	Ice
Typical Cooling Time (Hours)	20-100	1-10	0.1-1.0	0.3-2.0	0.1-0.3
Product Moisture Loss (%)	0.1-2.0	0.1-2.0	0-0.5	No Data	No Data
Water Contact with Product	No	No	Yes	Yes	Yes
Potential for Decay	Low	Low	High	High	Low

Table 1 Recommended Precooling Methods and Storage Conditions for Various Fruits and Vegetables

Produce	Precooling method[a]	Storage conditions
Apples (2, 14)	RC, FA, HC	0°C to 5°C, 1%–3% O_2, 1%–5% CO_2
Asparagus (14, 15)	HC, PI	0°C to 2°C, 95% to 100% RH
Apricots (2)	RC, FA	0°C to 5°C, 95% RH, 2% to 3% O_2, 2% to 3% CO_2
Artichokes (2, 49)	HC, FA, PI	0°C to 5°C, 90% to 95% RH, 2% to 3% O_2, 2% to 3% CO_2
Beans, snap (14, 49)	RC, FA, HC	8°C, 2% to 3% O_2, 4% to 7% CO_2
Beets (14, 33)	RC	0°C to 4°C, 95% RH
Blackberries (14, 33)	FA, RC	−0.5°C to 0°C, 90%–95% RH
Blueberry (20)	FA	Optimal at 1°C (3°C–4°C), 90% RH
Broccoli (2, 49)	FA, HC, PI, LI	Optimal at 0°C (0°C–5°C), 90%–95% RH, 1%–3% O_2, 5%–10% CO_2
Brussels sprouts (2, 15)	FA, HC, PI	0°C, 95%–100% RH
Cabbage (14, 33)	RC, FA	0°C, 92% RH
Cantaloupes, slip (2, 15)	HC, FA, PI	2°C–5°C, 95% RH
full slip (2, 15)	HC, FA, PI	0°C–2°C, 95% RH
Cauliflower (14, 15)	HC, VC	0°C, 95%–98% RH
Carrots (14, 33)	RC, PI	0°C to 2°C, 95% RH
Chinese cabbage (14, 15)	RC, FA, HC	0°C, 95%–100% RH
Celery (2, 49)	FA, HC, VC, WV	0°C–5°C, 90%–95% RH, 2%–4% O_2, 3%–5% CO_2
Cucumbers (2, 15)	RC, FA	10°C–13°C, 50%–55% RH
Eggplant (14, 15)	RC, FA	8°C–12°C, 90%–95% RH
Figs (2)	RC, FA, HC	0°C–5°C, 5%–10% O_2, 15%–20% CO_2
Garlic (2)	RC	0°C
Grapes (14, 33)	FA	−1°C to 0°C, 85% RH
Kiwifruit (2, 15)	FA, RC, HC	−0.5°C to 0°C, 90%–95% RH, 1%–2% O_2, 3%–5% CO_2; C_2H_4 must be below 20 ppb

Leeks (2, 15)	HC, PI	0°C, 95%–100% RH
Lettuce (14, 23)	HC, PI, VC	0°C, 95^{+}% RH
Mushrooms (2, 49)	FA, VC	Optimal at 0°C (0°C–5°C), normal O_2, 10%–25% CO_2
Nectarines (14, 15)	FA, HC	−0.5°C–0°C, 90%–95% RH
Okra (14, 49)	RC, FA	7°C–12°C, 90%–95% RH, normal O_2, 4%–10% CO_2
Onions (33)	No precooling	0°C, 75% RH
Peaches (14, 33)	FA, HC	−1°C to 0°C, 85% RH
Pears (14, 15)	FA, RC, HC	−1.5°C to −0.5°C, 90%–95% RH
Peas, green (14, 15)	FA, HC	0°C, 95%–98% RH
Peas, southern (14, 15)	FA, HC	4°C–5°C, 95% RH
Peppers, chili (dry) (2, 15)	RC, FA, VC	0°C–10°C, 32%–50% RH
Peppers, sweet (2, 15)	RC, FA, VC	7°C–13°C, 45%–55% RH
Plums (14, 15)	FA, HC	−0.5°C–0°C, 90%–95% RH
Potatoes (14, 33)	RC, FA	3°C–10°C, 90% RH
Pumpkins (33)	No precooling	10°C–13°C, 70% RH
Radish (14, 49)	PI	0°C, 90%–95% RH, 1%–2% O_2, 2%–3% CO_2
Raspberries (50)	FA	0°C to 0.5°C, 90% to 95% RH
Rutabagas (14, 15)	RC	0°C, 98%–100% RH
Spinach (14, 15)	HC, VC, PI	0°C, 95%–100% RH
Squash, summer (14, 15)	RC, FA	5°C–10°C, 95% RH
Squash, winter (15)	No precooling	10°C, 50%–70% RH
Strawberries (2, 11)	RC, FA	0°C, 95% RH, 5% to 10% O_2, 15% to 20% CO_2
Sweet Cherry (2, 51)	RC, FA, HC	0°C–5°C, 3%–10% O_2, 10%–15% CO_2
Sweet Corn (24, 52)	HC, VC, LI	0°C, 95% RH
Sweet Potatoes (33)	No precooling	10°C–15°C, 85% RH
Tamarillos (2, 15)	RC, FA	3°C–4°C, 85%–95% RH
Tomatoes (49)	RC, FA	Optimal at 12°C (12°C–20°C), 3%–5% O_2, 0%–3% CO_2
Turnip (14, 15)	RC, HC, VC, PI	0°C, 95% RH
Watermelons (11)	No precooling	4°C–10°C, 80%–85% RH

[a] RC, room cooling; FA, forced-air cooling; HC, hydrocooling; VC, vacuum cooling; PI, package icing; LI, liquid icing.