Fruit Ripening & Retail Handling Workshop

Cold Storage Disorders of Fruits and Vegetables

Mikal E. Saltveit
Mann Laboratory, Department of Plant Sciences
University of California, Davis

Why use cold storage?

• Shelf-life is inversely proportional to respiration (colder temp → slower respiration → longer shelf-life).
• The rate of respiration at least doubles for every 18 °F (10 °C) rise in temperature (a Q_{10} of 2).
• Low temperatures reduce microbial growth.
• Low temperatures reduce water loss (air at 10 °C can hold twice as much water as at 0 °C)

Respiration and Temperature

Ripe Strawberries After 7 days

Effect of handling temperatures on strawberry deterioration

<table>
<thead>
<tr>
<th>Treatment (48 h period)</th>
<th>Fruit condition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sound</td>
</tr>
<tr>
<td>1. 48 h at 5°C (41°F)</td>
<td>95</td>
</tr>
<tr>
<td>2. 24 h each at 5°C (41°F) and 20°C (68°F)</td>
<td>76</td>
</tr>
<tr>
<td>3. 2 x 12 h periods at 5°C (41°F) and 20°C (68°F)</td>
<td>70</td>
</tr>
<tr>
<td>4. 48 h at 20°C (68°F)</td>
<td>44</td>
</tr>
</tbody>
</table>

Slide from Marita Cantwell

Mitchell et al., 1996 Handling Strawberries, UC Publ. 2442
Relative humidity (%)

- 30
- 25
- 20
- 40
- 50
- 60
- 80
- 100

Vapor pressure (millibars)

- 0.016
- 0.020
- 0.024
- 0.028

Humidity (kg/kg)

Coil temperature = 0 °C (32 °F)
Room temperature = 5 °C (41 °F)
RH = 70%

Excessive water loss can occur at low relative humidity.

The Temperature window

Freezing
Chilling
Heat stress

-5 0 5 10 15 20 25 35

Outside the Optimum

- High temperature - scald, sunburn
- Non-freezing Temperatures - chilling sensitivity
- Sub-zero temperatures - frost injury, freezing

Ripening of Tomato Fruit

Chilling injury
Just right

Tomato fruit after 2 weeks at 20 °C. Softening and synthesis of pigments and aromas may be abnormal at cold (chilling injury) or high temperatures.

Problems with cold storage

- Temperatures below 32 °F (0 °C) can cause freezing (depends on the tissue’s sugar content).
- Freezing usually reduces quality and shelf-life
- Non-freezing temperatures below about 50 °F (10 °C) can cause chilling injury.
- Chilling injury may be hidden and only develop after the product is purchase by the consumer.
- A closed cold storage room allows accumulation of gasses: CO₂, C₂H₄

Freezing Injury

Water in the cell walls surrounding each plant cell contains less soluble solids (e.g., sugars) than does the cytoplasm in the cell, so ice crystals first form in the cell wall.

The solution in the cell wall gets more concentrated as ice crystals form. Water moves from the cell into the cell wall to re-establish osmotic equilibrium, and the cell dehydrates.

Cellular dehydration, not ice crystal formation, causes cellular injury associated with freezing.
Ice Crystal Formation

Ice crystals form by the accretion of water molecules on the surfaces of an existing surface. No motive force can be exerted by a growing crystal. The volume of an ice crystal actually decreases as it cools.

Volume change upon Freezing

<table>
<thead>
<tr>
<th>Water at 0 °C (32 °F)</th>
<th>0.9998 g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 g water</td>
<td>1.0002 cm³</td>
</tr>
<tr>
<td>Water is most dense at 4 °C (32 °F)</td>
<td></td>
</tr>
<tr>
<td>1 g ice</td>
<td>1.0000 cm³</td>
</tr>
<tr>
<td>Ice at 0 °C (32 °F)</td>
<td>0.9167 g/cm³</td>
</tr>
<tr>
<td>1 g ice</td>
<td>1.0909 cm³</td>
</tr>
</tbody>
</table>

Fruit ripening workshop Cold storage disorders

Sugars and Freezing Susceptibility

Why does fruit tissue close to the pit freeze first, and not tissue in the flesh?

Core tissues freeze before outer flesh tissues because of differences in soluble solids content within the fruit. Freezing point depression: dependent on the number of molecules or ions and their ability to organize water.

Examples of Freezing Injury

Why did it freeze on just those edges?

Tissue collapse

Water logging

Examples of Freezing Injury

Most Fruits and Vegetables are chilling tolerant

But many are chilling sensitive
**Chilling Injury**

- Chilling injury is a physiological disorder; however, symptom development can involve increased susceptibility to specific microbes.
- Chilling injury develops after exposure to non-freezing temperatures below a ‘critical’ temperature.
- The severity of the injury depends on the temperature of exposure, and the length of exposure.
- The ‘critical’ of ‘threshold’ temperature varies with: crop, cultivar, growing conditions, pre-treatments, etc.
- Symptoms usually develop upon return to room temperature.
- The post-chilling environment can mitigate or accentuate symptom development.

**Flowering plants originated in the tropics**

Flowering plants evolved in the tropics and most tropical and semi-tropical plants are chilling sensitive. Tropical, sub-tropical, and even some temperate fruit are chilling sensitive and damaged by non-freezing temperatures below 10 °C (50 °F).

**Symptoms of Chilling Injury**

- **Internal and external tissue browning**
- **Surface pitting & discoloration**
- **Tissue necrosis followed by attack by specific pathogens**

**Chilling of Bananas**

Chilled bananas develop a dull gray ‘smoke’ appearance upon ripening.

**Control**

**Chilled**
Chilling of Pineapples

- Endogenous Brown Spot

Fruit ripening workshop Cold storage disorders 25

Internal Breakdown of Stone Fruit

- Mealiness (soft but not juicy)
- Flesh Browning
- Lack of Flavor
- Failure to Ripen

Internal breakdown is induced by intermediate storage temperatures (2-8°C, 1-6 weeks)


Susceptibility Varies with Cultivar

<table>
<thead>
<tr>
<th>Category</th>
<th>Cultivar</th>
<th>0°C</th>
<th>5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Betty Anne</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>October Sun</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Flavor Rich</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Joanne Red</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>Angelina</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Fortune</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Hoku Red</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Black Amber</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Purple Majesty</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>Show Time</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Friar</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Earliqueen</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Plum market life (in weeks) held at 2 storage temperatures based on chilling injury symptom development


Conditioning or Delayed Cooling

- 0ºC 20 Days (43% Mealy)
- 5ºC 20 Days (100% Mealy)
- 20ºC 48 Hours + 5ºC 20 Days (0% Mealy)


Variation in Chilling Sensitivity

- Diurnal changes in chilling sensitivity
  - Cool mornings, hot afternoons, carbohydrate status
- Tomato seedlings are very chilling sensitive in the early morning and less sensitive later in the day.
- Tomato fruit also exhibit diurnal changes in chilling sensitivity.
- Changes can be duplicated with postharvest temperature conditioning.

Preventing Chilling Injury

- Are we preventing injury or symptom development?
- Don’t chill
- Controlled atmospheres
- Conditioning
  - High temperature pre-treatment
  - Low temperature treatment (above threshold)
  - Intermittent warming