Physiological Disorders of Fresh Fruits and Vegetables

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Physiological Disorders

• **Definition**: External or internal blemishes resulting from improper environmental or cultural conditions before and/or after harvest
  - Blemishes without an obvious causal fungal, bacterial, viral or insect agent
  - Blemishes not caused by mechanical injuries (i.e., cuts, punctures, bruises, abrasions, etc.)

Types of Physiological Disorders

• Disorders caused by adverse **temperature** conditions
• Disorders resulting from some physiological malfunction within the normal temperature range for the product
• Also, damage from environmental toxicants
Types of Physiological Disorders

- Temperature-related disorders
  - Freezing injury
  - Chilling injury
  - High temperature injury
    - Temperature effect
    - Radiant energy effect (sunburn/sunscald)

Types of Physiological Disorders

- Nutrition-related disorders
  - Calcium deficiency
  - Boron deficiency
  - Excess nitrogen

Types of Physiological Disorders

- Other disorders
  - Disorders of long-term storage
    - Senescence related
  - Controlled atmosphere disorders
    - Low O₂ or high CO₂
  - Toxic chemicals
    - Ammonia, SO₂, methyl bromide, ozone, CaCl
  - Ethylene disorders
I. Freezing Injury

• Reduction of the ambient temperature below that of the freezing point of the tissue
• Symptoms include water-soaked areas in the tissue, and collapse and even disruption of the epidermis
• Freezing temperatures may occur in the field or in the storage environment

Freezing Injury

• Freezing point depression
  – Dissolved solids in the cell sap reduce the freezing point of plant tissues below that of pure water
  – This freezing point depression, which is a function of the osmolality of the cell solution, ranges from less than 1 °C to a few °C

Freezing points for some common fruits and vegetables

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Freezing point range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>-2.4 - -1.7</td>
</tr>
<tr>
<td>Asparagus</td>
<td>-1.6 - -1.4</td>
</tr>
<tr>
<td>Cherry</td>
<td>-4.3 - -3.8</td>
</tr>
<tr>
<td>Cucumber</td>
<td>-0.9 - -0.8</td>
</tr>
<tr>
<td>Grape</td>
<td>-5.3 - -2.9</td>
</tr>
<tr>
<td>Lettuce</td>
<td>-0.6 - -0.3</td>
</tr>
<tr>
<td>Onion</td>
<td>-1.3 - -0.9</td>
</tr>
<tr>
<td>Orange</td>
<td>-2.3 - -2.0</td>
</tr>
<tr>
<td>Potato</td>
<td>-1.8 - -1.7</td>
</tr>
<tr>
<td>Tomato</td>
<td>-1.0 - -0.7</td>
</tr>
</tbody>
</table>
Freezing Injury

• Supercooling
  - When the temperature of tissues falls below the freezing point, ice crystals are not immediately formed because there is a substantial capacity for supercooling in plant tissues
    * i.e., the cell solution remains liquid even though it is below its freezing point


Tissue remains at this temp until all the extracellular water is frozen.

Freezing Injury

• Supercooling
  - Can be reversible.
  - May be devastating because of the rapidity with which freezing occurs when the supercooled solution finally freezes
    * Prolonged exposure to low temperature
    * Nucleation due to vibration

Freezing Injury

• Ice nucleation
  - The supercooled solution eventually freezes, either by prolonged exposure to low temperature or when nucleated by vibration.
  - Intracellular freezing of the cytoplasm and vacuolar sap is lethal.
Freezing Injury

- Extracellular freezing
  - Ice crystals in the dilute wall liquid increase the VPD across the cell membrane
  - Ice crystals continue to grow at the expense of the liquid in the cell, which may become plasmolysed (collapsed)
    - plasmolyze -> solutes move out (K⁺, Ca²⁺), get pH changes, get dehydration injury

- Extracellular freezing
  - Natural “freeze-drying”
  - Usually reversible
  - Reduces the freezing point of the cell sap by increasing its osmolality, thereby making the tissue more resistant to intercellular freezing

- Extracellular freezing
  - Can also be lethal due to:
    - Dehydration of the plasma membrane.
    - Puncturing of membranes when ice crystals grow into the space left inside the wall by the plasmolyzing cytoplasm.
Freezing Injury

• Symptoms of freezing injury
  – Watersoaked appearance
  – Limp, flaccid tissues
  – Secondary symptoms include discoloration (browning) and decay
  – Freezing from outside to inside, or wherever the SSC is lowest

Credit: UC Davis, PTC

Freezing Injury

• What if the commodity is exposed to freezing temperatures?
  – Don't move frozen tissue or tissue with temperature below 0°C
    • Vibration can cause nucleation of supercooled tissues and rapid freezing
  – If freezing was slight:
    • Slowly warm commodity to ~5°C to allow any ice crystals to melt and tissues to recover from the stress as best as possible
    • Market quickly because quality will likely deteriorate quickly (i.e., internal desiccation, accelerated decay, etc.). Depends on the freeze severity

Freezing Injury

• Work to avoid freezing temperatures in the first place
  – Choose cultivars and planting dates so that the produce is harvested before freezing temperatures are likely to occur.
  – Maintain refrigeration equipment and sensors and install alarms if temperatures fall below 0°C.
II. Chilling Injury

• Exposure to temperatures below a critical threshold temperature but still well above the freezing point
• Characterized by increased susceptibility to fungal attack, collapse and necrosis of tissues, water soaking, and tissue death

Chilling Injury

• Threshold temperature
  – Characteristic of a commodity
  – Lowest temperature at which no injury is seen, regardless of the length of storage
  – Below the threshold temperature, CI occurs
• Commonly in the 10-15°C range
  – Can vary from quite low (e.g., 3°C for some apple varieties) to quite high (as high as 20°C for some pineapples)

Causes of Chilling Injury

• Phase transition hypothesis
  – Sharp break in the rate of mitochondrial respiration plotted on an Arrhenius plot, suggests a sudden change in the activation energy of some key enzyme in respiratory metabolism at that point
  – Threshold temperatures are close to temperatures at which membranes of chilling sensitive plants change from a liquid to a crystalline state
Causes of Chilling Injury

• **Inhibition of cytoplasmic streaming**
  - Occurs within minutes of cold exposure
  - Inability of the cell to transport substrates, metabolites, and control molecules could result in metabolic imbalance and accumulation of toxic respiratory intermediates

Causes of Chilling Injury

• **Enzyme temperature sensitivity**
  - Differences in the temperature sensitivity of important regulatory enzymes such as phosphofructokinase (in glycolysis)
  - Because of the critical role that regulation of these enzymes plays in the regulation of metabolism overall, it may be that their malfunction could also be a cause of the symptoms of chilling injury

Causes of Chilling Injury

• **Peroxidation of membrane lipids**
  - Commonly observed in plants exposed to chilling stress
  - Sensitive plants may be unable to mobilize antioxidant defenses (against ROS) or enzyme repair systems at low temperatures
Chilling Injury Symptoms

• **Flesh discoloration**, as in apples, avocados, and peaches

Chilling injury resulting in pitting of the skin and darkening of the seeds and flesh

• **Pitting**, as in citrus fruits, cucumbers, peppers and tomatoes.

• **Necrosis**, as in seeds of eggplants, peppers and tomatoes.

• **Accelerated decay**, as in cucumber, melons, papaya and mango.

Pitting & Seed Necrosis

Eggplant cv. Classic 8 days at 5°C plus 1 day at 20°C
Pitting & Seed Necrosis

10 days at 5°C After transfer to 20°C for 1 day

Bell pepper cv. Bell Boy Chilling injury resulted in pitting of the skin and darkening of the seeds

Chilling Injury Symptoms
- Vascular discoloration, as in avocado and banana
- Ripening inhibition and irregular/uneven ripening, as in most climacteric fruit

Factors Affecting Chilling Injury Symptom Development
1. Temperature: the lower the temperature, the more severe the symptoms
2. Time: the longer the exposure, the more severe the symptoms
   - But, crops can recover from short exposures
3. Chilling injury is cumulative
   - Preharvest + postharvest exposure
4. Symptoms may not develop until after removal to higher temperature
   - Low temperature inhibits the reactions leading to symptom development
Factors Affecting Chilling Injury

- These factors alleviate chilling injury:
  1. **Advanced maturity**: chilling sensitivity decreases with maturation and ripening
  2. **Acclimation**: short periods of exposure to low, non-chilling temperatures
  3. **Previous high temperature exposure** (e.g., 2 days in air @ 38°C or 10 min in 53°C water)
  4. **Intermittent warming**: may allow metabolism or detoxification of toxic compounds (recall: peroxidation of membrane lipids hypothesis)

Factors Affecting Chilling Injury (cont.)

- These factors alleviate chilling injury (cont.):
  5. **Genetics**: different varieties of chilling susceptible species can differ in the chilling tolerance
  6. **High relative humidity conditions**: slows water loss to slow development of pitting
  7. **Modified or Controlled Atmospheres (esp. high CO₂)**: shown to inhibit chilling injury of avocado, mango, and grapefruit
  8. **Some fungicides**: e.g., thiabendazole used on grapefruit

III. High Temperature Injury

- High temperatures can inhibit key enzymes and thus disrupt normal metabolism, e.g., ripening

- Radiant energy from sun exposure causes **sunburn or sunscald**:
  - Ripening inhibition
  - Actual death of cells, resulting in collapsed and bleached areas on the commodity
“Checkerboarding” (high temperature injury) of tomatoes

“Scald” (hot water injury) on mangoes
“Sunscald” on tomatoes

Sunscald on cantaloupe melons

IV. Nutritional Disorders

- Low calcium levels in tissue
  - Bitter pit of apples
  - Cork spot of pears
  - Blossom end rot (BER) of tomatoes, peppers, melons
  - Blackheart of cabbage, celery
  - Tipburn of lettuce
  - etc., etc., etc.
“Tipburn” of Iceberg head lettuce

Nutritional Disorders
• Low calcium levels in tissue
  – Calcium moves through the transpiration stream
  – Deficiency symptoms appear in locations with minimal transpiration
    ➢ Blossom end of fruit
    ➢ Interior leaves of heading crops
  – Symptoms may not appear until during postharvest period

Nutritional Disorders
• Control of low calcium disorders
  – Resistant varieties
  – Harvest maturity: low maturity = low calcium
  – Fertilizer management
    • Excess N promotes vegetative growth, which is where most of the calcium goes due to transpiration
    • Calcium applications:
      ➢ Preharvest sprays
      ➢ Postharvest dips/infiltration
**Nutritional Disorders**

- **Low boron** levels in tissue
  - Cork flesh in tree fruits
  - Internal necrosis and blackspeck of cole crops
- **Excess nitrogen**.
  - Brown center-hollowheart of potato
  - Exacerbates calcium disorders
  - Increases susceptibility to disease and physical damage

**Blackspeck (boron deficiency + low temperature)**

**Cutting black (corte negro; low calcium? + low temperature) of mangoes**
V. Storage Disorders

- Disorders of long-term storage
  - Senescence related disorders.
  - Superficial scald (apples) related to oxidation of alpha-farnesene, a phenolic compound.
  - Water core (apples) a result of infiltration of intercellular spaces with translocation fluid containing sorbitol.
  - Pink rib (lettuce).

Kader & Cantwell, 2006

Storage Disorders

- Controlled atmosphere disorders
  - Low O₂ or high CO₂
  - Toxic chemicals
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Kader & Cantwell, 2006

Russet spotting