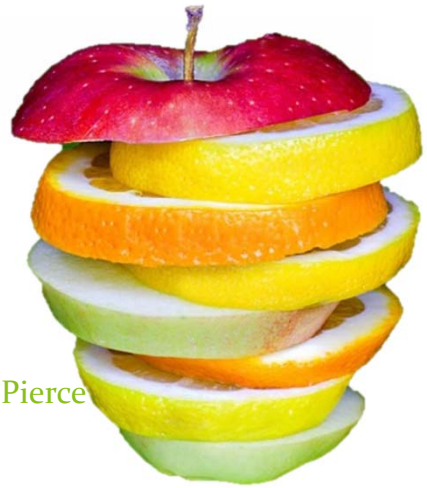
Physiological Disorders of Fresh Fruits and Vegetables



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1

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.)

2

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

3

Types of Physiological Disorders

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

4

Types of Physiological Disorders

- Nutrition-related disorders
  - Calcium deficiency #1
  - Boron deficiency
  - Excess nitrogen

5

Types of Physiological Disorders

- Other disorders
  - Disorders of long-term storage
    - Senescence related
  - Controlled atmosphere disorders
    - Low O_2 or high CO_2
  - Toxic chemicals
    - Ammonia, SO_2, methyl bromide, ozone, $CaCl_2$
  - Ethylene disorders

6

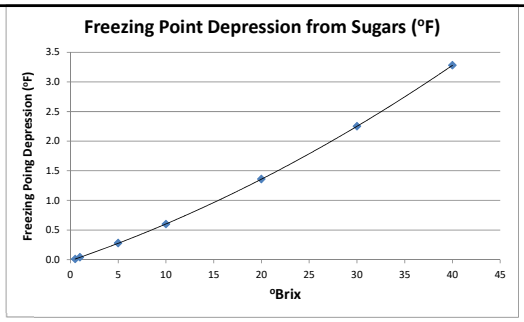
I. Freezing Injury

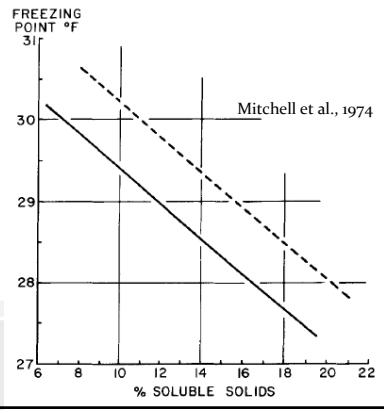
- Reduction of the ambient temperature below that of the freezing point of the tissue
- Symptoms include water-soaked areas in the tissue, and collapse and even disruption of the epidermis
- Freezing temperatures may occur in the field or in the storage environment

7

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





8

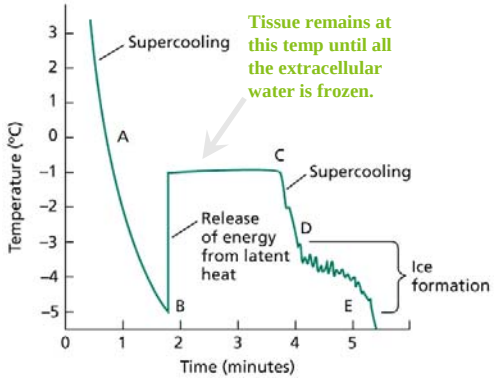
Freezing points for some common fruits and vegetables

Commodity	Freezing point range (°C)
Apple	-2.2 - -1.7
Asparagus	-1.4 - -1.1
Cherry	-4.3 - -3.8
Cucumber	-0.9 - -0.8
Grape	-5.3 - -2.9
Lettuce	-0.6 - -0.3
Onion	-1.3 - -0.9
Orange	-2.3 - -2.0
Potato	-1.8 - -1.7
Tomato	-1.0 - -0.7

9

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



Taiz & Zeiger, 2002, Web Topic 25.3

10

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

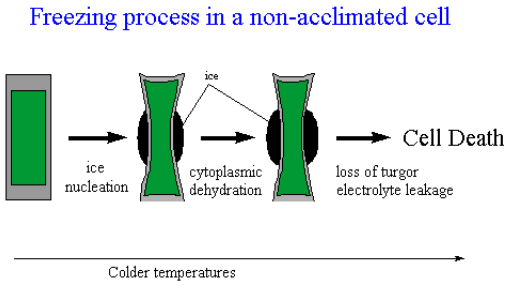
11

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**.

12

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^+, Ca^{2+}), get pH changes, get dehydration injury

http://www.agronomy.psu.edu/Courses/AGRO518/FREEZING.htm#contents

13

Freezing 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

14

Freezing Injury

- 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 plasmolysing cytoplasm.

15

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

16

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

17

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.

18

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

19

Chilling Injury

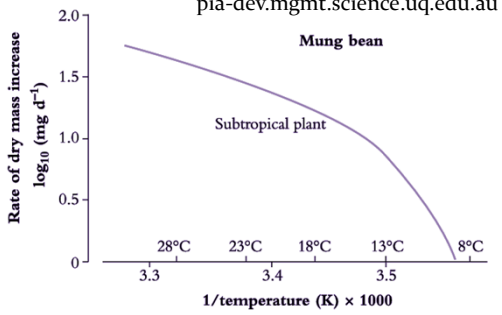
- **Threshold temperature**
  - Characteristic of a commodity
  - Lowest temperature at which no injury is seen, regardless of the length of storage
  - Below the threshold temperature, CI occurs
- Commonly in the 10-15°C range
  - Can vary from quite low (*e.g.*, 3°C for some apple varieties) to quite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

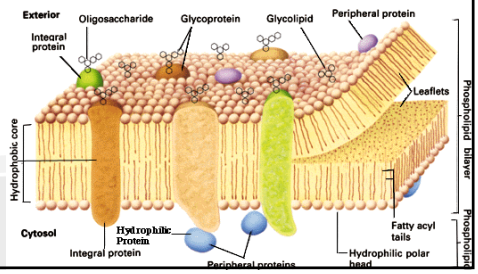
20

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

pia-dev.mgmt.science.uq.edu.au



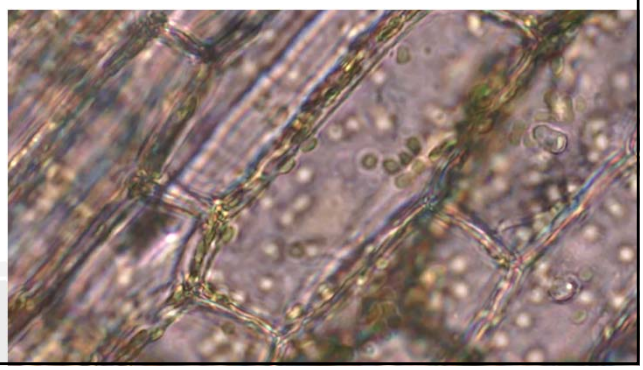


http://tiger.towson.edu/~cfanel1/istc301/cell-membrane.gif

21

Causes of Chilling Injury

- **Inhibition of cytoplasmic streaming (cyclosis)**
  - 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



Berkshire Community College Bioscience Image Library

22

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

23

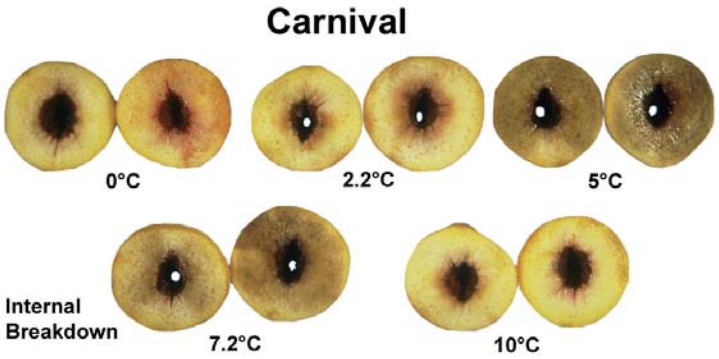
Causes of Chilling Injury

- **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

24

Chilling Injury Symptoms

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



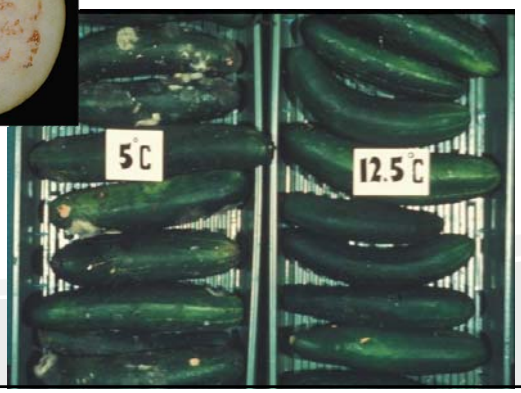
Credit: UC Davis, PTC

Credit: https://csiropedia.csiro.au/

25

Chilling Injury Symptoms

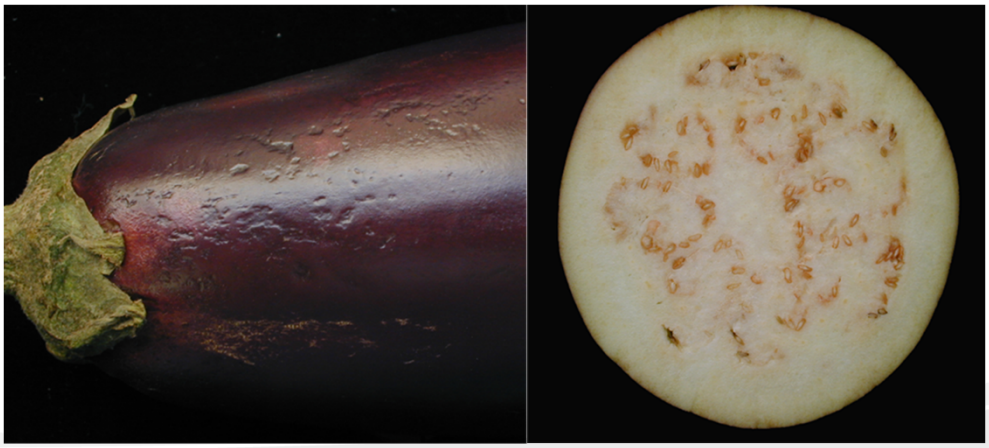
- **Pitting**, as in citrus fruits, cucumbers, peppers and tomatoes.
- **Necrosis**, as in seeds of eggplants, peppers and tomatoes.
- **Accelerated decay**, as in cucumber, melons, papaya and mango.



26

Pitting & Seed Necrosis

Eggplant cv. Classic 8 days at 5°C plus 1 day at 20°C

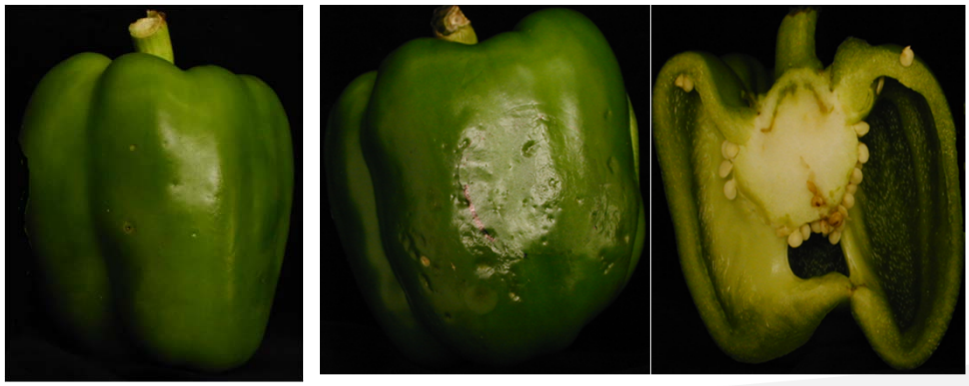


Chilling injury resulting in pitting of the skin and darkening of the seeds and flesh

27

Pitting & Seed Necrosis

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



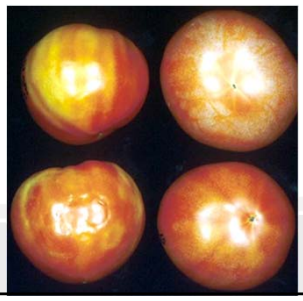
Bell pepper cv. Bell Boy

Chilling injury resulted in pitting of the skin and darkening of the seeds

28

Chilling Injury Symptoms

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



29

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

30

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)

31

Factors Affecting Chilling Injury

- 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 CO_2)**: shown to inhibit chilling injury of avocado, mango, and grapefruit
  8. **Some fungicides**: *e.g.*, thiabendazole used on grapefruit

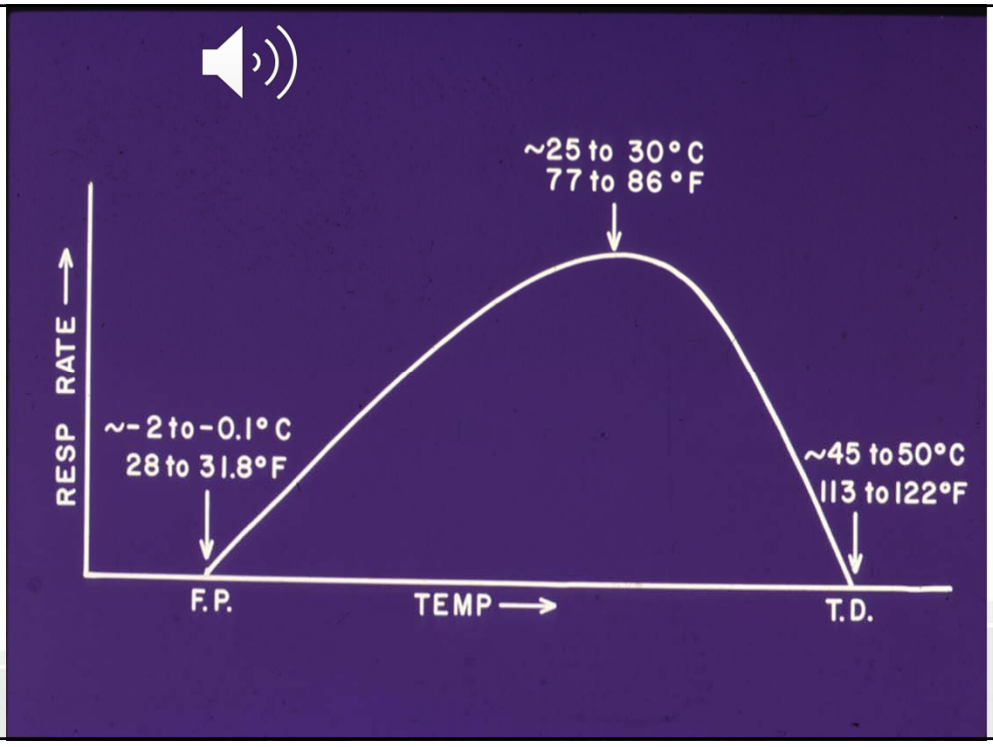
32

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

33



34

"Checkerboarding" (high temperature injury) of tomatoes

35

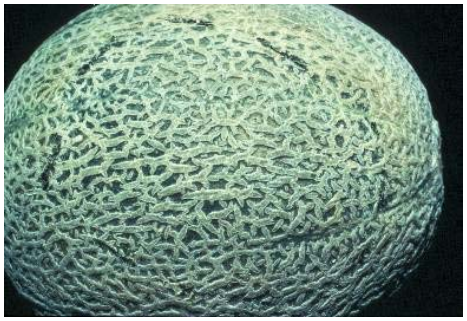
"Scald" (hot water injury) on mangoes

36

"Sunscald" on tomatoes

37

Sunscald on cantaloupe melons



← At harvest

After ripening →

38

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.

Kader & Cantwell, 2006

39

"Tipburn" of Iceberg head lettuce

40

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

41

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

42

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

43

Blackspeck (boron deficiency + low temperature)

Kader & Cantwell, 2006

44

Cutting black (corte negro; low calcium? + low temperature) of mangoes

45

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).

Credit: UC Davis PTC

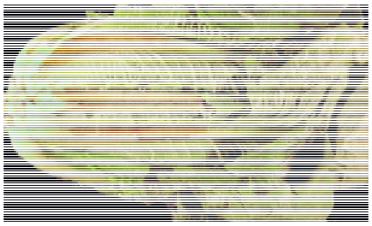
Kader & Cantwell, 2006

Credit: UC Davis, PTC

46

Storage Disorders

- Controlled atmosphere disorders
  - Low O_2 or high CO_2



Brown stain (CO_2 injury)

- Toxic chemicals
  - Ammonia, SO_2, methyl bromide, ozone, $CaCl_2$
- Ethylene disorders

Kader & Cantwell, 2006

Russet spotting

47