Postharvest Biology: An Overview

Profitable Horticulture Depends on Good Postharvest Handling

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Postharvest Losses and Waste are Costly
Represent loss of inputs and profits
Reduce postharvest losses and increase sustainability
--reduce land, chemical, energy other inputs
--conserve land, water, energy

<table>
<thead>
<tr>
<th>Locations</th>
<th>Developed Countries</th>
<th>Developing Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>From production to retail sites</td>
<td>2-23</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>5-50</td>
</tr>
<tr>
<td></td>
<td>5-50</td>
<td>22</td>
</tr>
<tr>
<td>At retail, foodservice and consumer sites</td>
<td>5-30</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2-20</td>
</tr>
<tr>
<td></td>
<td>2-20</td>
<td>10</td>
</tr>
<tr>
<td>Cumulative total</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

from Adel Kader, 2009, BM Gates project
Characteristics of Horticultural Crops

- High water content
- Easily damaged
- Diverse
  - genome
  - tissue type
  - physiological state
- Alive – a biological system
- Deterioration begins at harvest

Causes of Quality & postharvest Losses

**Leafy Vegetables**

- Lettuces
- Spinach
- Cabbage
- Chard
- Broccoli
- Celery
- Herbs
- Endives
- Asparagus

- Water loss
- Mechanical damage
- Loss of chlorophyll and other nutrients
- Respiration rates
- Microbial growth
- Sensitivity to ethylene
Causes of Quality & Postharvest Losses

Fruits

- Mechanical damage
- Maturity, immature, overmature
- Poor ripening, conditioning
- Softening, texture loss
- Changes in composition
- Water loss
- Chilling injury
- Microbial growth

Factors contributing to postharvest losses

- **TIME & TEMPERATURE**
- Respiration
- Ethylene
- Water loss
- Damage
- Diseases
- Continued growth
- Physiological disorders
- Light

From Gordon Mitchell, UC Davis
Temperature - why is it important?

• Rate of deterioration $\alpha$ rate of respiration

• Respiration:
  
  $\text{Sugar} + O_2 \rightarrow CO_2 + H_2O + \text{Energy (Heat)}$

• Respiration increases exponentially with $T$

Cauliflower heads and florets have very similar respiration rates 
& quality changes during storage

Hevajulige & Cantwell, UC Davis
### Respiration Rates of Some Perishable Products

<table>
<thead>
<tr>
<th>Category</th>
<th>Range at 5°C mg CO2/kg-h</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt;5</td>
<td>Nuts, dates</td>
</tr>
<tr>
<td>Low</td>
<td>5-10</td>
<td>Apple, citrus, grape, kiwifruit, onion, potato (mature)</td>
</tr>
<tr>
<td>Moderate</td>
<td>10-20</td>
<td>Apricot, banana, cherry, peach, pear, plum; carrot, lettuce, pepper, tomato, cucumber, carrot (no tops); potato (immature)</td>
</tr>
<tr>
<td>High</td>
<td>20-40</td>
<td>Strawberry, other berries, cauliflower Leeks, carrots (with tops), avocado</td>
</tr>
<tr>
<td>Very high</td>
<td>40-60</td>
<td>Artichoke, snap beans, Brussels sprouts, cut flowers, okra, watercress</td>
</tr>
<tr>
<td>Extremely high</td>
<td>&gt;60</td>
<td>Asparagus, broccoli, mushroom, peas, spinach, sweet corn</td>
</tr>
</tbody>
</table>

Respiration rate information for specific products:
Produce Facts: http://postharvest.ucdavis.edu/PF/

### Relative Perishability

- **Asparagus, Peas, Sweet Corn**
- **Artichoke, Broccoli, Strawberry**
- **Banana, Tomato, Peach**
- **Nuts, Dates**
- **Citrus, Garlic, Potato**
- **Apple, Carrot, Onion**

Relative Respiration Rate
Broccoli Shelf-life & Temperature

Days (to initiate yellowing)

Storage temperature

0°C 32°F
5°C 41°F
10°C 50°F
15°C 59°F
20°C 68°F

7 days
Broccoli Compositional Quality and Storage Temperature

Chlorophyll

Carotenoids

Ascorbic Acid

Sugars

Importance of Temperature to Maintain Quality

A
0°C  32°F

B
5°C  41°F

C
10°C  50°F
Effect of Temperature on Deterioration

<table>
<thead>
<tr>
<th>Temp. °F</th>
<th>Temp. °C</th>
<th>$Q_{10}$</th>
<th>Relative Velocity of Deterioration</th>
<th>Relative Shelf-life</th>
<th>Daily Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>0</td>
<td>--</td>
<td>1.0</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>3.0</td>
<td>3.0</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>68</td>
<td>20</td>
<td>2.5</td>
<td>7.5</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>86</td>
<td>30</td>
<td>2.0</td>
<td>15.0</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>104</td>
<td>40</td>
<td>1.5</td>
<td>22.5</td>
<td>4</td>
<td>25</td>
</tr>
</tbody>
</table>

$Q_{10} = \frac{\text{rate of deterioration at } T+10^\circ}{\text{rate of deterioration at } T}$

Temperature affects shelf-life by controlling respiration and decay

Mostly from data of Perkins-Veazie, Raspberries, USDA Agric Hdbk66
No fresh product freezes at 0°C (32°F)
Lettuce freezes at -0.2°C (31.7°F)

http://ucanr.edu/datastoreFiles/234-1931.pdf

1. Commercial Cooling Methods
   - Room Cooling
   - Forced Air Cooling
   - Vacuum Cooling
   - Hydrocooling
   - Icing
   - Cooling in refrigerated transport

Product requirements
Scale appropriate technology
Conventional, Organic products
Microbial food safety issues

2. Temperature Control during Transport and Distribution is a Major Challenge
Two Groups of Products
Temperature Compatibility

- **Non-chilling sensitive** products -- store near 0°C
- **Chilling sensitive** products -- store around 10°C (varies)
  - Occurs at low temperatures above freezing point
  - Sensitivity, exposure time, temperature

Symptoms of chilling injury

- Surface pitting
- Water soaking
- Browning
- Necrosis
- Rots
- Poor flavor
- Poor ripening

Commonly chilling symptoms do not appear until product is transferred from the cold room to a warmer temperature
Temperature and other Postharvest Recommendations

- http://postharvest.ucdavis.edu
  **Produce Facts**

- http://www.ba.ars.usda.gov/hb66/
  USDA Agriculture Handbook Number 66
  The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks

Some uses of Modified Atmospheres for fruits & vegetables
MA is a **Supplement** to Good Temperature Management

- MAP Salad Products
- MA for strawberry pallets to control Botrytis
- Bag-in-box MA for melons
Modified or Controlled Atmospheres

- Reducing oxygen
- Increasing carbon dioxide
- Removing carbon dioxide
- Removing ethylene and other volatiles
- Degree of precision differentiates MA and CA

Composition of Normal Air

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>78.08%</td>
<td>Nitrogen (N₂)</td>
</tr>
<tr>
<td>20.95%</td>
<td>Oxygen (O₂)</td>
</tr>
<tr>
<td>0.93%</td>
<td>Argon (Ar)</td>
</tr>
<tr>
<td>0.03%</td>
<td>Carbon dioxide (CO₂)</td>
</tr>
<tr>
<td>0.0001%</td>
<td>Ethylene (C₂H₄) (1 ppm)</td>
</tr>
</tbody>
</table>

Ethylene - an important factor

Plant hormone with positive and negative effects on fresh produce

- **Useful:**
  - Accelerates ripening
  - Causes abscission
  - Chlorophyll destruction

- **Problematic:**
  - Accelerates ripening
  - Causes abscission
  - Chlorophyll destruction
  - Accelerates senescence
Respiration rates of Ripening Fruits

Ethylene induces Ripening

Ethylene not involved in Ripening

Climacteric Fruits

Breadfruit
Cherimoya
Mango
Fig
Tomato
Apple

Nonclimacteric Fruits

Strawberry
Grape
Pineapple
Cherry
Lemon

Notice the difference in respiration scales!

Ethylene Production Rates at 20°C (68°F)

<table>
<thead>
<tr>
<th>Range (µL/kg-h)</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01-0.1</td>
<td>Citrus, grape, cherry strawberry</td>
</tr>
<tr>
<td></td>
<td><strong>MOST VEGETABLES</strong></td>
</tr>
<tr>
<td>0.1-1.0</td>
<td>Pineapple, blueberry, cucumber</td>
</tr>
<tr>
<td>1.0-10.0</td>
<td>Banana, mango, tomato, honeydew melon, fig</td>
</tr>
<tr>
<td>10-100</td>
<td>Apple, avocado, cantaloupe, nectarine, papaya, pear</td>
</tr>
<tr>
<td>&gt;100</td>
<td>Cherimoya, passion fruit, sapotes</td>
</tr>
</tbody>
</table>
Postharvest Compatibility Issues

- Temperature
- Relative Humidity
- Ethylene
- Odor

Transportation and Loading

Distribution warehouses and Storage rooms

Retail & Food Service outlets

Manage Ethylene Effects

1. **Avoidance**
   - Products, combustion engines, smoke

2. **Removal**
   - Ventilation (1 air exchange per hour), oxidation, absorption

3. **Inhibition of production**
   - Low temperature, chemical inhibitors of enzymes, antisense technology

4. **Inhibition of action**
   - Low temperature, high CO2, low O2, STS, 1-MCP (Smartfresh™)

5. **Germplasm**
   - Selection of mutants and molecular modification

Control 300 600ppb 1-MCP
**Water Loss (Transpiration)**

- <3% no visual effect, texture
- 3-5% visual quality affected
- >5% shrivel, lose salability

*Loss of Salable Weight*
*Loss Fresh Appearance*
*Loss of Texture*

Water loss is Cumulative
Temperature Control Important
Appropriate Packaging

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**WATER LOSS**

- Products are covered with holes - needed for gas exchange
- Damage increases water loss
- Loss of water depends on the vapor pressure deficit (VPD)
- VPD increases exponentially with rising temperature

Stomates in leaves; lenticels in fruits
Water loss and temperature

\[ \text{Wt loss (\%/day)} = \text{product } K \times \text{VPD} \]

**Psychrometric Chart**
Thermodynamic properties of air Temperature and Water Content

- VPD increases exponentially with rising temperature
- VPD increases linearly with falling humidity

Storage conditions

Field conditions

**Damage is a Major Problem**

- **TAKE CARE!**
- Careful harvesting
- Into lined baskets/bins
- Don’t throw, dump, or drop
- Avoid rough surfaces
- Minimize touch points
- Pack gently but securely
Do you see anything wrong in these photos?

‘Ranch Pack’ Peach Handling: Simple, Clean and Careful Handling for High Quality Product

Now packers wear hairnets, sometimes gloves

3rd party Inspectors Forced Air Cooling
Postharvest Diseases

- Important cause of postharvest loss
- Relatively few important genera
- Most are weak pathogens and need injury

Sour rot (Geotrichum)  Penicillium sp.

Gray mold (Botrytis)  Sclerotinia rot

Typically the more the product is handled, the greater the physical damage to the product and the greater the risk of postharvest disease
SPINACH: DAMAGE, DECAY, TEMPERATURE

Changes in Spinach quality:
- washed and bagged product stored at 4 Temperatures
- Decay causing Bacteria

Raw Foods Contain Microorganisms
Some are Pathogenic to Humans

Microbes present an "invisible challenge"

- They don't usually change the appearance, taste or odor of food.
- Fresh produce with no kill step
- Prevention of Contamination is key
Good Agricultural Practices: Key Areas for All Scales of Farming and Shipping

- Water
- Workers
- Waste
- Wildlife
- Record-keeping
- Traceability

- Prevention of Contamination
- Water Quality Concerns High on FDA Priority Risk List
- Temperature control can reduce risk

Continued growth is affected by temperature

- Sprouting (potato, onion, garlic)
- Rooting (onion, potato)
- Growth away from gravity (asparagus, flowers)
- Internal seed growth (cucumber, beans)
- Opening of immature buds (broccoli)
PHYSIOLOGICAL DISORDERS

- Disorders resulting from abnormal conditions during production and handling
- Abnormal temperatures
- Extended storage
- Abnormal gases
- Nutritional imbalance

Factors that Continue to Influence U.S. Consumers’ Produce Purchases

Food Safety is Assumed

Postharvest Problem

...Quality is maximized when the product is harvested more mature or ripe, whereas shelf- and storage life are extended if the product is harvested less mature or unripe....


Taste and the Sugar:Acid Ratio

<table>
<thead>
<tr>
<th>ACIDS</th>
<th>SUGARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Low</td>
<td>Insipid, tasteless</td>
</tr>
<tr>
<td>Moderate to High</td>
<td>Sour, tart</td>
</tr>
</tbody>
</table>

Soluble solids measured by a refractometer = sugars, but also organic acids, soluble pectins, anthocyanins, phenolics, ascorbic acid, others
Examples Contributions Fruits and Vegetables to Human Health

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Sources</th>
<th>Impacted Diseases</th>
<th>Sources</th>
<th>Impacted Diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Antioxidants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td>Broccoli, cantaloupe, citrus, guava, leafy greens, pepper, strawberry tomato, pineapple</td>
<td>Cancer, cataracts, heart disease, stroke, and more</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin A</td>
<td>Dark-green leafy vegetables, orange vegetables (sweetpotato), orange-flesh fruits (papaya, tomato)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin E</td>
<td>Nuts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flavonoids</td>
<td>Red, blue and purple fruits (berries, grapes, plum, pomegranate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiber</td>
<td>Most fruits and vegetables, nuts</td>
<td>Diabetes, heart disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Folate (Vit B9)</strong></td>
<td>Dark-green leafy vegetables; oranges, peas</td>
<td>Birth defects, cancer, heart disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Potassium</strong></td>
<td>Potato, sweetpotato, banana, greens</td>
<td>Hypertension, stroke</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Based on Appearance (Visual Quality)

Based on Flavor & Nutritional Quality

- Is this correct?
- Need more critical postharvest studies that determine flavor life as well as appearance life.
- Reassess current recommendations for whole and fresh-cut products.

Based on Firmness & Texture

Postharvest Life Under Optimum Conditions

General Principles

• Fresher the product (time), better the quality, flavor, and nutrition
  – True for vegetables
  – More complicated for fruits that require ripening
• Adhering to storage and handling guidelines results in better quality
• Postharvest treatments may extend the storage-life but not necessary preserve quality attributes

How do we successfully move so many products through diverse transportation/distribution channels? How long to market? What storage life is needed? What quality is needed?

1-2 days to harvest, cool, store
1-2 days local transport
7-21 days truck or marine transport
1-3 days to distribution center
1-3 days at retail
1-3 days at consumer
Total = 12 - 34 days

Product under ideal conditions? UNLIKELY!

More knowledge about a product allows for better decision making.
Factors Contributing to Postharvest Deterioration and Losses

- Respiration
- Ethylene
- Water loss
- Damage
- Diseases
- Continued growth
- Physiological disorders
- Light

TIME and TEMPERATURE

10 Basic Postharvest Handling Principles

1) Harvest at correct maturity
2) Reduce physical handling
3) Protect product from sun
4) Keep packingline or area simple and clean; ensure good worker hygiene
5) Select, classify, and pack carefully
6) Align cartons, strap pallet
7) Cool as soon as possible
8) Know market and product requirements
9) Coordinate efficient & rapid handling
10) Train and compensate workers adequately