I. Introduction

• Year-round availability reduces need for storage
• Transport represents a major portion of postharvest life
• U.S. per-capita vegetable consumption increase has mainly been in this group of vegetables
I. Introduction

• More perishable than root or fruit vegetables
• Major causes of deterioration
  – Water loss
  – Yellowing (chlorophyll loss)
  – Mechanical injury (& decay)
  – Physiological disorders
  – Growth & toughening (asparagus, celery)

II. Morphological Characteristics

• Derivation of Some Vegetables From Plant Tissue

This Group Includes:

• Leaves and associated parts:
  – Blades
    • Leaf lettuce
  • Spinach & greens
  • Chard
  • Endive
This Group Includes:
- Leaves and associated parts:
  - Petioles
  - Celery
  - Rhubarb

http://www.hort.purdue.edu/
This Group Includes:

- Other vegetative tissues:
  - Stems – asparagus
  - Immature flower parts
  - Artichokes
  - Broccoli
  - Cauliflower

II. Morphological Characteristics

- In relation to water loss
  - Leafy vegetables
    - Very high surface:volume ratio (20 to 40:1)
    - Stomata – escape routes for water loss
    - Thin cuticle makes them very susceptible to water loss
    - Buds are much less susceptible to wilting than leaves

- Stem vegetables
  - High surface:volume ratio (3 to 6:1)
  - Cut ends contribute to water loss
  - Susceptible to water loss

- Floral vegetables
  - Unopened flower buds borne on stems (50-60% by weight)
  - Relative susceptibility to water loss is similar to stem vegetables
Examples of the Surface/Volume Ratios of Fruits and Vegetables

<table>
<thead>
<tr>
<th>Surface/volume ratio (cm²/cm³)</th>
<th>Plant material</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>Individual edible leaves</td>
</tr>
<tr>
<td>0.1–1</td>
<td>Smaller soft fruits</td>
</tr>
<tr>
<td>1–5</td>
<td>Leguminous fruits; nuts; larger soft fruits; stem and floral vegetables; rhizomes; shallot</td>
</tr>
<tr>
<td>0.5–1.5</td>
<td>Tubers; tuberous roots; tap-roots; pome, stone and citrus fruits; cucurbitosus fruits; banana; onion</td>
</tr>
<tr>
<td>0.2–0.5</td>
<td>Densely packed cabbage; large Siouxa turnips; yams; coconut</td>
</tr>
</tbody>
</table>

Adapted from Burton, 1982

Percentage Loss of Original Weight From Various Commodities During Storage

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Initial rate of water loss (% day⁻¹ mbar⁻¹ wvpd)</th>
<th>Percentage loss during successive 2-week periods (max. permissible max. permissible)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td>0.5</td>
<td>7.06 4.80 4.55 3.85</td>
</tr>
<tr>
<td>Sweetpotato</td>
<td>0.6</td>
<td>8.72 5.67 5.10 5.05</td>
</tr>
<tr>
<td>Beet (w/ leaves)</td>
<td>0.9</td>
<td>12.86 10.19 10.51 9.25</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>1.2</td>
<td>17.04 9.07 8.14 8.51</td>
</tr>
</tbody>
</table>

Storage temperatures 0–2°C; RH 85–87.5% (Singh et al. 1952)

Water Loss, as a Percentage of Original Weight, at Which Commodities Become Unsaleable

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Max. permissible water loss (%)</th>
<th>Commodity</th>
<th>Max. permissible water loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>8</td>
<td>Onion</td>
<td>10</td>
</tr>
<tr>
<td>Beans, broad</td>
<td>6</td>
<td>Raspberries</td>
<td>7</td>
</tr>
<tr>
<td>Beans, garbanzo</td>
<td>5</td>
<td>Rutabaga, swede</td>
<td>7</td>
</tr>
<tr>
<td>Beets, with leaves</td>
<td>7</td>
<td>Rutabaga, new</td>
<td>7</td>
</tr>
<tr>
<td>Blackberries</td>
<td>6</td>
<td>Peas, pod, swede</td>
<td>5</td>
</tr>
<tr>
<td>Broccoli sprouts</td>
<td>8</td>
<td>Peas, pod, new</td>
<td>5</td>
</tr>
<tr>
<td>Cabbage</td>
<td>7</td>
<td>Peas, green</td>
<td>7</td>
</tr>
<tr>
<td>Carrots, storing</td>
<td>8</td>
<td>Peas, maincrop</td>
<td>7</td>
</tr>
<tr>
<td>Carrots, bunching</td>
<td>4</td>
<td>Peas, maincrop</td>
<td>7</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>7</td>
<td>Spinach, swede</td>
<td>7</td>
</tr>
<tr>
<td>Celery</td>
<td>10</td>
<td>Strawberry</td>
<td>7</td>
</tr>
<tr>
<td>Celeri</td>
<td>10</td>
<td>Strawberries</td>
<td>7</td>
</tr>
<tr>
<td>Celery</td>
<td>10</td>
<td>Strawberries</td>
<td>7</td>
</tr>
<tr>
<td>Lettuce, pointed</td>
<td>7</td>
<td>Turnips, swede</td>
<td>7</td>
</tr>
<tr>
<td>Lettuce, Verdis</td>
<td>9</td>
<td>Turnips, with leaves</td>
<td>7</td>
</tr>
<tr>
<td>Lettuce, Winter</td>
<td>1</td>
<td>Turnips, with leaves</td>
<td>7</td>
</tr>
</tbody>
</table>

Approximate values from Robinson et al. (1975).
II. Morphological Characteristics

- In relation to texture
  - Collenchyma and sclerenchyma tissues make celery fibrous or stringy
  - Toughness of asparagus is related to lignification
  - Turgidity of these vegetables is important to their tenderness
  - Solidity (firmness) of buds increases with maturation

III. Compositional Characteristics

- Contain chlorophyll
- High in water content, succulent, tender, non-acid
- Many vegetables of this group are high in ascorbic acid (Vitamin C) content
- Carotenoids - antioxidants
- Also high in Vitamin A
- Very good sources of minerals (P, K, Fe, Na, Ca)

Leafy & Floral Vegetables High in Vitamins C and A

<table>
<thead>
<tr>
<th>Vitamin C (mg/100 g fr. wt.)</th>
<th>Vitamin A (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parsley (172)</td>
<td>Kale (8,900)</td>
</tr>
<tr>
<td>Turnip greens (139)</td>
<td>Parsley (8,500)</td>
</tr>
<tr>
<td>Broccoli (103)</td>
<td>Spinach (8,100)</td>
</tr>
<tr>
<td>Brussels sprouts (102)</td>
<td>Turnip greens (7,600)</td>
</tr>
<tr>
<td>Collards (92)</td>
<td>Chard (6,900)</td>
</tr>
<tr>
<td>Cauliflower (98)</td>
<td>Broccoli (2,500)</td>
</tr>
<tr>
<td>Cabbage (47)</td>
<td></td>
</tr>
<tr>
<td>Asparagus (48)</td>
<td></td>
</tr>
</tbody>
</table>

11/8/2018
IV. Maturity & Quality Indices

- Harvest indices of some leafy, floral and stem vegetables
  - Asparagus: spear length (12.5-20 cm)
  - Broccoli: compact flower heads, no open flowers
  - Cabbage & lettuce: solidity of head
  - Cauliflower: head size and appearance
  - Celery: size (overmaturity results in pithiness)
IV. Maturity & Quality Indices

- Quality criteria for some commodities
  - Asparagus: straightness, diameter, percent green color, no defects
  - Cabbage: solidity, no seedstems, color, no defects
  - Cauliflower: cleanliness, compactness, white color, size, no defects
  - Celerity: stalk form, compactness, color, no seedstems, no defects
  - Lettuce (head): color; maturity (solidity), no seedstems, freedom from defects and decay
  - Freshness and turgidity are quality factors for all

V. Postharvest Physiology

- Respiration rate
  - Very/extremely high (more than 40 mg CO₂/kg-h at 5°C): asparagus, Brussels sprouts, spinach & turnip greens
  - High (20 to 40 mg CO₂/kg-h at 5°C): artichoke, broccoli, celery & leaf lettuce
  - Moderate (10 to 20 mg CO₂/kg-h at 5°C): cabbage, cauliflower, celery, kohlrabi & head lettuce

<table>
<thead>
<tr>
<th>Class</th>
<th>(mg CO₂/kg-h) at 5°C</th>
<th>Commodities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>&lt; 10</td>
<td>Dates, dried fruits and vegetables, radish</td>
</tr>
<tr>
<td>Low</td>
<td>10 – 20</td>
<td>Apple, beet, celery, citrus fruits, cranberry, garlic, grape, honeydew melon, kiwifruit, onion, papaya, pomegranate, pineapple, potato, watermelon</td>
</tr>
<tr>
<td>Moderate</td>
<td>20 – 40</td>
<td>Apricot, banana, blueberry, cherries, cantaloupe, carrot (topped), celery, cherry, cucumber, fig, green bean, lettuce (leaf), mango, nectarine, olive, peach, pear, plum, potato (tubers), radish (topped), summer squash, tomato</td>
</tr>
<tr>
<td>High</td>
<td>40 – 80</td>
<td>Avocado, blackberry, corn (with top), cauliflower, leeks, lettuce (leaf), lime, bean, onion, potato (with top), raspberry</td>
</tr>
<tr>
<td>Very High</td>
<td>80 – 160</td>
<td>Artichoke, bean sprouts, cherimoya, car flowers, edibles, green onions, kohlrabi, okra, passion fruit, eggplant, watermelon</td>
</tr>
<tr>
<td>Extremely High</td>
<td>&gt; 160</td>
<td>Asparagus, broccoli, Brussels sprouts, mushrooms, peaches, peas, spinach, squashes, sweet corn</td>
</tr>
</tbody>
</table>
Rates of CO₂ Production (mg kg⁻¹ h⁻¹) at Different Temperatures
(from Robinson et al., 1975)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Celery</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Beetroot (bunching, with leaves)</td>
<td>14</td>
<td>12</td>
<td>13</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Rhubarb</td>
<td>14</td>
<td>11</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Turnip (bunching with leaves)</td>
<td>15</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Lettuce</td>
<td>16</td>
<td>14</td>
<td>11</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Broccoli sprouts</td>
<td>17</td>
<td>15</td>
<td>11</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Watercress</td>
<td>18</td>
<td>16</td>
<td>12</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>20</td>
<td>18</td>
<td>15</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Asparagus</td>
<td>28</td>
<td>24</td>
<td>20</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Carrots (bunching, with leaves)</td>
<td>35</td>
<td>31</td>
<td>27</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>Spinach</td>
<td>35</td>
<td>31</td>
<td>27</td>
<td>25</td>
<td>22</td>
</tr>
</tbody>
</table>

V. Postharvest Physiology

- Ethylene production
  - Very low (< 0.1 μl/kg-h), and very sensitive to ethylene effects (detrimental)

- Responses to controlled atmospheres
  - 2-3% O₂ retards senescence (except asparagus, which is intolerant of low O₂)
  - Susceptibility to elevated CO₂ varies greatly
    - Lettuce, celery & endive: injury if CO₂ > 5%
    - More than 5% CO₂ induces off-odors and off-flavors in cooked cauliflower
    - Elevated CO₂ (5-9%) retards soft rot development, toughening and yellowing of asparagus; also retards yellowing of broccoli
V. Postharvest Physiology

- **Responses to controlled atmospheres**
  - Cabbage can be held for up to 6 months in CA at 0°C (2-3% O₂ + 5-8% CO₂); this is used commercially in the northeastern U.S.
  - CA is also used commercially during marine transportation of lettuce (1-2% O₂ + ≤1% CO₂)
  - Carbon monoxide (2-3% CO) has been used as a discoloration inhibitor on lettuce in marine transportation
  - CA prevents color and chlorophyll degradation in broccoli
  - CA reduces stalk elongation and slight pithiness and also prevents butt end cut browning in celery

### Recommended CA for some leafy, floral and stem vegetables

<table>
<thead>
<tr>
<th>Vegetable type</th>
<th>O₂</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>13-16</td>
<td>5-7</td>
</tr>
<tr>
<td>Broccoli</td>
<td>1-2</td>
<td>10</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>1-2</td>
<td>5</td>
</tr>
<tr>
<td>Cabbage</td>
<td>2-3</td>
<td>5-8</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>2</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Celery</td>
<td>2-4</td>
<td>3-5</td>
</tr>
<tr>
<td>Lettuce</td>
<td>2-3</td>
<td>0-1</td>
</tr>
</tbody>
</table>

V. Postharvest Physiology

- **Temperature-related physiological disorders**
  - **Freezing injury**: preharvest and postharvest
  - **Chilling injury**: only asparagus is susceptible (1 to 4 weeks at 0-3°C)
  - **Solar injury**: solar browning of cauliflower curds
**V. Postharvest Physiology**

- Calcium deficiency-related physiological disorders
  - **Tipburn**: cabbage, Brussels sprouts, lettuce
  - **Blackheart**: celery, endive, escarole

- Senescence-related physiological disorders
  - **Bolting** (development of seedstalks):
    - lettuce & leek
  - **Pithiness** (spongy internal tissue):
    - sign of senescence in celery
  - **Riciness** (granular appearance):
    - sign of senescence in cauliflower
    - Yellowing:
      - common sign of senescence, enhanced by C\(_2\)H\(_4\)

- Physiological disorders of lettuce
  - **Brown stain**: caused by 2% or higher CO\(_2\) at 0-5°C
  - **Russet spotting**: caused by C\(_3\)H\(_4\) at 0.1 ppm or higher
  - **Rusty-brown discolouration**: 'Climax' cultivar, increased by lettuce mosaic virus
  - **Pink rib**: a symptom of senescence
  - **Low O\(_2\) injury**: less than 1% O\(_2\)
VI. Pathological Breakdown

- Bacterial soft rot: chard, celery, lettuce, spinach
- Gray mold rot (Botrytis): artichoke, celery, lettuce, rhubarb
- Watery soft rot: celery, lettuce, cabbage
- Downy mildew: lettuce, spinach
- Big vein: lettuce
- Rhizoctonia: cabbage

VII. Postharvest Handling Procedures

- Harvesting
  - Mostly by hand, some harvesting aids are in use (i.e., "mule trains")
  - Mechanical harvesting systems have been developed for lettuce, cabbage, Brussels sprouts, etc., but are not used commercially
  - For lettuce the harvesting machine, maturity (density) is sensed using gamma rays or X-rays, and the desired heads cut, lifted, and trimmed mechanically

- Handling systems: field packing (lettuce "mule train")
  - Select, cut, trim, pack in carton, transport to vacuum cooler, cool, load, transport to destination
  - Wrapped lettuce: workers in mobile field units trim, wrap, and pack into cartons, transport to vacuum cooler, etc., as above

Courtesy Steven Sargent
VII. Postharvest Handling Procedures

• Handling systems: packinghouse
  – Select, cut, transport to packinghouse in bulk, trim, size, pack into cartons, cool, etc.
  – Fresh-cut (shredded) lettuce – bulk lettuce sent to central facilities: select, trim, cool
  • In cold room: cut, rinse, remove excess water, pack into (MAP) bags, place into cartons, ship.

• Cooling methods
  – Vacuum cooling: lettuce (crisphead)
  – Hydro-vacuum cooling: celery, cauliflower, others
  – Hydrocooling: leaf lettuce, celery, spinach, green onions, leek, artichoke
  – Package ice: broccoli, spinach, parsley
  – Room cooling: artichoke, cabbage

• Packinghouse operations
  – Cleaning and trimming, use of chlorine in wash water
  – Sorting to eliminate defects
  – Sizing in some cases
  – Wrapping of individual units (e.g., wrapped cauliflower, sleeved celery)
  – Packaging: shipping containers may be RPCs or waxed fiberboard cartons to withstand hydrocooling and in-package ice exposure
  – Cooling by an appropriate method
VII. Postharvest Handling Procedures

• Temporary storage
• Transport
• Destination handling
• Retail handling

VIII. Recommended Conditions

• Temperature management procedures
  – Avoid delays between harvesting and cooling, especially during warm weather
  – Cool to +1°C (± 1°C); avoid freezing; most will tolerate contact icing
  – Transfer immediately after cooling into refrigerated transit vehicles or holding rooms
  – Maintain +1°C (± 1°C) and 95-100% RH during transit and temporary storage

• Duration of holding: long-term storage/transport (>1-2 weeks) is not typical, except with cabbage, Chinese cabbage, and celery
• Air movement: minimum required for proper temperature control
• Avoid exposure to ethylene throughout the handling system
• Atmospheric composition: see section on responses to controlled atmospheres – air exchange sufficient to maintain adequate O₂ and avoid injurious CO₂ levels