### Root, Tubers & Bulbs

**General Characteristics**
- Storage organs (carbohydrates)
- Relatively low respiration rates
- Low surface to volume ratios
- Bulky and weighty
- Relatively long shelf-life (months)
- Postharvest sprouting, rooting

### Many root crops are chilling sensitive: Jicama as example

- Chilling insensitive roots: 0-5°C
- Most chilling sensitive roots: 10-15°C
- Potatoes 4-8°C
- Low humidity for onion, garlic

### Curing or wound healing is essential for many root and tubers

- High humidity is essential to maintain live cells that are capable of healing

### Roots cured in the lab or in commercial storage

- Potatoes can show similar internal breakdown
  - cv Yellow Finn stored 5 mo. at 2°C
Curing Conditions

<table>
<thead>
<tr>
<th></th>
<th>Potato</th>
<th>Tropics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>15-20°C (59-68°F)</td>
<td>25-35°C (77-85°F)</td>
</tr>
<tr>
<td>% RH</td>
<td>95 or higher</td>
<td>95 or higher</td>
</tr>
<tr>
<td>Time, days</td>
<td>5-10</td>
<td>1-7</td>
</tr>
</tbody>
</table>

Sweet potatoes

Sweetpotato storages
- Evaporative cooling
- Mechanical refrigeration
- 59-60°F (15-16°C)
- High humidity

Sweetpotato Handling
For market

Beuregard variety
6 kg cartons for Europe

IMAPESA, Palos Blancos, Sula Santa Barbara Honduras

Harvest and storage of jicama in Mexico

Composition of Potato Tubers

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Weight g</th>
<th>dry weight %</th>
<th>Starch %</th>
<th>Sugar %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowering</td>
<td>9</td>
<td>16</td>
<td>64</td>
<td>4.8</td>
</tr>
<tr>
<td>Flowering ends</td>
<td>11</td>
<td>17</td>
<td>66</td>
<td>5.2</td>
</tr>
<tr>
<td>Leaves decline</td>
<td>28</td>
<td>19</td>
<td>72</td>
<td>2.9</td>
</tr>
<tr>
<td>80% leaves dead</td>
<td>33</td>
<td>21</td>
<td>73</td>
<td>0.8</td>
</tr>
<tr>
<td>100% leaves dead</td>
<td>51</td>
<td>20</td>
<td>72</td>
<td>0.7</td>
</tr>
</tbody>
</table>

cv. Irish Cobbler; data from Burton, 1966
### Potatoes

20% dry matter
18% carbohydrate
2% protein

**Vitamins**
- Ascorbic Acid (Vit C; ~20mg/100g FW)
- Folate (Vit B9; ~20µg/100g FW)
- Pyridoxine (Vit B6; 0.25mg/100g FW)

**Minerals**
- Potassium
- Iron
- Magnesium
- Calcium
- Zinc
- Phosphorus

**Phytonutrients**
- Phenolics
- Anthocyanins
- Flavonols
- Carotenoids
- Glycoalkaloids

### Quality characterization of potatoes harvested at different times after different plant kill dates.

- 2 cultivars: Morning gold and Carlingford
- 4 kill dates each with 5 harvest dates
- Size, dry weight, sugar content, skin integrity (
  - weight loss, skin score, torque measurement), respiration rates

### Specific gravity

$$C = \frac{W_{air}}{W_{air} - W_{water}}$$

Specific gravity is directly correlated to % dry matter

### Starch-Sugar Conversions

- Higher storage temperature favors starch accumulation
- Lower temperatures favor sugar increase
- Maturity at harvest
- Cultivar
- Length of storage
  - senescent sweetening
  - sugar increase with sprouting

### During storage, aim to minimize respiration rates

Sugars react with amino acids to form a dark color when potato is fried. Sugars at 2% fresh weight may result in rejection at processing plant.
Potato Storage

- **Early crop or Short-term storage**
  - Usually not store; ship immediately
  - Cure, store 4-7°C (40-45°F) 2-4 months

- **Late crop or Long-term storage**
  - Sprout inhibitor
  - 5-8°C (41-47°F) >90% RH
  - Store 7 to 12 months

- **Seed potato storage**
  - Low temperature (2-5°C) in the dark
  - Diffuse light storage at 10-20°C

Idaho facility is store 250,000 cwt potatoes. The storage has a center plenum for delivery of air via 2 separate bays.

Potato Dormancy

**Sprouting is undesirable:**
- Higher weight loss
- Texture changes
- Compositional changes

- Natural dormancy prevents sprouting for about 2-3 months after harvest.
- For longer periods, need to inhibit sprout growth
  - Temperature
  - Preharvest control
  - Postharvest fumigation after curing

Preharvest Control
- Maleic hydrazide 2-3 wks before harvest, 2500ppm foliar spray

Postharvest Control
- CIPC (Chlorpropham) dust, aerosol, 10-20 ppm, after curing
- Other chemicals: 1,4-dimethylnaphthalene (I,4 Sight)
- Irradiation at 0.03-0.15 kGy
- Temperature: no sprouting if store below 4°C
- Ethylene
- Natural sprout inhibitors (suppressants), carvone, aldehydes (WSU), essential oils from mints

Packaging

- Netted bags-burlap, polyethylene
- Plastic wrapped tray
- Opaque plastic or paper bag
- Microwaveable pouches

Glycoalkaloids in Potatoes

- **α-Solanine, α-Chaconine**
  - Highest content in peel and sprouts
  - Cultivars vary considerably
    - 5 mg/100 g fresh wt. is typical
    - >20 mg/100 g is a health hazard
    - >30 mg/100g causes bitterness
  - Increase with bruising, wounding
  - Increase greatly with light and warmer storage temperatures

Idaho potato Center: [http://www.kimberly.uidaho.edu/potatoes/](http://www.kimberly.uidaho.edu/potatoes/)


Oregon State University: [http://oregonstate.edu/potatoes/storproc.htm](http://oregonstate.edu/potatoes/storproc.htm)

Manitoba Canada potato storage structures and management: [http://www.gov.mb.ca/agservices/tops/potatoes/bda04s06.html](http://www.gov.mb.ca/agservices/tops/potatoes/bda04s06.html)


Potato Information and Exchange: [http://potatoes.wsu.edu/research](http://potatoes.wsu.edu/research)

Exeter Engineering, Exeter CA: [www.exeter-engineering.com](http://www.exeter-engineering.com)
Toxic glycoalkaloid formation is closely associated with greening

Control greening and glycoalkaloids:
- No Light
- Low Temperature
- Short Duration
- Opaque or other packaging
- Other treatments

http://potatoes.wsu.edu/research/equipment.htm
Mechanical and Physiological Disorders of Potato (other than Sprouting)

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Symptoms</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greening</td>
<td>surface turns green with light</td>
<td>minimize exposure to light</td>
</tr>
<tr>
<td>Black heart</td>
<td>sharply defined, purplish-grey to</td>
<td>sharply defined, purplish-grey to</td>
</tr>
<tr>
<td></td>
<td>black area in center or cavities</td>
<td>black area in center or cavities due to O2</td>
</tr>
<tr>
<td></td>
<td>due to O2 starvation</td>
<td>starvation</td>
</tr>
<tr>
<td>Chilling injury</td>
<td>grey to red-brown areas or</td>
<td>provide good air circulation to prevent</td>
</tr>
<tr>
<td></td>
<td>black heart</td>
<td>heating and oxygen deprivation; avoid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>chilling injury</td>
</tr>
<tr>
<td>Freezing injury</td>
<td>vascular tissue turns black</td>
<td>store tubers above 4°C</td>
</tr>
<tr>
<td></td>
<td>and tubers leak when thawed</td>
<td>store tubers above -1°C</td>
</tr>
<tr>
<td>Blackspot</td>
<td>internal black spots due to</td>
<td>minimize bruising; warm to 15°C before</td>
</tr>
<tr>
<td></td>
<td>bruising; can cause shatter in</td>
<td>grading</td>
</tr>
<tr>
<td></td>
<td>some potatoes</td>
<td></td>
</tr>
</tbody>
</table>

Modified from http://www.extension.umn.edu/distribution/horticulture/DG8239.html

Potato Diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Causal Agent</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry rot</td>
<td>Fusarium spp.</td>
<td>brown, firm, sunken flesh; sunken and wrinkled surfaces with blue or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>white protuberances</td>
</tr>
<tr>
<td>Soft rot</td>
<td>Erwinia carotovora</td>
<td>soft, water cavities in flesh; foul smell; in non-russeted varieties;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>shallow, round lesions around lenticels</td>
</tr>
<tr>
<td>Leak</td>
<td>Pythium</td>
<td>oozing tubers; well defined areas between healthy and diseased flesh;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pink than black flesh with granular, miliary rot</td>
</tr>
<tr>
<td>Late blight</td>
<td>Phytophthora infestans</td>
<td>small, shrunk, dark spots in flesh; foul smell</td>
</tr>
<tr>
<td>Ring rot</td>
<td>Corynbacterium asepсидicum</td>
<td>vascular ring yellow</td>
</tr>
</tbody>
</table>

Modified from http://www.extension.umn.edu/distribution/horticulture/DG8239.html

Water sanitation problem. Decay due to Erwinia bacteria

Severe bacterial soft rot in Stored potatoes.

Figure 6: Advanced stages of infection of soft rot occurring prior to tuber harvest. The irregularity of the point of starch attachment and extension through the vascular pith layer of the tuber, and the brittleness of the flesh, is characteristic of soft rot caused by secondary tuber or organism.

From Trevor Suslow, UC Davis

http://info.ag.uidaho.edu/pdf/CIS/CIS1131.pdf

Phytophthora erythroseptica

Figure 1. Tuber symptoms of pink rot. Infected tubers first appear cream colored when skived open. The salmon-pink coloration appears after 15 to 20 minutes at room temperature.

http://info.ag.uidaho.edu/pdf/CIS/CIS1131.pdf

Phytophthora infestans, Late blight

Figure 3. Potato tubers with late blight infection. The tuber in the center shows symptoms of infection through an eye. The tuber slices on either side depict the granular, brown dry decaying association with late blight.

http://info.ag.uidaho.edu/pdf/CIS/CIS1131.pdf
Important Constituents—Health Benefits, Phytonutrients

• Quercetin (flavonoid)
  – Antioxidant activity—delay or slow the oxidative damage to cells
  – Reduce/eliminate free radicals in the body,
  – Inhibit low-density lipoprotein oxidation (heart disease),
  – Protect and regenerate vitamin E (a powerful antioxidant)

• Sulfur-containing compounds
  – Allyl and diallyl sulfides and others—Flavor
  – Reduce blood cholesterol levels
  – Improve immune function
  – Lower blood sugar levels
  – Increase production of enzymes that protect cells against cancer-causing substances (carcinogens)

http://www.onions-usa.org/

Field packing of sweet white onions

Forced air curing of onion skins

Curing with natural ventilation under shade cloth
Onion Curing Conditions

- Windrow in the field
- Sacks in the field
- Sacks, bins in a protected shed/shade house
- Storage room with slatted floor, heated air
- 1-4 weeks depending on conditions
- Best skin color at 24-32°C (75-90°F)
- Used heated air at same temperature
- Modify air flow rate, dry surface rapidly
- Use lower humidity air if onions are wet (25-35%)

Onion Bulb Storage

- Well cured
- Relative humidity 60-70% (reduce molds, rooting)
- 0°C (32°F) long-term
- 20°-30°C (68-86°F) 1-2 months
- 5°-18°C (41°-65°F) favor sprout growth
- Odor easily transferred to other products

Botrytis Neck Rot

*Botrytis allii, B. squamosa, B. cinerea*

- Symptoms usually appear after harvest
- Infections originate in the field.
- Develops best under cool & humid conditions (15-20°C)

Control

- Grow varieties known to store well
- Follow production practices that promote crop storability.
- Avoid excessive and late applications of nitrogen.
- Do not irrigate within 10 to 14 days of lifting onions.
- Allow tops to dry approximately 1 week before topping.
- Harvest only when the crop is mature, and during dry weather.
- Good storage onions
  - at least three wrapper scales
  - tight neck when dried
- Provide good ventilation for curing onions before storage.

http://cru.cahe.wsu.edu/CEPublications/eb1359/eb1359.html

Black Mold

*Aspergillus*

- High temperatures (85-95°F) and moisture favor disease development.
- Bulbs should be protected from moisture during harvesting and shipping.
Sour Skin
Pseudomonas (Burkholderia) cepacia

Bacterial soft rot
Erwinia carotovora & other species

Onion Handling and Storage Attributes

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Spring/summer</th>
<th>Fall/winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Onions</td>
<td></td>
<td>Storage Onions</td>
</tr>
<tr>
<td>Storing Ability</td>
<td>Typically not stored, unless under controlled atmosphere or refrigeration</td>
<td>Designed specifically to withstand long periods of storage</td>
</tr>
<tr>
<td>Storage/Shelf-life</td>
<td>30 – 60 days</td>
<td>30 – 180 days</td>
</tr>
<tr>
<td>Retail Shelf-life</td>
<td>30 days or less</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Room temperature – Dry storage</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>Keep in a dry, well ventilated place</td>
<td></td>
</tr>
<tr>
<td>Freezing Injury</td>
<td>Moderately sensitive</td>
<td>Hardier than other types</td>
</tr>
<tr>
<td>Highest freezing point</td>
<td>&gt; 20°F (~ 4°C)</td>
<td>&gt; 20°F (~ 4°C)</td>
</tr>
<tr>
<td>Odor Sensitivity</td>
<td>Odors will be absorbed by apples, celery and pears</td>
<td>Will absorb odors produced by apples and pears</td>
</tr>
<tr>
<td>Sweetness</td>
<td>Sweet/mild to slightly pungent flavors</td>
<td>Varies from mild to very pungent flavors</td>
</tr>
<tr>
<td>Aroma</td>
<td>Mild to slightly pungent</td>
<td>Mildly pungent to strong</td>
</tr>
<tr>
<td>Interior Texture</td>
<td>Soft to medium</td>
<td>Medium to firm</td>
</tr>
<tr>
<td>Exterior</td>
<td>Thin, light colored skin</td>
<td>Multiple layers of thick, dark skin</td>
</tr>
</tbody>
</table>

http://www.onions-usa.org

Garlic Composition

- **Alliin** is the main precursor to important flavor and potentially biological active sulfur-compounds in garlic.
- **Allicin** is the main thiosulfinate produced: provides flavor and pungency and is bioactive.

Alliin and allicin concentrations vary by:
Garlic variety (8-29 mg alliin/g DW in 190 accessions)
Irrigation and fertilization practices (higher with inc water)
Storage conditions and duration

Garlic Sprouting

Intermediate temperatures (8-18°C) favor sprouting

Garlic Bulb Storage

- Well cured
- Relative humidity 60-70% (reduce molds, rooting)
- -2°C to 0°C (28.5°-32°F) long-term
- CA beneficial (1-3%O2 + 10-15%CO2)
- 20°-30°C (68-86°F) 1-2 months
- 5°-18°C (41°-65°F) favor sprout growth
- Odor easily transferred to other products
Handling Carrots and related roots

- 0°C for storage
- Very high humidity
- Packaging
- Topped to reduce water loss

Carrot varieties
Carotene-uniformity of color
Sugar
Fiber-texture
Cracking susceptibility

Mechanical harvest of carrots

Longitudinal cracking is highly dependent on variety

After sizing, carrots are hydrocooled, defects removed, and then packaged

Carrot Flavor Defects

- **Harshness: Terpenes**
  - Variety
  - Growing conditions
- **Bitterness: Isocoumarin (other cpds)**
  - Postharvest defect induced by ethylene
  - Most of bitterness in peel
  - Threshold 0.15ppm C2H4 at 0-5°C

Parsnips also become bitter with ethylene exposure