I. Introduction

- Subterranean structures eaten as vegetables
  - These vegetables are ‘storage organs’ for the plant and serve as propagules for the plants to re-grow after winter or dry season rest period
  - Hence, they resist deterioration and are well adapted to long-term holding
- A very diverse group of crops

I. Introduction

- Sub-groups with similarities as to postharvest requirements and handling procedures:
  1. Temperate zone root vegetables: beet, carrot, parsnip, radish, rutabaga, turnip
  2. Potato
  3. Onion and garlic
  4. Subtropical and tropical ‘root’ vegetables: cassava, ginger, jicama, malanga, sweetpotato, taro, waterchestnut, yam
I. Introduction

• Potatoes are the most important vegetable among this group, both worldwide and in the United States, with about 390 and 2 million tons annual production, respectively (FAO, 2014)*

In U.S.:
- 29% for table stock,
- 66% for processing and
- 6% for seed and animal feed

(USDA-ERS, 2010)

- 56 million tons in China

I. Introduction

• Potato, sweetpotato, onion, garlic, and temperate-zone root crops are available year-round in the U.S. market
  - Demand patterns are relatively inflexible
  - They are not high-value crops, so international transport is not common
  - Therefore, storage is very important in most cases to even out supply, seasonal production

I. Introduction

• The total production of root crops in the tropical areas of the world exceeds 225 million tons annually. Provide staple food for about 1 billion people
  - Cassava is the most important root crop in the tropics (about 50% of total root crops production)

• Postharvest losses of tropical root crops are enormous and very important from both the economic and nutritional standpoints
I. Introduction

- Principle causes of postharvest losses:
  1. Mechanical injuries (esp. at harvest)
  2. Water loss
  3. Decay
  4. Improper curing
  5. Chilling injury (tropical/subtropical)
  6. Sprouting and rooting

This Group Includes:

- Temperate storage vegetables:
  - Bulbs
    - Onion
    - Garlic
  - Rhizomes
    - Horseradish

This Group Includes:

- Temperate storage vegetables:
  - Tap roots
    - Beet
    - Carrot
    - Celeriac
This Group Includes:
- Temperate storage vegetables:
  - Tap roots
    - Parsnip
  - Radish
  - Turnip

This Group Includes:
- Subtropical storage vegetables:
  - Corms
    - Waterchestnut
  - Tap roots
    - Jicama
  - Tubers
    - Potato

This Group Includes:
- Tropical storage vegetables:
  - Corms
    - Malanga (Xanthosoma)
    - Taro (Colocynthis)
  - Rhizomes
    - Ginger
This Group Includes:

- Tropical storage vegetables:
  - Storage roots
    - Cassava
  - Sweetpotato
  - Tubers
    - Yam

II. Morphological Characteristics

- In relation to water loss
  - Low surface area to weight ratio (3:1 to 6:1)
  - Susceptibility to water loss influenced by extent of periderm formation and number and distribution of lenticels
  - Carrots and beets have much thinner periderm than do potatoes and sweetpotatoes
  - Growth (sprouting) and presence of tops greatly accelerates water loss

III. Compositional Characteristics

- Water content lower than other vegetables
  - Ranges between 61% (sweetpotato, garlic) and 94% (radish)
- High in carbohydrates:
  - Potato (21%), sweetpotato (33%), taro (23%), parsnip (18%), carrots and beets (10%)
- Starch to sugar conversion occurs at low temps (0–5°C) and can be desirable (parsnips) or undesirable (potatoes)
III. Compositional Characteristics

- Carrots are highest among all vegetables in vitamin A content (about 11,000 IU/100 g FW)
- Sweetpotatoes are also very high in vitamin A (8,000 IU)
- Potato (18 mg/100 g), radish (25), turnip (30), rutabaga (35), and sweetpotato (20) are fairly high in vitamin C content
- In comparison, oranges contain 60 mg vitamin C per 100 g
- Many of these storage vegetables are a good source of minerals, especially K, Fe, Ca and P

IV. Maturity & Quality Indices

- Maturity (harvest) indices
  - Temperate root crops are harvested when the size of the storage organ is acceptable for marketing (i.e., immature)
  - Tropical/subtropical 'root' crops are typically harvested when the aboveground parts (leaves) begin to dry, which signals physiological maturity of the underground storage organ
    - Physiological maturity = full size, fully developed skin, and maximum starch or dry matter content
    - The aboveground parts of the plant may be removed or killed to hasten belowground maturation

- Examples of maturity (harvest) indices for selected storage vegetables:
  - Carrot: root size
  - Radish: days from planting
  - Potato: drying of foliage
  - Taro: leaves start drying
  - Garlic and onion: tops dry, neck tissues begin to soften
  - Sweetpotato: senescence of vines
IV. Maturity & Quality Indices

- Quality criteria for storage vegetables:
  - **Fresh** - firm, crisp, and dense, never flaccid or shriveled;
    surface smooth, clean, and free from growth cracks, insect
damage and unhealed physical injuries like bruises,
abrasions or cuts; shape and size reasonably uniform; decay
is never acceptable
  - **Cooked** - the quality of the cooked product is greatly
dependent on the composition, primarily starch and
sugars, which in turn is influenced by harvest maturity

V. Causes of Deterioration

1. Mechanical injury
   - Why because it promotes:
2. Water loss and
3. Decay
4. Chilling injury (tropical root vegetables)
5. Sprouting (related to temperature)
6. Dry matter loss (due to respiration) can be significant
during extended storage

- Sprouting and rooting
  - Naturally prone to sprouting and rooting, and will tend to
do so when stored at higher than optimal storage
temperatures with high relative humidity
  - Initiation of onion & garlic sprouting is most strongly
favored by intermediate temperature (~10°C)
  - Sprouting greatly accelerates water loss and causes
compositional changes that can impair the cooking quality
V. Causes of Deterioration

- Use of sprout inhibitors
  - Preharvest application (2 to 4 weeks before harvest) of maleic hydrazide (MH-30) on potato, onion, and garlic
  - Postharvest application of CIPC (isopropyl N-(3-chlorophenyl) carbamate) on potato, as a vapor or dust or solution
  - Irradiation (0.15 to 1.0 kGy) has been approved for commercial use on potato and onion in many countries including the U.S. No commercial use has been reported except in Japan and the former Soviet Union

VI. Postharvest Physiology

- Root vegetables produce very small quantities of ethylene (less than 0.1 ul/kg-h) and are not particularly sensitive
- Based on respiration rates, these vegetables can be divided into two groups:
  - Very low rates (less than 8 mg/kg-h at 0°C): e.g., beet, celeriac, onion, parsnip, potato, and turnip
  - Low rates (8-12 mg/kg-h at 0°C): e.g., carrot, horseradish, and radish

VI. Postharvest Physiology

- Root crops with tops have higher respiration rates than roots alone
  - carrots with tops: 35 mg CO₂/kg-h at 0°C
  - carrot roots alone: 12 mg CO₂/kg-h at 0°C
- Potatoes harvested immature ("new potatoes") respire twice as fast as those harvested mature and are more perishable
- Cured potatoes and sweetpotatoes have lower respiration rates than if not cured
VI. Postharvest Physiology

• Curing (= wound healing):
  – Most of these crops have the ability to heal surface wounds
  – It is only necessary to hold the crop for a few days to a week under the temperature and humidity conditions that favor wound healing
  – Curing reduces both decay and water loss by promoting the production of one to several layers of cells, called the periderm, which have waxy material (suberin) in the walls that resists water movement and decay organisms
  – However, "curing" of onions and garlic is actually just drying the outermost scales

• Responses to controlled atmospheres
  – Controlled atmospheres have not been very useful in extending storage life of beets, carrots, celeriac, horseradish, and turnip, although reduced O₂ (2-3%) atmospheres reduce their respiration rates by about 30% at 0°C
  – A 1 to 2% O₂ atmosphere is beneficial for radish because it reduces root and top growth during prolonged holding (3-4 weeks at 0°C)
  – Other storage vegetables have sufficiently long storage life potential that CA is typically unnecessary

• Responses to controlled atmospheres
  – CA is not recommended for use on potatoes
    – Although low O₂ prevents potato greening, it retards periderm formation, and enhances sprouting
    – Onions are sensitive to elevated CO₂ but they tolerate very low O₂
    – However, storage in 1% O₂ is used commercially for extended sweet (e.g., ‘Vidalia’) onion storage because it is a unique crop with limited supplies
    – Reduces lignification in fresh cut carrot, which is induced by ethylene. CA decreases the formation of lignin.
VI. Postharvest Physiology

- Responses to modified atmospheres
  - Film wraps used for root vegetables to reduce water loss must be ventilated to avoid CO₂ accumulation and O₂ depletion, as well as to avoid sprout formation
  - Cassava roots are coated with paraffin wax to reduce water loss and lower internal O₂ levels in order to avoid vascular streaking (a stress ethylene-related disorder)

- Physiological disorders: Chilling injury
  - Cassava: internal breakdown, increased water loss, failure to sprout, increased decay, and loss of eating quality
  - Ginger: accelerated softening and shriveling, oozes moisture from the surface; decay
  - Jicama: internal discoloration, loss of crisp texture (rubbery), decay

- Potato: 'Mahogany browning' (0-3°C): reddish-brown areas in the flesh; adverse effects on cooking quality

- Sweetpotato: internal brown-black discoloration, adverse effects on cooked quality ('hard core'), and accelerated decay

- Yam: tissue softening internal discoloration (grayish flecked with reddish brown), shriveling, and decay
Chilling injury of subtropical & tropical 'root' crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Threshold Temp. (°C)</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>5</td>
<td>Internal breakdown, increased water loss, decay, loss of eating quality</td>
</tr>
<tr>
<td>Ginger</td>
<td>13</td>
<td>Accelerated softening and shriveling, exuding moisture, decay</td>
</tr>
<tr>
<td>Jicama</td>
<td>13</td>
<td>Internal discoloration and water soaking, decay</td>
</tr>
<tr>
<td>Malanga</td>
<td>7</td>
<td>Surface pitting, internal discoloration, decay</td>
</tr>
<tr>
<td>Sweetpotato</td>
<td>15</td>
<td>Dark internal discoloration, increased decay, hard core when cooked</td>
</tr>
<tr>
<td>Taro</td>
<td>7</td>
<td>Internal discoloration and water-soaking, decay</td>
</tr>
<tr>
<td>Waterchestnut</td>
<td>5 (immature)</td>
<td>Internal discoloration and water-soaking, decay</td>
</tr>
<tr>
<td></td>
<td>0 (mature)</td>
<td></td>
</tr>
<tr>
<td>Yam</td>
<td>16</td>
<td>Internal discoloration, softening, shriveling, decay</td>
</tr>
</tbody>
</table>

VI. Postharvest Physiology

- Other physiological disorders
  - Freezing injury
  - Sunburn or sunscald of onion, garlic, potato
  - Solar greening of onion, potato

http://www.solanum.net/ntu.htm

- Other physiological disorders
  - Translucent scales of onions and waxy breakdown of garlic (high temperature or senescence related)
  - Blackheart of potatoes (low O₂, especially at high temp.)

http://postharvest.ucdavis.edu
VI. Postharvest Physiology

• Other physiological disorders
  – Pithiness of radishes (senescence related)
  – Internal black spot of beets (may be related to B deficiency)
  – Internal black spot of potatoes (K deficiency, other factors)
  – Vascular streaking of cassava (related to mechanical injury and water loss, which promote wound/stress ethylene production)

VII. Pathological Breakdown

• The postharvest pathogens of root crops are generally soil-borne organisms and thus may be well established on the items at the time of harvest

• Damage that breaks the skin of the storage organ is the primary route of infection, but even apparently undamaged organs can become infected under conditions conducive to pathogen growth

VII. Pathological Breakdown

• Free water on the surface of tropical/subtropical root crops should be avoided
  – Cleaning is best accomplished by dry brushing if possible in order to avoid wetting the crop
  – Water used for cleaning should be treated with chlorine to keep the pathogen load low, and be followed by a chlorinated water rinse step, then thorough drying
VII. Pathological Breakdown

- Postharvest chemicals other than chlorine for decay control are generally not allowed
- Storage at above the optimum temperature for the crop will promote pathogen growth

- Bacterial soft rot: onion, carrot, parsnip, potato
- Fusarium rot: garlic, onion, potato, cassava
- Gray mold rot: garlic, onion, carrot, parsnip
- Rhizopus soft rot: carrot, sweetpotato, cassava
- Black mold rot (Aspergillus niger): onion, cassava

- Smudge (Colletotrichum circinans): onion
- Blue mold rot: garlic, cassava
- Black rot (Stemphylium radicinum): carrots
- Watery soft rot (Sclerotinia sclerotiorum): carrots
- Charcoal rot (Macrophomina phaseoli): sweetpotato
- Black rot (Ceratocystis fimbriata): sweetpotato
VIII. Postharvest Handling Procedures

• Harvesting
  – Most of these crops are machine harvested
  – Sweetpotato vine cutting and lifting of the roots is
    commonly done by machine, while the roots are usually
    removed from the soil by hand to reduce injuries
  ➢ Physical damage during harvest is undoubtedly the major
    cause of postharvest losses among these crops

VIII. Postharvest Handling Procedures

• Curing – must be started immediately after harvest
  – The most effective and simple means of reducing water loss
    and decay during subsequent storage of onions, garlic, potato,
    sweetpotato and other tropical root vegetables
  – Injuries or bruised surfaces are allowed to heal and
    periderm is thickened on potato, sweetpotato, etc.
  – Some water loss takes place during curing

VIII. Postharvest Handling Procedures

• Curing of onion and garlic
  – Curing of onions and garlic is a process of drying the outermost
    scales, not wound healing
  – May be done in the field in dry
    regions, where they are undercut
    or hand-pulled and allowed to dry
    for 5-10 days (depending on
    ambient temperatures, before
    topping)
### Curing Conditions

<table>
<thead>
<tr>
<th>Crop</th>
<th>Temp (°C)</th>
<th>RH (%)</th>
<th>Duration (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>30-40</td>
<td>90-95</td>
<td>2-5</td>
</tr>
<tr>
<td>Malanga</td>
<td>30-35</td>
<td>85-90</td>
<td>4-7</td>
</tr>
<tr>
<td>Onion &amp; Garlic</td>
<td>35-45</td>
<td>60-75</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Potato</td>
<td>30-40</td>
<td>85-90</td>
<td>4-7</td>
</tr>
<tr>
<td>Sweetpotato</td>
<td>30-32</td>
<td>85-90</td>
<td>4-7</td>
</tr>
<tr>
<td>Taro</td>
<td>30-35</td>
<td>85-90</td>
<td>4-7</td>
</tr>
<tr>
<td>Yam</td>
<td>32-40</td>
<td>90-100</td>
<td>1-4</td>
</tr>
</tbody>
</table>

*Forced, heated-air drying

### VIII. Postharvest Handling Procedures

- Preparation for market and marketing
  - **Cleaning:** dry; washing, removal of excess moisture
  - **Sorting:** to eliminate defects
  - **Sizing:** usually mechanical sizing
  - **Packing:** in shipping containers
  - **Palletization and unitization**

- **Storage:** refrigerated; ventilated
- **Loading into transport vehicles:** Bulk transport of some commodities to processing plants
- **Destination handling** (distribution centers, wholesale markets, etc.): Consumer packaging at destination
- **Delivery to retail**
- **Retail handling:** refrigerated for temperate; not for others
VIII. Postharvest Handling Procedures

• Cooling
  – All temperate-zone root crops plus waterchestnuts can be hydrocooled
  – Potato, onion and garlic, and the subtropical and tropical root crops are usually cooled by room cooling

• Special treatments
  – Treatments for sprout inhibition
  – Insect control: fumigation, use of insecticides
  – Rodent control
  – Storage methods other than refrigerated storage
    • In-soil storage
    • Storage in pits, trenches, or clamps
    • Ventilated storage: cellars, aboveground warehouse

IX. Recommended Conditions

• Temperate-zone root vegetables
  – Temperature of 0°C, RH of 95–100%; adequate air circulation to remove vital heat

• Potato
  – For fresh market and propagation: 4°C, 90–95% RH; enough air circulation to prevent CO₂ accumulation; exclusion of light
  – For processing (chipping, etc.): 8 to 12°C, 90–95% RH; adequate ventilation, exclusion of light
IX. Recommended Conditions

- Garlic and onion
  - Temperature of 0°C (or 28-30°C for a few weeks)
  - Intermediate temperatures favor sprouting
  - 65-70% RH; ventilation of 0.5-1 m³/min for each m³ of onions
  - Avoid exposure to light
  - Storage potential is cultivar dependent

### Temperate zone root vegetables

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Temp (°C)</th>
<th>RH (%)</th>
<th>Storage life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bunched</td>
<td>0</td>
<td>98-100</td>
<td>10-14 days</td>
</tr>
<tr>
<td>topped</td>
<td>0</td>
<td>98-100</td>
<td>4-6 months</td>
</tr>
<tr>
<td>Carrots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bunched</td>
<td>0</td>
<td>95-100</td>
<td>2 weeks</td>
</tr>
<tr>
<td>mature, topped</td>
<td>0</td>
<td>98-100</td>
<td>7-9 months</td>
</tr>
<tr>
<td>immature, topped</td>
<td>0</td>
<td>98-100</td>
<td>4-6 weeks</td>
</tr>
<tr>
<td>Celeriac</td>
<td>0</td>
<td>97-99</td>
<td>6-8 months</td>
</tr>
<tr>
<td>Horseradish</td>
<td>-1.0-0</td>
<td>98-100</td>
<td>10-12 mo</td>
</tr>
<tr>
<td>Parsnip</td>
<td>0</td>
<td>98-100</td>
<td>4-6 mo</td>
</tr>
<tr>
<td>Radish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>spring</td>
<td>0</td>
<td>95-100</td>
<td>3-4 weeks</td>
</tr>
<tr>
<td>winter</td>
<td>0</td>
<td>95-100</td>
<td>2-4 mo</td>
</tr>
<tr>
<td>Rutabaga</td>
<td>0</td>
<td>98-100</td>
<td>4-6 mo</td>
</tr>
<tr>
<td>Turnip</td>
<td>0</td>
<td>95</td>
<td>4-5 mo</td>
</tr>
</tbody>
</table>
### IX. Recommended Conditions

#### Potato, onion and garlic

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Temp (°C)</th>
<th>RH (%)</th>
<th>Storage life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>early</td>
<td>4</td>
<td>95-98</td>
<td>4-5 months</td>
</tr>
<tr>
<td>late</td>
<td>4</td>
<td>95-98</td>
<td>5-10 months</td>
</tr>
<tr>
<td>processing</td>
<td>8-12</td>
<td>95-98</td>
<td>up to 10 months</td>
</tr>
<tr>
<td>Onion</td>
<td>0</td>
<td>65-70</td>
<td>1-8 months</td>
</tr>
<tr>
<td>Garlic</td>
<td>0</td>
<td>65-70</td>
<td>6-7 months</td>
</tr>
</tbody>
</table>

#### Tropical-zone root vegetables (cured properly)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Temp (°C)</th>
<th>RH (%)</th>
<th>Storage life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>5-8</td>
<td>80-90</td>
<td>2-4 weeks</td>
</tr>
<tr>
<td>Ginger</td>
<td>12-14</td>
<td>65-75</td>
<td>up to 6 mo</td>
</tr>
<tr>
<td>Sweetpotato</td>
<td>12-14</td>
<td>85-90</td>
<td>up to 6 mo</td>
</tr>
<tr>
<td>Taro</td>
<td>13-15</td>
<td>85-90</td>
<td>up to 4 mo</td>
</tr>
<tr>
<td>Yam</td>
<td>13-15</td>
<td>near 100</td>
<td>up to 6 mo</td>
</tr>
<tr>
<td>or, 28-30</td>
<td>65-70</td>
<td></td>
<td>3-5 weeks</td>
</tr>
</tbody>
</table>