Postharvest Biology & Handling of Vegetables

II. Storage Organs

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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**

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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

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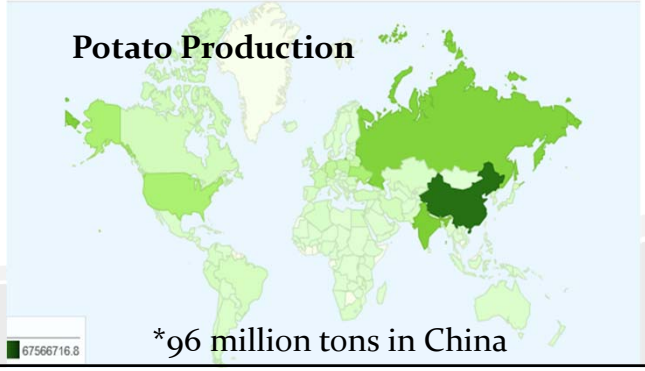
I. Introduction

- 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)



*96 million tons in China

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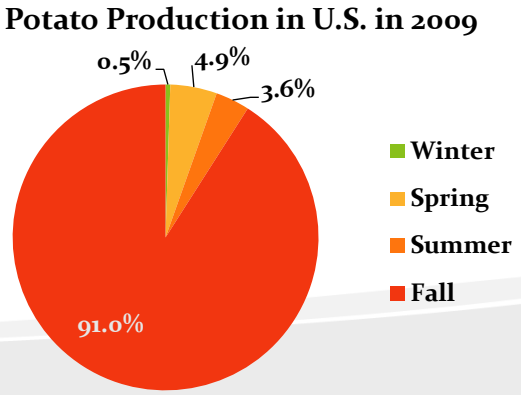
I. Introduction

- 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



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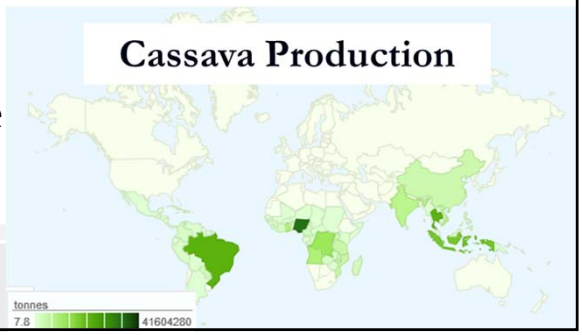
I. Introduction

- 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



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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

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This Group Includes:

- Temperate storage vegetables:
  - **Bulbs**
    - Onion
    - Garlic

http://aggie-horticulture.tamu.edu

http://www.davidwhittemore.com

  - **Rhizomes**
    - Horseradish

http://www.siuc.edu/

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This Group Includes:

- Temperate storage vegetables:
  - **Tap roots**
    - Beet
    - Carrot
    - Celeriac

http://food.oregonstate.edu/

http://www.uga.edu

http://www.uga.edu

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This Group Includes:

- Temperate storage vegetables:
  - **Tap roots**
    - Parsnip
    - Radish
    - Turnip

http://www.mariquita.com

http://aggie-horticulture.tamu.edu

http://food.oregonstate.edu/

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This Group Includes:

- Subtropical storage vegetables:
  - **Corms**
    - Waterchesnut
  - **Tap roots**
    - Jicama
  - **Tubers**
    - Potato

http://khmerkromrecipes.com

http://www.uga.edu

http://aggie-horticulture.tamu.edu

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This Group Includes:

- Tropical storage vegetables:
  - **Corms**
    - Malanga (*Xanthosoma*)
    - Taro (*Colocasia*)
  - **Rhizomes**
    - Ginger

http://botany.cs.tamu.edu

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This Group Includes:

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

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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

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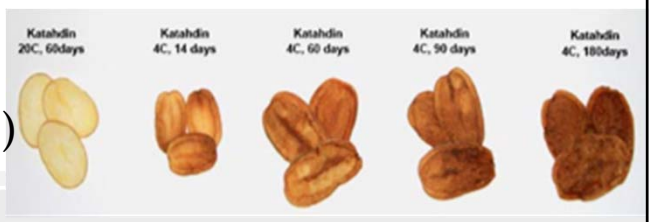
III. Compositional Characteristics

- 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)



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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 45 mg vitamin C per 100 g
- Many of these storage vegetables are a good source of minerals, especially K, Fe, Ca and P

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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 below-ground maturation

http://oregonstate.edu/dept/kes

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IV. Maturity & Quality Indices

- 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

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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

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V. Causes of Deterioration

1. Mechanical injury
   - #1 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

Adel Kader, UC Davis
http://postharvest.ucdavis.edu

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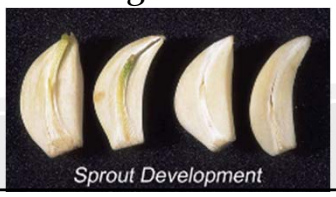
V. Causes of Deterioration

- 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



http://postharvest.ucdavis.edu

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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

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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

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VI. Postharvest Physiology

- Root crops with tops have higher respiration rates than roots alone
  - carrots with tops: 35 mg CO_2/kg-h at 0°C
  - carrot roots alone: 12 mg CO_2/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

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VI. Postharvest Physiology

http://postharvest.ucdavis.edu

- 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*

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VI. Postharvest Physiology

- Responses to controlled atmospheres
  - Controlled atmospheres have not been very useful in extending storage life of beets, carrots, celeriac, horseradish, and turnip, although reduced O_2 (2-3%) atmospheres reduce their respiration rates by about 30% at 0°C
  - A 1 to 2% O_2 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

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VI. Postharvest Physiology

- Responses to controlled atmospheres
  - CA is not recommended for use on potatoes
    - Although low O_2 prevents potato greening, it retards periderm formation, and enhances sprouting
  - Onions are sensitive to elevated CO_2, but they tolerate very low O_2
    - However, storage in 1% O_2 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.

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VI. Postharvest Physiology

- Responses to modified atmospheres
  - Film wraps used for root vegetables to reduce water loss must be ventilated to avoid CO_2 accumulation and O_2 depletion, as well as to avoid sprout formation
  - Cassava roots are coated with paraffin wax to reduce water loss and lower internal O_2 levels in order to avoid *vascular streaking* (a stress ethylene-related disorder)

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VI. Postharvest Physiology

- **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

http://postharvest.ucdavis.edu

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VI. Postharvest Physiology

- Physiological disorders: Chilling injury
  - **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

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Chilling injury of subtropical & tropical 'root' crops

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

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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

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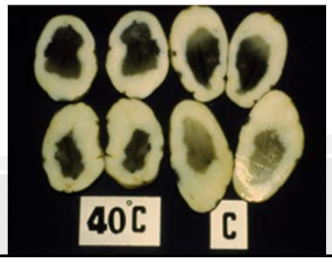
VI. Postharvest Physiology

- Other physiological disorders
  - **Translucent scales** of onions and **waxy breakdown** of garlic (high temperature or senescence related)

http://postharvest.ucdavis.edu

  - **Blackheart** of potatoes (low O_2, especially at high temp.)



http://postharvest.ucdavis.edu

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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)


www.bath.ac.uk

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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

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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

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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

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VII. Pathological Breakdown

- **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

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VII. Pathological Breakdown

- **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

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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*

Radish harvester

Potato harvester

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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

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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)

http://www.wildchicken.com/

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Curing Conditions

Crop	Temp (°C)	RH (%)	Duration (d)
Cassava	30-40	90-95	2-5
Malanga	30-35	85-90	4-7
Onion & Garlic	35-45	60-75	0.5-1*
Potato	15-20	85-90	5-10
Sweetpotato	30-32	85-90	4-7
Taro	30-35	85-90	4-7
Yam	32-40	90-100	1-4

*Forced, heated-air drying

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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**

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VIII. Postharvest Handling Procedures

- Preparation for market and marketing
  - **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

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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

Carrot hydrocooling

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VIII. Postharvest Handling Procedures

- **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

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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, 95-98% RH; enough air circulation to prevent CO_2 accumulation; exclusion of light
  - For processing (chipping, etc.): 8 to 12°C, 95-98% RH; adequate ventilation; exclusion of light

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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 m^3 min^{-1} air for each m^3 of onions
  - Avoid exposure to light
  - Storage potential is cultivar dependent

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IX. Recommended Conditions

Temperate zone root vegetables

Commodity	Temp (°C)	RH (%)	Storage life
Beets			
bunched	0	98-100	10-14 days
topped	0	98-100	4-6 months
Carrots			
bunched	0	95-100	2 weeks
mature, topped	0	98-100	7-9 months
immature, topped	0	98-100	4-6 weeks
Celeriac	0	97-99	6-8 months

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IX. Recommended Conditions

Temperate zone root vegetables (cont.)

Commodity	Temp (°C)	RH (%)	Storage life
Horseradish	-1.0-0	98-100	10-12 mo
Parsnip	0	98-100	4-6 mo
Radish			
spring	0	95-100	3-4 weeks
winter	0	95-100	2-4 mo
Rutabaga	0	98-100	4-6 mo
Turnip	0	95	4-5 mo

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IX. Recommended Conditions

Potato, onion and garlic

Commodity	Temp (°C)	RH (%)	Storage life
Potato			
early	4	95-98	4-5 months
late	4	95-98	5-10 months
processing	8-12	95-98	up to 10 months
Onion	0	65-70	1-8 months
Garlic	0	65-70	6-7 months

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IX. Recommended Conditions

Tropical-zone root vegetables (cured properly)

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

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