**Root, Tuber & Bulb Crops**

- Carrot & Relatives
  - Umbelliferae Family (Parsley Family)
- Beet
  - Chenopodiaceae Family (Goosefoot Family)
- Radish, Turnip, Rutabaga & Horseradish
  - Cruciferae Family
- Sweet Potato
  - Convolvulaceae Family (Morningglory Family)
- Potato (Irish potato)
  - Solanaceae Family (Nightshade Family)
- Jerusalem Artichoke
  - Compositae Family (Sunflower Family)
- Onion, Leek & Garlic
  - Alliaceae Family

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**Carrot**

- *Daucus carota var. sativus*
- Biennial, Cross pollinated (sometimes severe inbreeding depression)
- Cool season crop (<85°F)
- Center of Origin: Afghanistan
- Originated from ‘Queen Anne’s Lace’
- Believed that when carrot brought to North America, at least one plant reverted to wild type and escaped to become weed

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**Early cultivated carrots were “red”, yellow, white and purple, with red probably the most common**

Wild carrot  Early cultivated carrot

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**Orange carrots were selected by breeders**

- Yellow selections replaced “red” carrots sometime after the 12th century (yellows still widely cultivated in Western Asia)
- Orange carrots were bred in the mid-1700s in The Netherlands, and quickly became the choice carrot in Europe

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**Carrot Types: Imperator**

- Imperator: Long (8-10”) with narrow shoulders that taper smoothly toward the tip
- Uses: Most common fresh and “cut-and-peel” processed; late maturing with good storage usually grown in winter

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**Carrot Types - Danvers**

- Danvers: Medium length (usually ~6”) with broad shoulders that taper toward the tip
- Type first developed in Danvers, Massachusetts in 1870s
- Uses: Fresh and processed; good quality for both, but tend to become woody with age Grows in heavier and shallow soils better than the longer Imperator types
Carrot Types - Nantes

Nantes: Medium length (~6”) with cylindrical shape (almost no taper) and rounded ends
Originated in Nantes, France
Uses: Fresh; early maturing and can be grown in late spring for summer crop

Carrot Types - Chantenay

Chantenay: Medium to short length (~5”) with broad shoulders that taper toward the tip
Originated in Chantenay, France
Uses: Primarily processing; grown in summer, lighter in color and coarser in texture than other types. Shorter length will tolerate heavier soils than other types

Carrots can be an excellent source of Anthocyanins - β-carotene - Lycopene

Carrot Industry

- Fresh Market: ~76% of total production
- Processing: ~24% of total production
- Many States produce substantial acreage of carrots

Plant Growth & Development

- Carrot is a biennial grown as an annual
- Root is an enlarged taproot that accumulates starch and sugar
  - Mature roots have two distinct regions:
    - Inner core of mostly xylem and pith
    - Outer core of secondary phloem and periderm
      - Sugars, β-carotene higher in phloem than xylem
      - Fibers more prevalent in xylem than phloem

Temperature Requirements

- Optimum temperature for growth and development: 60°-70°F
  - Temperatures <55°F tend to make roots longer and more slender and paler (less carotene)
  - High temperatures can cause stronger flavor and coarse texture
- Post-juvenile plants (>¼”) can be vernalized by temperatures <45°F
  - Will bolt if followed by warmer temperatures
Soil Requirements

• Grow best in deep, loose, well-drained sandy loam soil
• Heavy clay soils tend to produce more leaves and forked roots
  – Can be managed with accurately regulated irrigation
• Stones, heavy clods, other obstructions can cause misshapen roots

Crop Establishment

• Can only be direct seeded
  – Transplants will always result in forked roots
• Optimum germination temperatures: 50°-85°F
• Seedling growth is weak, so soil crusting must be managed
• Plant spacing affects root shape & development
  – Increased spacing = larger roots (processing)
• Will benefit from raised beds (deeper, warmer, drier soil)

Cultural Practices

• Weed control is critical because young, slow growing plants cannot compete with weeds
• Require an evenly distributed water supply
  – Generally require a weekly irrigation
  – Fluctuations in water can cause cracking

Pests & Diseases

• Major problems:
  – Pests or diseases that affect roots
• Root-knot Nematodes:
  – Cause swellings (galls) inhibiting them from their normal function, resulting in forks & deformities
• Wireworms, grubworms, others:
  – Feed on roots
• Aster Yellows:
  – Multiple tops & multiple hair-like roots emerging from shrunken taproot
  – Virus transmitted by leafhoppers

Harvesting

• Can harvest at any edible size
• Processing crop: ~1-½” diameter at shoulder
• Fresh market: ~¾”-1-½” diameter at shoulder
  – Usually younger stage than processing crop
• Generally, smaller carrots are more tender & juicier
• Usually mechanically harvested, except for bunching carrots (tops left attached for marketing); harvesters remove tops during harvest

Postharvest

• Optimum storage conditions: 32°F 98-100% RH
• Shelf-life:
  – Mature, topped: 7-9 months
  – Immature, bunched (with tops): 2-3 weeks
  – Immature, topped: 4-6 weeks
Nutritional Value

- Highest content of carotenes (α & β)
  - β-carotene is cleaved in the human body to create two Vitamin A molecules
  - α-carotene yields one molecule

Diversity of carrot compounds

- One 7" long carrot contains ~270% of the RDA for Vitamin A
- But this is only valid for carrots with orange color

Parsnips

- Carrot relative with same features (Umbelliferae, biennial, out-crosser)
- Pastinaca sativa
- Generally minor crop, but considered the “medieval potato”
- Culture requirements essentially the same as carrot, except not as heat tolerant; best grown at 60-65°F
- Cool temperatures (near freezing) at maturity convert starches to sugars, resulting in increased quality
- Parsnip seed is short-lived, usually not more than one year

Salsify

- Compositae family (Sunflower)
- Cool season biennial
- Tragopogon porrifolius
  - Oyster plant (flavor)
    - Black rooted types technically referred to as Scorzonera, but not a common name
- Culture similar to parsnip/carrot
- Cold temperatures tend to sweeten the root

Salsify Flowering – Typical Composite

Beet

- Chenopodiaceae Family
  - Spinach family
- Beta vulgaris var. Crassa
  - Same species as Swiss Chard & Sugar Beets
- Cool season biennial, cross pollinated (wind)
- Center of Origin: Europe, North Africa, West Africa (Mediterranean Region)
- Relatively new crop (var. Cicla is very old)
**Beet Industry**

- Relative small production (~118,000 tons)
- Processing: ~60%  
  - Mostly Wisconsin & New York
- Fresh Market: ~40%  
  - Texas leads the US
- Small market for pigment extraction

**Climatic Requirements**

- Note: All enlarged roots are storage organs
  - Maximum yield and quality will occur when growth conditions allow for excess energy manufacturing in the plant beyond what is required for normal growth & development
- Optimum temperatures: 60-65°F, but will tolerate warmer temperatures
- Temperatures >50°F for 2-3 weeks will vernalize
- Heavy soils or crusting will reduce germination/emergence

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**Plant Growth & Development**

- Storage root develops as alternating rings of conductive tissue and storage tissue (zoning)
- Compound: betalains  
  - Different from anthocyanins
    - Contain Nitrogen
    - betaine (red)
    - Suppressed at high temperatures (leads to increased zoning)
- Poor growing conditions leads to small fibrous roots

**Crop Establishment**

- "Seed" is actually a dried fruit containing 2-6 seeds (Seedball)
- Usually direct seeded, but may be transplanted for an early crop
- Plant spacing ~1", but wider (2-3") when also used for greens
- May require hand thinning because of seedball

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**Pests & Diseases**

- Diseases usually not a major problem for beet production (other than damping-off)
- Insects include leaf miners, cutworms, aphids & leafhoppers
- Physiological Disorders  
  - Black spot: Caused by Boron deficiency.  
    - Beets have generally high micronutrient requirements
  - Poor root formation: Overcrowding
  - Woody roots & poor coloring: inappropriate environment

**Harvesting & Postharvest**

- Harvest when they reach desired size:  
  - Fresh market: usually 1-½ to 2-½" diameter
  - Processing: usually when 40% are over 2"  
  - Root size is controlled primarily by spacing and cultivar, not by maturity date
- Harvest & handling similar to carrot:  
  - Machine harvest & topped
  - Bunched beets harvested by hand
- Shelf-life: 4 – 6 months @ 32°F and 98-100% RH (topped)
  - Bunched beets: 10-14 days at same conditions
Crucifer Rooted Crops

- Radish, Turnip, Rutabaga & Horseradish
- Culture very similar to other Crucifer crops, but some key differences

**Radish (Raphanus sativus)**
- Easy to grow (Greek raphanos means “easy to grow”)
- Cool season, fast-maturing
- Biennial, cross-pollinated
- Center of Origin: China

Radish

- Minor commercial importance, but extensive in home gardens
- Types:
  - Spring: Typical round, red radish
  - French Breakfast: Elongated spring type
    - 25-30 days to maturity
  - Daikon: Elongated white
    - 40-50 days to maturity
  - Winter: Multiple shapes and colors, usually larger, more elongated & later maturing
    - 50-60 days to maturity

Planting & Culture

- Will grow well under crowded conditions
  - 8-10” rows, sometimes 3-4 seed per inch for early maturing types
  - Later maturing types generally 2-3” apart
- Require high fertility due to rapid growth
  - Reduced or checked growth results in tough, woody, pithy & pungent roots

Diseases & Pests

- Most of insects & diseases of other Crucifer crops also affect radish
  - More susceptible to nematode damage because the root is the product
- Physiological Problems:
  - Cracks & splits: overmature
  - Small roots, off-flavor: temperature too high (~80°F maximum for maturity)

Harvest & Postharvest

- Commercial crops machine harvested just like beets & carrots (lifted and topped)
  - Once over harvest
- Bunching radishes are hand harvested
- Shelf-life:
  - Summer types: 2-3 weeks @ 33°F & 95-100% RH
  - Winter types: 3-4 months at same conditions (with tops removed)

Turnips & Rutabagas

- Two closely related species in terms of cultural and culinary characteristics
- Turnip: Brassica rapa Raphifera group
- Rutabaga: Brassica napus Napobrassica group (also called “Swede turnips”)
- Center of Origin: Europe/North Asia
- Biennials, cross-pollinated, cool season
  - Optimum root development at 40-60°F
- Rutabagas slightly larger than turnips
- Turnips mature in about 2 months, while rutabagas may take 3 months
Planting & Culture

• Similar to carrots & beets, except not as exacting in requirements
• Turnips usually grown as fall and spring crop in the South, while rutabagas typically grown as a fall crop in the North
• Typically direct seeded, 3-4” apart for turnips & 4-8” for rutabagas

Diseases & Pests

• Most of insects & diseases of other Crucifer crops also affect turnips & rutabagas
• More disease & insect problems than radish because of longer time in the field
• Physiological Problems:
  – Bitter, off-flavors: Conditions that result in slow growth or stress

Harvesting & Postharvest

• Best quality when “medium” sized
  – Turnips: 2-3” diameter
  – Rutabagas: 3-4” diameter
• Often said that best quality comes from crop harvested after a light frost
• Turnips often machine harvested like carrot & beet
• Rutabagas not usually machine harvested
• Shelf-life: 4-6 months at 32o-35oF & 90-95% RH (topped)
  – May be coated with wax to prevent dehydration

Horseradish

• Crucifer family
• Armoracia rusticana
• Perennial, grown as an annual, cross pollinated, warm season (not too cold or hot)
• Center of Origin: Southern Europe
• Used as processed condiment for meats & fish
• Unique pungent aroma and taste comes from the sulfur compound allyl isothiocyanate (possibly anti-carcinogenic)
  – If exposed to air, pungency is rapidly lost after being ground or processed

Planting & Culture

• Grows best when warm in the early season, and cool in late season
• Early growth is concentrated on foliage under warm temperatures, moving to root growth in late summer and fall under cool temperatures
• Vegetatively propagated from secondary roots of previous crop (trimmed from previous harvest)
• One-year-old secondary roots (6”-18” long) are planted 4”-5” deep 18”-24” apart
• The “sets” are slant cut on bottom end and straight cut on top end, and planted at a 45° angle, with the top end elevated
• Commercial production is highly developed

Culture

• To obtain straight roots, growers sometimes use a procedure known as “lifting”:
  – The crown is pulled slightly out of the soil and the upper side roots and outer leaves are removed, and then pushed back down and covered with soil
  – Procedure usually done twice during the season
  – Procedure is expensive though, and only done where a premium is paid for straight root
• Weed control is difficult since crop is grown on so few acres and hardly any herbicides are labeled for use
Diseases & Pests

• Although a crucifer crop, diseases and pests are few, possibly because crop is high in certain phytochemicals and is grown on so few acres

Harvest & Postharvest

• Harvest after tops killed by frost
• Commercial crop is mechanically lifted from the soil and hand loaded
• May also be allowed to overwinter in the field and harvested in early spring
• Shelf-life: Several months at 30-32°F and 98-100% RH, but usually not an issue since usually processed within a few weeks of harvest
• Roots harvested when actively growing will not store as well as those conditioned by cold temperatures

Sweet Potato

• Only important food crop in the Convolvulaceae family (Morning-glory)
• Ipomoea batatas
• Center of Origin: Tropical America
• Warm season, perennial grown as an annual
• Very important source of carbohydrates for much of tropical and sub-tropical world
• Edible root contains about 27% carbohydrate and high concentrations of carotenoids and other nutrients
• Fresh sweet potatoes provide ~50% more calories than Irish potatoes

Types

• Soft-fleshed
  – Deep yellow-orange color, sweeter and moister than firm-fleshed types
  – Sometimes called “Yams” although the true yam is a different genus (Dioscorea) grown only in tropical climates
• Firm-fleshed
  – Yellow skins with white, yellow or light orange flesh

Industry

• Produced in 30 States, but commercially important in 10 mostly Southern States where crop is a main food source
  – North Carolina, Louisiana, California, Mississippi, Alabama, Texas, Georgia & South Carolina
• World-wide production is significant in most tropical regions
  – Africa leads in acreage, but China is the largest producer, with over 80% of world-wide production

Climatic & Cultural Requirements

• Warm season, not frost tolerant
  – Optimum growth: 70°F soil temperature and 85°F air temperature
  – Minimum soil temperature: 59°F
  – Damage results under prolonged air temperatures <50°F
• Soil types are critical for high yields of quality roots:
  – Very light soils produce low yields of high quality roots
  – Heavy soils produce high yields of low quality roots
  – Best balance of yields & quality come on well-drained, sandy loam or silt loam soil
Planting & Crop Establishment

- Vegetatively propagated
  - Transplants ("Slips")
    - Produced from seed roots
    - Adventitious shoots that are removed from the seed root and rooted
    - Most common in US
  - Vine cuttings
    - Common in tropics
- Spacing will affect root size (plant spacing, not row spacing)
  - Best economic yields usually with 12" spacing, but later cultivars are usually planted farther apart
- Soil aeration is required and usually obtained by bedding the rows (8"-10" high)

Weed Control

- Good weed control is critical early in development, but once the vine has spread, sweet potatoes will normally suppress further weed growth

Cultivars

- Since sweet potatoes are vegetatively propagated, you would expect great uniformity for a given cultivar
  - But this is not often the case, as a great deal of variation occurs even between slips from the same root stock
  - Yellow and red skinned potatoes have been found on the same plant
  - Variability attributed to spontaneous mutations
    - Sweet potato has a higher than normal mutation rate
    - Most mutations are deleterious
  - Growers typically practice selection in the field

Diseases & Pests

- Sweet potato has few insect pests
  - Sweet potato weevil an exception
- Nematodes can cause losses of roots
- Several diseases
  - Black Rot (fungal disease different from crucifer disease)
    - Most destructive; can occur during propagation, on plants in the field, and on roots in storage
  - Scurf
    - Fairly unique to sweet potatoes; no apparent injury to above ground plant, but produces a brown to black discoloration to the skin, eventually causing root shrivelling
    - Storage diseases
      - Can be unique to stored roots, or may be a field disease that continues to develop while in storage

Harvesting

- Sweet potatoes will continue to grow as long as the plant stays green
- Harvest is made when highest percentage of roots are at the desired size
- Usually occurs about 130 to 150 days after planting
- Vine removal necessary prior to mechanical digging
- Sweet potatoes have a thin skin and are susceptible to damage which may lead to disease development in storage

Postharvest

- Proper curing critical for long shelf-life
  - 80-85°F and 85-90% RH for 4-7 days
  - Promotes the formation of cork layers on wounded surfaces
- Storage: 55-60°F, 85-90% RH
- Shelf-life: 4-7 months, with some cultivars keeping for one year
- Some sugar will convert to starch in storage, and an average of 2% weight loss will occur
- Susceptible to chilling injury below 55°F, resulting in discoloration, internal breakdown and off-flavors when cooked