Postharvest Biology & Handling of Vegetables

I. Leafy & Succulent Crops

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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

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I. Introduction

- Bulky; low value per unit weight
- Mostly temperate-zone (cool season) crops – no chilling injury
- Very high perishability-water content-surface:volume ratio
  - Rapid senescence
  - Water loss susceptibility
  - Physical damage susceptibility
  - Freezing susceptibility

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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)

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II. Morphological Characteristics

- Derivation of Some Vegetables From Plant Tissue

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This Group Includes:

- Leaves and associated parts :
  - Blades
    - Leaf lettuce
    - Spinach & greens
    - Chard
    - Endive

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This Group Includes:

- Leaves and associated parts :
  - Petioles
    - Celery

    - Rhubarb

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This Group Includes:

- Leaves and associated parts :
  - Buds
    - Head lettuce

    - Cabbage

    - Brussels sprouts

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This Group Includes:

- Leaves and associated parts :
  - Shoots
    - Green onions

http://www.hort.purdue.edu/

  - Swollen blades
    - Leeks

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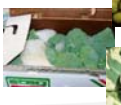
This Group Includes:

- Other vegetative tissues :
  - Stems – asparagus

  - Immature flower parts
    - Artichokes

http://www.oceanmist.com/

    - Broccoli



    - Cauliflower

http://www.kyagr.com

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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

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II. Morphological Characteristics

- In relation to water loss
  - 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

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Examples of the Surface/Volume Ratios of Fruits and Vegetables

Surface/volume ratio ($cm^2 cm^{-3}$)	Plant material
50-100	Individual edible leaves
5-10	Smaller soft fruits
2-5	Leguminous fruits; nuts; larger soft fruits; stem and floral vegetables; rhubarb; shallot
0.5-1.5	Tubers; tuberous roots; tap-roots; pome, stone and citrus fruits; cucurbitous fruits; banana; onion
0.2-0.5	Densely packed cabbage; large Swede turnips; yams; coconut

Adapted from Burton, 1982

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Percentage Loss of Original Weight From Various Commodities During Storage

Commodity	Initial rate of water loss (% day^{-1} $mbar^{-1}$ wvpd)	Percentage loss during successive 2-week periods 1	2	3	4
Cabbage	0.5	7.06	4.80	4.55	3.85
Sweetpotato	0.6	8.57	5.67	5.10	5.05
Beet (w/ leaves)	0.9	12.86	10.19	10.51	9.25
Cauliflower	1.2	17.02	9.07	8.14	8.51

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

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Water Loss, as a Percentage of Original Weight, at Which Commodities Become Unsaleable. Approximate values from Robinson et al (1975).

Commodity	Max. permissible water loss (%)	Commodity	Max. permissible water loss (%)
Asparagus	8	Onion	10
Beans, broad	6	Parsnip	7
Beans, runner	5	Potato, maincrop	7
Beetroot, with leaves	7	Potato, new	7
Blackberries	6	Peas in pod, early	5
Brussels sprouts	8	Peas in pod, maincrop	5
Cabbage	7	Peppers, green	7
Carrots, storing	8	Raspberries	6
Carrots, bunching	4	Rhubarb, forced	5
Cauliflower	7	Spinach	3
Celery	10	Sprouting broccoli	4
Cucumber	5	Strawberries	6
Leeks	7	Sweetcorn	7
Lettuce, 'Unrivalled'	5	Tomato	7
Lettuce, 'Kordaat'	3	Turnips, with leaves	5
Lettuce, 'Kloek'	3	Watercress	7

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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

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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)

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Leafy & Floral Vegetables High in Vitamins C and A

Vitamin C (mg/100 g fr. wt.)	Vitamin A (IU)
Parsley (172)	Kale (8,900)
Turnip greens (139)	Parsley (8,500)
Broccoli (113)	Spinach (8,100)
Brussels sprouts (102)	Turnip greens (7,600)
Collards (92)	Chard (6,500)
Cauliflower (78)	Broccoli (2,500)
Cabbage (47)	
Asparagus (48)	

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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)

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Maturity Stages of Iceberg Lettuce

http://postharvest.ucdavis.edu

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Maturity (Solidity) of Lettuce at Harvest vs. Postharvest Quality and Shelf-life

Solidity class	Postharvest considerations
1)Soft-to- 2) Fairly firm	More susceptible to physical damage, higher respiration rate
3) Firm	Maximum storage-life
4) Hard-to- 5) Extra-hard	More susceptible to russet spotting, pink rib, and other physiological disorders; decreased storage-life

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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**: cleanness, compactness, white color, size, no defects.
  - **Celery**: 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

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V. Postharvest Physiology

- Respiration rate
  - **Very/extremely high** (more than 40 mg CO_2/kg-h at 5°C): asparagus, Brussels sprouts, spinach & turnip greens
  - **High** (20 to 40 mg CO_2/kg-h at 5°C): artichoke, broccoli, celery & leaf lettuce
  - **Moderate** (10 to 20 mg CO_2 /kg-h at 5°C): cabbage, cauliflower, celery, kohlrabi & head lettuce

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Class	(mg CO_2/kg-hr) at 15°C	Commodities
~~Very Low~~	~~< 10~~	~~Dates, dried fruits and vegetables, nuts~~
Low	10 - 20	Apple, beet, celery, citrus fruits, cranberry, garlic, grape, honeydew melon, kiwifruit, onion, papaya, persimmon, pineapple, potato (mature), sweet-potato, watermelon
Moderate	20 - 40	Apricot, banana, blueberry, cabbage, cantaloupe, carrot (topped), celeriac, cherry, cucumber, fig, gooseberry, lettuce (head), mango, nectarine, olive, peach, pear, plum, potato (immature), radish (topped), summer squash, tomato
High	40 - 80	Avocado, blackberry, carrot (with tops), cauliflower, leeks, lettuce (leaf), lima bean, radish (with tops), raspberry
Very High	80 - 160	Artichoke, bean sprouts, cherimoya, cut flowers, endive, green onions, kale, okra, passion fruit, snap bean, watercress
Extremely High	> 160	Asparagus, broccoli, Brussels sprouts mushroom, parsley, peas, spinach, sweetcorn

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Rates of CO_2 Production (mg kg^{-1} h^{-1}) at Different Temperatures
(from Robinson *et.al.*, 1975)

Commodity	Temperature (°C) 0	5	10	15	20
Cabbage	3	7	8	13	20
Celery	7	9	12	23	33
Beetroot (bunching, with leaves)	11	14	22	25	40
Rhubarb	14	21	35	44	54
Turnip (bunching with leaves)	15	17	30	43	52
Lettuce	16	24	31	50	80
Brussels sprouts	17	30	50	75	90
Watercress	18	36	80	136	207
Cauliflower	20	34	45	67	126
Asparagus	28	44	63	105	127
Carrots (bunching, with leaves)	35	51	74	106	121
Spinach	50	70	80	120	150
Sprouting broccoli	77	120	170	275	425

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V. Postharvest Physiology

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

http://postharvest.ucdavis.edu

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V. Postharvest Physiology

- Responses to controlled atmospheres
  - 2-3% O_2 retards senescence (except asparagus, which is intolerant of low O_2)
  - Susceptibility to elevated CO_2 varies greatly
    - Lettuce, celery & endive: injury if CO_2 >1-2%
    - More than 5% CO_2 induces off-odors and off-flavors in cooked cauliflower
    - Elevated CO_2 (5-10%) retards soft rot development, toughening and yellowing of asparagus; also retards yellowing of broccoli

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V. Postharvest Physiology

- Responses to controlled atmospheres
  - Cabbage can be held for up to 6 months in CA at 0°C (2-3% O_2 + 5-8% CO_2); this is used commercially in the northeastern U.S.
  - CA is also used commercially during marine transportation of lettuce (1-2% O_2 + ≤1% CO_2)
  - 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

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Recommended CA for some leafy, floral and stem vegetables

Vegetable type	O_2 +	CO_2
Asparagus	13-16	5-7
Broccoli	1-2	10
Brussels sprouts	1-2	5
Cabbage	2-3	5-8
Cauliflower	2	<5
Celery	2-4	3-5
Lettuce	2-3	0-1

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V. Postharvest Physiology

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

http://postharvest.ucdavis.edu

www.omafra.gov.on.ca

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V. Postharvest Physiology

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

T.A. Zitter, Cornell University

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V. Postharvest Physiology

- 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_2H_4

www.cals.ncsu.edu

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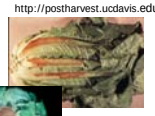
V. Postharvest Physiology

- Physiological disorders of lettuce
  - **Brown stain**: caused by 2% or higher CO_2 at 0-5°C
  - **Russet spotting**: caused by C_2H_4 at 0.1 ppm or higher
  - **Rusty-brown discoloration**: 'Climax' cultivar, increased by lettuce mosaic virus
  - **Pink rib**: a symptom of senescence
  - **Low O_2 injury** (less than 1% O_2)

http://postharvest.ucdavis.edu



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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

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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

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VII. Postharvest Handling Procedures

- 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

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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



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VII. Postharvest Handling Procedures

- 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

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VII. Postharvest Handling Procedures

- 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

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VII. Postharvest Handling Procedures

- Temporary storage
- Transport
- Destination handling
- Retail handling


Images courtesy of Trevor Suslow

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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

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VIII. Recommended Conditions

- **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 O_2 and avoid injurious CO_2 levels

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