Postharvest Handling Leafy Vegetables

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Causes of Quality & Postharvest Losses

Leafy Vegetables

- Lettuces
- Spinach
- Cabbage
- Chard
- Broccoli
- Celery
- Herbs
- Endives
- Asparagus
- Green Onions

Water loss
Mechanical damage
Loss of chlorophyll and other nutrients
Respiration rates
Microbial growth
Sensitivity to ethylene

Effect of Temperature on Deterioration

<table>
<thead>
<tr>
<th>Temp. °F</th>
<th>Temp. °C</th>
<th>Q10</th>
<th>Relative Velocity of Deterioration</th>
<th>Relative Shelf-life</th>
<th>Daily Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>0</td>
<td>--</td>
<td>1.0</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>3.0</td>
<td>3.0</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>68</td>
<td>20</td>
<td>2.5</td>
<td>7.5</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>86</td>
<td>30</td>
<td>2.0</td>
<td>15.0</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>104</td>
<td>40</td>
<td>1.5</td>
<td>22.5</td>
<td>4</td>
<td>25</td>
</tr>
</tbody>
</table>

Q10 = rate of deterioration at T+10°C / rate of deterioration at T

Broccoli Compositional Quality and Storage Temperature

- Fresh appearance
- Green florets
- Tender stem
- No discoloration
- No decay
- No off-odors

Storage temperature

Broccoli Shelf-life & Temperature

cv. Legacy

Chlorophyll, Carotenoids, Ascorbic Acid, Sugars

Cantwell, unpublished
### Specialty Brassicas Comparative Study

<table>
<thead>
<tr>
<th>Specialty Brassicas</th>
<th>Comparative Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gai-lan</td>
<td></td>
</tr>
<tr>
<td>Choi-sum</td>
<td></td>
</tr>
<tr>
<td>Broccoli raab, rapini</td>
<td></td>
</tr>
<tr>
<td>Broccolini</td>
<td></td>
</tr>
</tbody>
</table>

*Marketable quality
Compositional quality
Response to Temperature* Response to atmospheres

<table>
<thead>
<tr>
<th>Component</th>
<th>Florets</th>
<th>Stem Tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Initial</td>
</tr>
<tr>
<td></td>
<td>5C</td>
<td>8d</td>
</tr>
<tr>
<td></td>
<td>10C</td>
<td>8d</td>
</tr>
<tr>
<td>Total sugars, mg/g FW</td>
<td>5.2</td>
<td>17.4</td>
</tr>
<tr>
<td>Ammonia, µmole/100g FW</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Antioxidant activity</td>
<td>117</td>
<td>47</td>
</tr>
<tr>
<td>Vitamin C, mg/100g FW</td>
<td>235</td>
<td>87</td>
</tr>
</tbody>
</table>


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### Broccoli Storage Conditions

- **0°C with very high humidity**
- **MA: 5-8% O2 + 7-10% CO2**

**Iceless Broccoli**

- Temperature yellowing
- Moisture loss-softening

**Broccoli raab**

- **Iceless Broccoli**
  - Minimize delay from harvest to cooling
  - Use plastic liners to reduce water loss
  - Keep it cold

- **Broccoli Storage Conditions**
  - **0°C with very high humidity**
  - **MA: 5-8% O2 + 7-10% CO2**

**Leafy green grower, Singapore**

Aug 2007

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**ICELESS BROCCOLI**

- Minimize delay from harvest to cooling
- Use plastic liners to reduce water loss
- Keep it cold

- **Broccoli Storage Conditions**
  - **0°C with very high humidity**
  - **MA: 5-8% O2 + 7-10% CO2**

Leafy green grower, Singapore

Aug 2007
Broccoli Shelf-life & Variety

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Days 7.5°C Score 2</th>
<th>Range</th>
<th>Average</th>
<th>% Head Rot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packman</td>
<td>17-19</td>
<td>17.7</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Liberty</td>
<td>12-17</td>
<td>15.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Patriot</td>
<td>12-17</td>
<td>14.4</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Grn Valiant</td>
<td>13-15</td>
<td>14.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Brigadier</td>
<td>9-12</td>
<td>11.2</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Majestic</td>
<td>9-14</td>
<td>11.1</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>12-15</td>
<td>13.7</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

M. Castello, Nov 1997

Black Speck Disorder on Chinese Cabbage

- Black speck development on Napa cabbage stored in air or in ethylene is the same.
- PAL enzyme levels similar; 1-MCP does not reduce black speck.
- Cultivars vary greatly in their susceptibility to black speck.

Cauliflower Quality

color is cream white
freedom from mechanical injury
freedom from decay
no discoloration on cut edges
minimal number of small pieces; good integrity of cut florets
good aroma and odor as fresh or microwaved food
retain high content of sugars and Vitamin C
**Cauliflower Discoloration**  
*(in relation to storage temperature)*

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**Opportunities related to more nutritious lettuces**

<table>
<thead>
<tr>
<th>Constituent (fresh wt. basis)</th>
<th>Romaine</th>
<th>Iceberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll (mg/100 g)</td>
<td>21.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Carotenoids (mg/100 g)</td>
<td>5.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Sugar (mg/g)</td>
<td>20.4</td>
<td>20.0</td>
</tr>
<tr>
<td>Vitamin C (mg/100 g)</td>
<td>23.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Phenolics (A&lt;sub&gt;430&lt;/sub)&gt;</td>
<td>0.44</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Cantwell and Ermens 2006

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**Maturity Stages of Iceberg Lettuce**

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**Respiration rates of specialty salad greens and full size lettuces**

From M. Cantwell, UC Davis 1998
**Russet Spotting**

**Ethylene-induced Disorder on Lettuces**

Large differences among varieties in susceptibility

Russet spot scores: 1 (none), 3, 5 and 9, respectively.

<table>
<thead>
<tr>
<th>Variety</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<tbody>
<tr>
<td>Sonoma</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Spreckles</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Salinas 521</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
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<td>Raider</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Salinas 517</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Buena Vista</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Stinger</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Van Sal 210</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Salinas</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Ace</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Champ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Salinas 88</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Ridgemark</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

A. Iceberg Lettuces

B. Romaine Lettuces

Variety

Development of Russet Spot Disorder on Iceberg and Romaine Lettuces. Intact heads were stored in 5 ppm ethylene at 5°C (41°F) plus 1 week in air.

**1-MCP Prevents Russet Spot Disorder on Iceberg Lettuce**

Brown Stain

- Brown stain—CO2
- Pink rib—overmature heads
- Heart Discoloration—O2/CO2

**Heart Leaf Injury**

Lettuce disorders

- Brown stain—CO2
- Pink rib—overmature heads
- Heart Discoloration—O2/CO2

**Symptoms of Freezing in Lettuce**

- Normal
- Frozen

**Lettuce Storage Conditions**

- 0°C (32°F) but freezing point is -0.2°C (31.5°F)
- Shelf-life:
  - 0°C (32°F): >4 weeks
  - 5°F (41°F): ~3 weeks
- High relative humidity, avoid free moisture
- Controlled atmospheres
  - Low O2 beneficial, CO2 >3% damaging
- Ethylene sensitive
Traditional Packing of Romaine:
Do not place cut lettuce on the ground
Waxed cartons or cartons with liners rather than crates

Simple packaging to reduce water loss.
Need to cool product before packaging (rooms or hydrocool)
or used vented packaging and vacuum cool (romaine lettuces)

Spinach Quality Parameters
- Green and uniform color
- Minimum breakage
- No dirt; Clean and disinfected
- No decay
- Composition
  - nitrates, oxalates
- Shelf-life
Manual harvest of bunched Spinach: vacuum cooled
Note: no longer use slickers, use aprons

Mechanical harvest of young spinach for washed and packaged product

http://www.ramsayhighlander.com

Yellowing Rating Scale for Spinach

<table>
<thead>
<tr>
<th>Color score</th>
<th>L*</th>
<th>Chroma</th>
<th>Hue</th>
<th>Chlorophyll mg/g FW</th>
<th>Carotenoids mg/g FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39.2</td>
<td>18.1</td>
<td>129.5</td>
<td>1.49</td>
<td>0.29</td>
</tr>
<tr>
<td>2</td>
<td>40.7</td>
<td>21.6</td>
<td>126.6</td>
<td>1.17</td>
<td>0.26</td>
</tr>
<tr>
<td>3</td>
<td>45.0</td>
<td>27.5</td>
<td>123.4</td>
<td>0.75</td>
<td>0.18</td>
</tr>
<tr>
<td>4</td>
<td>47.6</td>
<td>31.3</td>
<td>121.4</td>
<td>0.50</td>
<td>0.16</td>
</tr>
<tr>
<td>5</td>
<td>59.8</td>
<td>44.6</td>
<td>110.9</td>
<td>0.22</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Color values measured in upper right hand corner of each leaf; data average 4-6 leaves per category

Impact of Temperature on Quality Changes

**Spinach:** Commerical washed and bagged product stored at 4 temperatures

**BUT….**

Target Temp. 0ºC (32ºF)

Quality categories (leaf damage) for commercial packaged spinach

<table>
<thead>
<tr>
<th>Category number and name</th>
<th>Category Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No damage</td>
</tr>
<tr>
<td>2</td>
<td>Slight damage</td>
</tr>
<tr>
<td>3</td>
<td>Moderate damage</td>
</tr>
<tr>
<td>4</td>
<td>Severe damage</td>
</tr>
<tr>
<td>5</td>
<td>Leaf Pieces</td>
</tr>
</tbody>
</table>

*Near intact refers to leaves cut at the base with mechanical harvester

DEFECTS ON FIELD-GROWN PACKAGED LEAFY GREENS

DAMAGE FOLLOWED BY DECAY, MOSTLY BACTERIAL

August 2008
Changes in ammonium, chlorophyll and carotenoid concentrations in spinach after 0 and 21 days in air at 5°C (41°F). Data averaged from 11 spinach cultivars (Cantwell, 2001).

Ammonium increases in spinach in response to temperature and stressful atmospheres.

Spinach Storage

- Young and mature spinach leaves respond similarly to storage conditions.
- Young leaves have less physical damage.
- Excessive N fertilization results in weaker leaves.
- Low temperatures are essential for adequate shelf-life:
  - 0°C (32°F): 3 weeks
  - 5°C (41°F): 2 weeks
- Modified atmospheres, keep CO2 at 5% or less.
- High CO2 atmospheres stressful to spinach.

Ammonia increases in spinach in response to temperature and stressful atmospheres.

Asparagus

2-3°C (34-36°F) best temperature; Asparagus is slightly chill sensitive. CA with high CO2 is beneficial.

<table>
<thead>
<tr>
<th>TIP</th>
<th>SUGARS LOW</th>
<th>PROTEIN &amp; ACIDITY HIGH</th>
<th>Slight Lignification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDDLE</td>
<td>Total Solids 8-14%</td>
<td>% Water High</td>
<td></td>
</tr>
<tr>
<td>BASE</td>
<td>Sugars HIGH</td>
<td>Protein &amp; Acidity LOW</td>
<td>Maximum Lignification</td>
</tr>
</tbody>
</table>

M. Cantwell, UC Davis

http://www.freshplaza.com/fotoarchief/apr11.htm
Asparagus storage conditions
- 2.5°C (slightly chilling sensitive)
- High humidity
- 1-2 weeks; 3 weeks MA
- Modified atmospheres
  - O₂: 5-10%
  - CO₂: 7-10%

Tip decay (bacterial)

Data averaged over 2 Tests & 2 Fields, 2004

Storage Conditions for Fresh Herbs
- 0°C (32°F) but freezing point is -0.2°C (31.5°F)
  - Shelf-life at 0°C (32°F): 3-4 weeks
  - Shelf-life at 5°C (41°F): 2-3 weeks
  - Shelf-life based on aroma quality: 1-2 weeks
  - Exception: chilling sensitive basil 12.5°C (55°F) best
- High relative humidity, protective packaging, but avoid free moisture condensation
- Modified atmospheres can be beneficial
- Ethylene sensitive

Basil
Highly susceptible to water loss
Very chilling sensitive

Situation:
Excellent quality crop
Harvesting late in day
High temperatures, ~30°C
Low RH, ~50%;
Little protection from ambient
Long delays to packinghouse

Detrimental ethylene effects
- Yellowing
- Epinasty
- Abscission

Paulenas and Cantwell, 2008

UC115 compared to UC157. Asparagus stored at 2.5°C (36°F) up to 21 days.
Basil loses moisture very rapidly
Basil is very chilling sensitive

Chilling injury Score 3

Basil stored 2 days in plastic bags

Shiso, a basil relative, is also chilling sensitive

July 31, 2006

2 days

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>32°F</td>
</tr>
<tr>
<td>5°C</td>
<td>41°F</td>
</tr>
<tr>
<td>10°C</td>
<td>50°F</td>
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</tbody>
</table>

Basil loses moisture very rapidly
Basil is very chilling sensitive

Exposed

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>32°F</td>
</tr>
<tr>
<td>10°C</td>
<td>50°F</td>
</tr>
</tbody>
</table>

2 days

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>32°F</td>
<td>50°F</td>
</tr>
</tbody>
</table>

Weight loss in relation to VPD in 4 products

Belgian Endive—keep cold and away from light

Celery hearts
Trimmed, washed and packaged
Mobile processing unit
Chlorine rinse
Drain and package in perforated bag

With permission from T&A, June 2007

Production Conditions: Quality Implications

China: row covers
Belgium: Horticlim, mobile gully system
China: nutrient film technique