Maturation and Maturity Indices

When to Harvest?

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Maturation and Maturity Indices

IMPORTANCE
✓ Maturity Indices = Harvest Indices
✓ Sensory and Nutritional Quality
✓ Use—Fresh market or Processed
✓ Adequate shelf-life
✓ Facilitate marketing—standards
✓ Productivity—yield at harvest and use
Developmental Continuum

Watada et al., 1984
Terminology

**PHYSIOLOGICAL MATURITY**
The stage of development when a plant part will continue development even if detached; mature fruits

**HORTICULTURAL MATURITY**
The stage of development when a plant part possesses the necessary characteristics for use by consumers

<table>
<thead>
<tr>
<th>Physiological Maturity</th>
<th>Horticultural Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FRUITS</strong></td>
<td><strong>VEGETABLES</strong></td>
</tr>
<tr>
<td>• Immature</td>
<td>• Immature</td>
</tr>
<tr>
<td>• Mature</td>
<td>• Mature</td>
</tr>
<tr>
<td>• Ripening</td>
<td>• Overmature</td>
</tr>
<tr>
<td>• Ripe</td>
<td></td>
</tr>
<tr>
<td>• Overripe</td>
<td></td>
</tr>
</tbody>
</table>
Maturity Indices

- **Asparagus**
  - Size
  - Apex closed

- **Broccoli/Cauliflower**
  - Size
  - Florets closed

- **Carrot**
  - Size

- **Lettuce, head**
  - Size
  - Firmness, solidity
  - Flavor-sweetness, bitterness

- **Lettuce, Romaine**
  - Size
  - Number of leaves

Days from seeding, transplant

Maturity Stages of Iceberg Lettuce

- **Weight**
- **Firmness**
- **% Green**
- **Sweetness**
- **Bitterness**
- **Phenolics**

1 2 3 4 5
Maturity Indices
Bulb Onions
Composition of Potato Tubers

<table>
<thead>
<tr>
<th></th>
<th>Weight g</th>
<th>dry wt, %</th>
<th>Starch %</th>
<th>Sugar %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowering</td>
<td>9</td>
<td>16</td>
<td>64</td>
<td>4.8</td>
</tr>
<tr>
<td>Flowering ends</td>
<td>11</td>
<td>17</td>
<td>66</td>
<td>5.2</td>
</tr>
<tr>
<td>Leaves decline</td>
<td>28</td>
<td>19</td>
<td>72</td>
<td>2.9</td>
</tr>
<tr>
<td>80% leaves dead</td>
<td>33</td>
<td>21</td>
<td>73</td>
<td>0.8</td>
</tr>
<tr>
<td>100% leaves dead</td>
<td>51</td>
<td>20</td>
<td>72</td>
<td>0.7</td>
</tr>
</tbody>
</table>

“new potatoes”

mature potatoes

cv. Irish Cobbler; data from Burton, 1966

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Maturity Indices

- **Onions/Garlic**
  - Size
  - Drying and collapse of the “neck”
  - Drying of leaf scales

- **Potatoes**
  - Death of the plant
  - Size of tubers
  - Starch content; specific gravity
  - Periderm development
Maturity Indices

- **Beans**
  - Size
  - Seed development

- **Cucumber**
  - Size
  - External color

- **Okra**
  - Size
  - External color

- **Summer Squash**
  - Size
  - External color

*Immature fruit vegetables: very rapidly developing and changing*

Harvest Maturity
Maturity Indices for **fruit vegetables**

- **Peppers**
  - Size
  - Color
  - Firmness
  - Seed and locule development

- **Tomato**
  - External and Internal color
  - Development of locules (jelly)
  - Firmness
  - Size
  - Development of cuticle

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**Harvest & Maturity Indices**

**Peppers & Chiles**

**Jalapeños**
Tomato Maturity & Ripening Stages

1. **GREEN** The tomato surface is completely green. The shade of green may vary from light to dark.

2. **BREAKERS** There is a definite break of color from green to bruised fruit tannish-yellow, pink or red or 10% or less of the tomato surface.

3. **TURNING** Tannish-yellow, pink or red color shows on over 10% but not more than 30% of the tomato surface.

4. **PINK** Pink or red color shows on over 30% but not more than 90% of the tomato surface.

5. **LIGHT RED** Pinkish-red or red color shows on over 60% but red color covers not more than 90% of the tomato surface.

6. **RED** Red means that more than 90% of the tomato surface, in aggregate, is red.

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**Checker boarding**

Due to poor separation of maturity stages of round tomatoes at packing

*At Packhouse*

*At Distribution*

TOV at harvest and after 4 days at distribution center. Likely these green fruit will not ripen.
Composition of Ripe Grape Tomato Harvested at 3 Stages of Maturity

<table>
<thead>
<tr>
<th>Initial Maturity Stage</th>
<th>Weight fruit, g</th>
<th>Red color, hue</th>
<th>Firmness, N force</th>
<th>Soluble solids, %</th>
<th>Sugars mg/mL</th>
<th>Titratable acidity, %</th>
<th>Vitamin C mg/100mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4.9</td>
<td>36.8</td>
<td>11.5</td>
<td>5.9</td>
<td>27</td>
<td>0.59</td>
<td>96</td>
</tr>
<tr>
<td>4</td>
<td>5.7</td>
<td>36.3</td>
<td>13.6</td>
<td>6.7</td>
<td>30</td>
<td>0.68</td>
<td>97</td>
</tr>
<tr>
<td>5</td>
<td>5.9</td>
<td>37.7</td>
<td>13.7</td>
<td>7.5</td>
<td>33</td>
<td>0.67</td>
<td>99</td>
</tr>
<tr>
<td>LSD.05</td>
<td>0.6</td>
<td>ns</td>
<td>1.5</td>
<td>0.8</td>
<td>3</td>
<td>0.09</td>
<td>ns</td>
</tr>
</tbody>
</table>

Minimum harvest stage should be Stage 4 (pink-orange)

Cantwell, UC Davis, 2003

Physalis (Goldenberry; Cape Gooseberry) & Stage of Maturity/Ripeness

<table>
<thead>
<tr>
<th>Color</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight, g</td>
<td>1.78</td>
<td>1.94</td>
<td>2.07</td>
<td>1.76</td>
<td>2.16</td>
</tr>
<tr>
<td>% SS</td>
<td>10.8</td>
<td>11.7</td>
<td>12.8</td>
<td>13.6</td>
<td>13.8</td>
</tr>
<tr>
<td>pH</td>
<td>3.99</td>
<td>4.23</td>
<td>4.62</td>
<td>4.95</td>
<td>5.05</td>
</tr>
<tr>
<td>% TA</td>
<td>1.06</td>
<td>0.78</td>
<td>0.50</td>
<td>0.34</td>
<td>0.32</td>
</tr>
<tr>
<td>SS/TA</td>
<td>10.2</td>
<td>15.0</td>
<td>25.6</td>
<td>40.0</td>
<td>43.1</td>
</tr>
</tbody>
</table>

Cantwell, UC Davis, 2007
**Group 1* Non climacteric Fruits**
Fruits that are not capable of continuing ripening process (physiological changes) once removed from the plant.

*No increase in sugar content; decrease in respiration after harvest. Changes in firmness, external color, and aroma may occur*

<table>
<thead>
<tr>
<th>Blackberry</th>
<th>Loquat</th>
<th>Pomegranate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherry</td>
<td>Litchi</td>
<td>Prickly Pear</td>
</tr>
<tr>
<td>Grape</td>
<td>Mandarin</td>
<td>Rambutan</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>Muskmelons</td>
<td>Raspberry</td>
</tr>
<tr>
<td>Lemon</td>
<td>Orange</td>
<td>Strawberry</td>
</tr>
<tr>
<td>Lime</td>
<td>Pepper (Bell)</td>
<td>Tamarillo</td>
</tr>
<tr>
<td>Longan</td>
<td>Pineapple</td>
<td>Watermelon</td>
</tr>
</tbody>
</table>

**Composition of Ripe Strawberry**
Harvested at different stages. Held at 70°F (21°C) to complete color change.
Maturity and Ripeness Stages of Cherries

Harvest too early
- Small size
- Poor color
- Poor flavor

Harvest too late
- Soft fruit
- Increased decay susceptibility
- More shrivel, stem browning, and pitting

California strawberries and cherries
Distribution Center Singapore
May 16, 2008

Strawberries from Oxnard; Cherries from Lodi
Air-shipped
Cantaloupe Maturity/Ripeness

- Fruit begins to separate from the stem
  - Abscission zone; “slip”
  - External color between net
  - Net well developed with wax
  - Subtending leaf dries up
  - Internal color, firmness, soluble solids

Composition of fig cultivars separated by stage of maturity (ripeness). All the fruit were in boxes of ‘Commercial Maturity’ (Cantwell & Crisosto, 2010)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Maturity stage</th>
<th>Weight, g</th>
<th>Firmness, N</th>
<th>Soluble solids, %</th>
<th>Titratable acidity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Mission</td>
<td>Under-ripe</td>
<td>29.9</td>
<td>12.1</td>
<td>14.3</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Commercial maturity</td>
<td>32.2</td>
<td>7.2</td>
<td>17.5</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Tree ripe</td>
<td>34.5</td>
<td>4.0</td>
<td>21.0</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>Under-ripe</td>
<td>45.1</td>
<td>11.0</td>
<td>15.2</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Commercial maturity</td>
<td>56.3</td>
<td>4.4</td>
<td>15.9</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Tree ripe</td>
<td>57.6</td>
<td>2.4</td>
<td>17.9</td>
<td>0.28</td>
</tr>
<tr>
<td>Kadota</td>
<td>LSD.05</td>
<td>3.7</td>
<td>1.3</td>
<td>1.9</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Lack of sufficient uniformity of maturity/ripeness within a box leads to repacking or marketing losses.
### Indian Kew Pineapples and Composition at Different Stages of Ripeness

<table>
<thead>
<tr>
<th>Days from Anthesis</th>
<th>Shell Color</th>
<th>Chl mg/g</th>
<th>Dry wt. %</th>
<th>Soluble solids %</th>
<th>Titratable acidity %</th>
<th>Total sugar %</th>
<th>Vit C mg/100g</th>
<th>Sensory score*</th>
</tr>
</thead>
<tbody>
<tr>
<td>115-120</td>
<td>Green</td>
<td>0.77</td>
<td>12.97</td>
<td>7.9</td>
<td>0.66</td>
<td>6.49</td>
<td>13.7</td>
<td>3.0</td>
</tr>
<tr>
<td>135-140</td>
<td>1/8</td>
<td>0.76</td>
<td>15.26</td>
<td>12.6</td>
<td>0.74</td>
<td>8.87</td>
<td>13.9</td>
<td>4.6</td>
</tr>
<tr>
<td>141-145</td>
<td>1/4</td>
<td>0.63</td>
<td>16.09</td>
<td>18.2</td>
<td>0.77</td>
<td>11.25</td>
<td>14.4</td>
<td>5.4</td>
</tr>
<tr>
<td>146-150</td>
<td>1/2</td>
<td>0.53</td>
<td>17.65</td>
<td>18.9</td>
<td>0.77</td>
<td>11.99</td>
<td>14.9</td>
<td>6.8</td>
</tr>
<tr>
<td>151-155</td>
<td>2/3</td>
<td>0.21</td>
<td>17.76</td>
<td>18.0</td>
<td>0.83</td>
<td>12.44</td>
<td>15.3</td>
<td>6.7</td>
</tr>
<tr>
<td>156-160</td>
<td>Full</td>
<td>0.14</td>
<td>19.89</td>
<td>16.3</td>
<td>0.96</td>
<td>12.74</td>
<td>14.5</td>
<td>6.4</td>
</tr>
<tr>
<td>LSD.05</td>
<td></td>
<td>0.01</td>
<td>0.17</td>
<td>0.87</td>
<td>0.07</td>
<td>0.08</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* Sensory determined by panel of 10 untrained members based on nine point hedonic scale


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### Large increase in %SS during last days development

Evolution of some physical, chemical and physiological parameters during fruit development and ripening on the tree of ‘Golden Globe’ Plum.

Relationship between sugar/acid ratio and sensory panelist's Response to the question about Willingness to Buy navel oranges

<table>
<thead>
<tr>
<th>Sampling week</th>
<th>% samples below sugar/acid Ratio of 8.1*</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 14-18</td>
<td>39</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td>Nov 28-Dec 2</td>
<td>27</td>
<td>53</td>
<td>47</td>
</tr>
<tr>
<td>Dec 12-16</td>
<td>13</td>
<td>63</td>
<td>37</td>
</tr>
</tbody>
</table>

*from California A grade standard
Source: Ivans and Feree, 1987

California Navel Maturity Standards

The California Standard is easily converted to a table format, similar to the SSC/TA tables currently in use

It is a slight modification of the BrimA calculation proposed by Jordan et al

Steps involved in determining the California Standard
- Juice sample using Boswell Press
- Determine Brix using standard protocols
- Determine Titratable Acidity using standard protocols
- Use Table or formula to determine California Standard

Formula for California Standard:
California Standard = (Brix – (TA * 4)) * 16.5

http://www.cdfa.ca.gov/is/i_%26_c/citrus.html
**Group 2* Climacteric Fruits**

Fruits that can be harvested and ripened off the plant. Fruits undergo significant physiological changes.

† have large increases in sugar during ripening because they have starch

<table>
<thead>
<tr>
<th>Apple†</th>
<th>Mango †</th>
<th>Pepper (chili)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apricot</td>
<td>Mangosteen</td>
<td>Persimmon †</td>
</tr>
<tr>
<td>Avocado</td>
<td>Nectarine</td>
<td>Plum</td>
</tr>
<tr>
<td>Banana †</td>
<td>Papaya</td>
<td>Quince †</td>
</tr>
<tr>
<td>Cherimoya †</td>
<td>Passion fruit</td>
<td>Sapodilla † (chico)</td>
</tr>
<tr>
<td>Guava †</td>
<td>Peach</td>
<td>Sapotes †</td>
</tr>
<tr>
<td>Kiwifruit †</td>
<td>Pear †</td>
<td>Tomato</td>
</tr>
</tbody>
</table>

*Except for avocado, banana, mango and pear, best flavor if ripened on the plant*

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**Papaya (Exotica2), slow ripening cultivar (Malaysia)**

Harvest at first color

PH treatment with Ethrel

2 days after treatment, Differences in maturity

Accentuated; some fruit overripe

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**What should be done? When should harvest?**
Mangosteen and eating Quality—maturity issues

<table>
<thead>
<tr>
<th>Color Index</th>
<th>Color of Fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pale yellow green</td>
</tr>
<tr>
<td>2</td>
<td>Blotchy pink</td>
</tr>
<tr>
<td>3</td>
<td>Pinkish red</td>
</tr>
<tr>
<td>4</td>
<td>Maroon Red</td>
</tr>
<tr>
<td>5</td>
<td>Dark maroon violet</td>
</tr>
<tr>
<td>6</td>
<td>Violet black</td>
</tr>
</tbody>
</table>

Mango maturity indices
Fullness of shoulders
Internal and external color
Lenticels and hairs on pit
Starch content
Specific gravity
Golden Delicious at Retail Market: How is the maturity in this box?

**Indicators of Harvest Maturity: APPLES**

- Days from full bloom
- Time/temp (heat units) from anthesis
- Days from harvest to onset of ethylene production
- Ground color
- Soluble solids content (SSC)
- Flesh firmness and SSC
- Starch disappearance pattern
- Internal ethylene concentration
- Changes in firmness or starch content

Streif Index considers starch, sugar, firmness

*For many products it is necessary to use several indices to accurately determine maturity*
% Dry Weight and Maturity

- Vegetables
  - Potato
  - Onion
  - Garlic
- Fruits
  - Avocado
  - Apples
  - Mango
  - Kiwi

Oil content avocado linearly correlated with % dry weight

Maturity Indices

Requirements for establishing

- Simple, easy to carry out
- Objective vs subjective indicators
- Related to quality
- Related to storage life
- Represents a progressive change with maturity
- Permits prediction of maturity from year to year
- Inexpensive
Use of Maturity Indices

Limitations

• Soil conditions, nutrition, irrigation
• Season, climate
• Position on the plant
• Pruning, other cultural practices
• Varieties

Predicting Maturity

• Days from planting to harvest
• Progressive changes in size, composition
• Difficult to predict; need new tools and methods
  – Nondestructive firmness measurement, fruits
  – Chlorophyll fluorescence, broccoli; green tissues
  – NIR spectroscopy, sugar concentration in melon
  – MR imaging constituents, internal defects
  – Gene expression rapid assessment
Maturity and Shelf-life

Quality is maximized when the product is harvested more mature or ripe, whereas shelf- and storage life are extended if the product is harvested less mature or unripe.


<table>
<thead>
<tr>
<th>Lower maturity</th>
<th>Higher maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never ripens</td>
<td>More decay</td>
</tr>
<tr>
<td>Shrivels</td>
<td>Better flavor</td>
</tr>
<tr>
<td>Poor flavor</td>
<td>Too soft</td>
</tr>
<tr>
<td>No repeat buys</td>
<td>Bruises easily</td>
</tr>
<tr>
<td>Long shelf-life</td>
<td>Poor shelf-life</td>
</tr>
</tbody>
</table>

Discerning consumers say.....
This fruit looks great, but ..................

I love blueberries but these are too tart

I prefer the Spanish mandarins because they are sweeter than California fruit

These Chilean avocados have no flavor

This honeydew melon has no sweetness

I love blueberries but these are too tart

I prefer the Spanish mandarins because they are sweeter than California fruit

These Chilean avocados have no flavor

This honeydew melon has no sweetness
Maturity Indices Exercise

<table>
<thead>
<tr>
<th>Fruit or Vegetable</th>
<th>Possible Maturity Indices</th>
<th>Currently Used Maturity Indices</th>
<th>Current indices adequate or Not</th>
<th>What practical indicators could add?</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Maturity and Product Quality

- Know the consequences of harvesting at different stages of maturity/ripeness on final eating quality.
- Make sure workers involved in harvest and selection are well trained to ID correct maturity/ripeness.
- Most indices are a compromise between eating quality and shelf-life.
- As consumers, take back fruit with poor eating quality