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

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**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

**Physiological Maturity**

**FRUITS**
- Immature
- Mature
- Ripening
- Ripe
- Overripe

**VEGETABLES**
- Immature
- Mature
- Overmature

**Terminology**

**Developmental Continuum**

Watada et al., 1984

**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

Immature     Mature        Overmature
Maturity Stages of Iceberg Lettuce

1. Weight
2. Firmness
3. % Green
4. Sweetness
5. Bitterness
6. Phenolics

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

Composition of Potato Tubers

<table>
<thead>
<tr>
<th>Maturity Stage</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>17</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

Maturity Indices

- Beans
  - Size
  - Seed development

- Cucumber
  - Size
  - External color

- Okra
  - Size
  - External color

- Summer Squash
  - Size
  - External color

Immature fruit vegetables: vary rapidly developing and changing
Maturity Indices

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

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

**Harvest Maturity**

**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, 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

**European Color Chart Tomatoes**

**Composition of Ripe Grape Tomato Harvested at 3 Stages of Maturity**

<table>
<thead>
<tr>
<th>Initial Maturity Stage</th>
<th>Weight of fruit, g</th>
<th>Red color N force</th>
<th>Firmness, %</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>98</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>32</td>
<td>0.67</td>
<td>99</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.6</td>
<td>ns</td>
<td>1.5</td>
<td>0.6</td>
<td>3</td>
<td>0.09</td>
<td>ns</td>
</tr>
</tbody>
</table>

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

Average 7 cvs, Cantwell, 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>12.8</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>

Physalis from Davis Farmers’ Market, Aug 2007

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**Group 1* Non climacteric Fruits**

Fruits that are not capable of continuing ripening process (physiological changes) once removed from the plant.

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Stage of Maturity/Ripeness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackberry</td>
<td>Loquat</td>
</tr>
<tr>
<td>Cherry</td>
<td>Litchi</td>
</tr>
<tr>
<td>Grape</td>
<td>Mandarin</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>Muskmelons</td>
</tr>
<tr>
<td>Lemon</td>
<td>Orange</td>
</tr>
<tr>
<td>Lime</td>
<td>Pepper (Bell)</td>
</tr>
<tr>
<td>Longan</td>
<td>Pineapple</td>
</tr>
</tbody>
</table>

*No increase in sugar content; Changes in firmness, external color, and aroma may occur

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**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

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**Composition of Ripe Strawberry**

Harvested at different stages. Held at 70°F (21°C) to complete color change.

<table>
<thead>
<tr>
<th>Maturity</th>
<th>% SS</th>
<th>% Acid</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% color</td>
<td>4.28</td>
<td>0.80</td>
<td>5.35</td>
</tr>
<tr>
<td>50% color</td>
<td>4.56</td>
<td>0.79</td>
<td>5.77</td>
</tr>
<tr>
<td>75% color</td>
<td>4.98</td>
<td>0.68</td>
<td>7.32</td>
</tr>
<tr>
<td>100% color</td>
<td>5.48</td>
<td>0.59</td>
<td>9.28</td>
</tr>
</tbody>
</table>

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**Honeydew and other melons are more difficult to harvest at the proper stage of maturity or ripeness—need to harvest BEFORE abscission zone forms**

- Size
- External Color
- Firmness (blossom end)
- Surface hairs, smoothness, wax
- Aroma
- Internal cavity condition
- Pulp color and firmness
- Sugar content (soluble solids)
- Density

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**Maturity and Ripeness Stages of Cherries**

- Harvest too early
  - Small size
  - Poor color
- Harvest too late
  - Soft fruit
  - Increased decay susceptibility
  - More shrivel, stem browning and pitting

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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>28.9</td>
<td>12.1</td>
<td>14.3</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Commercial</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>Kadota</td>
<td>Under-ripe</td>
<td>40.1</td>
<td>11.0</td>
<td>15.2</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Commercial</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>
</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>0.68</td>
<td>6.40</td>
<td>13.7</td>
<td>3.0</td>
</tr>
<tr>
<td>125-140</td>
<td>1/8</td>
<td>0.76</td>
<td>15.26</td>
<td>12.6</td>
<td>0.54</td>
<td>8.37</td>
<td>13.9</td>
<td>4.6</td>
</tr>
<tr>
<td>140-145</td>
<td>1/4</td>
<td>0.63</td>
<td>16.09</td>
<td>18.2</td>
<td>0.77</td>
<td>11.23</td>
<td>14.4</td>
<td>4.4</td>
</tr>
<tr>
<td>145-150</td>
<td>1/2</td>
<td>0.53</td>
<td>17.65</td>
<td>16.9</td>
<td>0.73</td>
<td>11.99</td>
<td>14.9</td>
<td>6.8</td>
</tr>
<tr>
<td>150-155</td>
<td>1/4</td>
<td>0.21</td>
<td>17.76</td>
<td>18.0</td>
<td>0.82</td>
<td>12.44</td>
<td>15.3</td>
<td>6.7</td>
</tr>
<tr>
<td>155-160</td>
<td>Full</td>
<td></td>
<td></td>
<td>10.99</td>
<td></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>0.18</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


### Group 2* Climacteric Fruits ‡ has significant amount of starch

Fruits that can be harvested and ripened off the plant.

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

*Except for avocado, banana, mango & pear, best flavor if ripened on the plant; ‡These fruits have large increases in sugar during ripening.

**What should be done? When should harvest?**

Papaya (Exotica2), slow ripening cultivar
Harvest at first color
PH treatment with Ethrel
2 days after treatment, Differences in maturity
Accentuated; some fruit overripe

### 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>

Irregular color changes from smooth to warty skin
Nutlets: not hard enough, fruit not ripe enough
Mango maturity indices
- Fullness of shoulders
- Internal and external color
- Lenticels and hairs on pit
- Starch content
- Specific gravity

Indicators of Harvest Maturity: APPLES
- Days from full bloom
- Time/temperature (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>

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

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>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>