Fruit Development, Ripening and Quality Relationships

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Stages of Fruit Development

Development
- The series of processes from the initiation of growth to death of a plant or plant part.

Growth
- The irreversible increase in physical attributes (characteristics) of a developing plant or plant part.

Maturation
- The stage of development leading to the attainment of physiological or horticultural maturity.

Physiological maturity
- The stage when a plant or plant part will continue developing even if detached

Horticultural maturity
- The stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose

Ripening
- The set of processes that occur from the later stages of growth and development through the early stages of senescence and that results in characteristic aesthetic and/or eating quality, as evidenced by changes in composition, color, texture, or other sensory attributes.
**Stages of Fruit Development**

**Senescence**
- The last stage of development during which degradation of biological components occur.

**Physiological Changes Accompanying Senescence of Horticultural Crops**

**Cellular:**
- Loss of chlorophyll, disassembly of chloroplast structure
- Degradation of cell walls
- Altered membrane composition, loss of fluidity
- Loss of cellular compartmentation, release of vacuolar contents

**Composition:**
- Altered sugar content, and switch to alternative substrates for respiration
- Net loss of RNA
- Increased protease activity, net loss of protein
- Altered amino acid content

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**Stages of Fruit Development**

**Physical Changes Accompanying Senescence of Horticultural Crops**

**Color:**
- Loss of green color
- Synthesis of new pigments (carotenoids, flavonoids)

**Texture:**
- Softening
- Wilting
- Drying

**Loss of resistance to pathogens:**
- Development of infections
- Lesions

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**Respiration and ethylene production rates of climacteric and non-climacteric fruits**
### Maturity and Ripening

**Group 1:** Fruits that are not capable of continuing their ripening process once removed from the plant.

- Blackberry
- Cherry
- Grape
- Grapefruit
- Lemon
- Lime
- Longan
- Lychee
- Mandarin
- Muskmelons
- Orange
- Pepper (bell)
- Pineapple
- Pomegranate
- Prickly pear
- Rambutan
- Raspberry
- Strawberry
- Tamarillo
- Tangerine
- Watermelon

Strawberries must be picked fully-ripe because they do not continue to ripen after harvest.

#### California Minimum Maturity Indices for Selected Non-Climacteric Fruits

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Minimum maturity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pomegranate</td>
<td>Red juice color and below 1.85% acid in juice</td>
</tr>
<tr>
<td>Grape</td>
<td>14 to 17.5% SS (depending on cultivar and production area) or a SS/A ratio of 20 or higher</td>
</tr>
<tr>
<td>Strawberry</td>
<td>&gt;3/4 of fruit surface showing a pink or red color</td>
</tr>
</tbody>
</table>

SS=soluble solids, A=acidity

### Maturity and Ripening

**Group 2:** Fruits that can be harvested and ripened off the plant.

- Apple
- Apricot
- Avocado
- Banana
- Cherimoya
- Guava
- Kiwifruit
- Mango
- Nectarine
- Papaya
- Passion fruit
- Peach
- Pear
- Persimmon
- Plum
- Quince
- Sapodilla
- Sapote
- Tomato
- Pepper (chili)

#### Maturity and Ripeness Stages of Apricots

- Stage 1: Yellowish-green to orange color (depending on cultivar)
- Stage 2: Yellowish-green color, and/or below 23 lb-force firmness, and/or above 13% SS
- Stage 3: Starch pattern, above 10.5 to 12.5% SS and below 18 to 23 lb-force firmness (depending on cultivar)
- Stage 4: Yellowish-green to orange color (depending on cultivar)
- Stage 5: Red or dark red color

#### California Minimum Maturity Indices for Pome Fruits

<table>
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<tr>
<td>Apple</td>
<td>Starch pattern, above 10.5 to 12.5% SS and below 18 to 23 lb-force firmness (depending on cultivar)</td>
</tr>
<tr>
<td>Pear (Bartlett)</td>
<td>Yellowish-green color, and/or below 23 lb-force firmness, and/or above 13% SS</td>
</tr>
<tr>
<td>Persimmon</td>
<td>Yellowish-green to orange color (depending on cultivar)</td>
</tr>
</tbody>
</table>

SS=soluble solids
Quality Attributes of Fruits
- Vary depending on protagonist in PH chain
- Consumer-centric “quality” ultimately drives marketability
- Overall consumer acceptance strongly correlated with “Flavor acceptance”

Sensory Attributes of Foods
- Appearance
- Taste
- Odor/smell/aroma
- Irritation
- Texture/mouthfeel
- Temperature

Sensory Attributes of Foods
- First attributes perceived
- Shape, size
- Color (uniformity, intensity)
  - Strongly-set expectations
  - Emotional connotations
- Gloss (wax)

Sensory Attributes of Foods
- Aroma — perceived in nose
  - Volatile compounds released from various items (food, flowers...)

Sensory Attributes of Foods
- Taste is the sensation perceived in the mouth, more specifically on the tongue.
  - Sweet
  - Salty
  - Bitter
  - Sour (acid)
  - Umami (protein – savory)

Mean values for fruit-maturity variation in flesh composition of fresh fruits of 8 clingstone peach cultivars:

<table>
<thead>
<tr>
<th>Maturity stage</th>
<th>Total phenolics (mg Eq/g)</th>
<th>Total antioxidant (mg Eq/g)</th>
<th>Soluble solids (%)</th>
<th>Total sugars (%)</th>
<th>Treatable acidity (% TSS)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature</td>
<td>27.5a</td>
<td>8.3a</td>
<td>1.7a</td>
<td>10.9a</td>
<td>0.61a</td>
<td>17.3a</td>
</tr>
<tr>
<td>Optimum maturity</td>
<td>31.5b</td>
<td>11.7b</td>
<td>2.0b</td>
<td>10.3b</td>
<td>0.69b</td>
<td>21.4b</td>
</tr>
<tr>
<td>Optimum storage</td>
<td>22.2b</td>
<td>12.7b</td>
<td>2.2b</td>
<td>10.3b</td>
<td>0.96b</td>
<td>23.8b</td>
</tr>
</tbody>
</table>
The Aroma of a Strawberry

Over 200 volatile compounds!!

Guinard, 2005

Sensory Attributes of Foods

Chemical irritation ("pungency")

- Stimulated by chemical irritants
  - Ex: capsaicin, piperin, glucosinolates, etc...

Sensory Attributes of Foods

Texture and Mouthfeel

- Astringency (tannins, calcium oxalate)
- Sense of touch (mechanoreceptors)

Sensory Attributes of Foods

Chemical irritation ("pungency")

- Stimulated by chemical irritants
  - Ex: capsaicin, piperin, glucosinolates, etc...

Taste Perception and Produce Composition

<table>
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<tr>
<th>Quality</th>
<th>Class of compound</th>
<th>Examples</th>
</tr>
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<tbody>
<tr>
<td>Sweet</td>
<td>Sugars</td>
<td>Sucrose, fructose, glucose</td>
</tr>
<tr>
<td></td>
<td>Some proteins</td>
<td>Thaumatin, monellin</td>
</tr>
<tr>
<td>Sour</td>
<td>Acids</td>
<td>Citric acid, tartaric acid,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>malic acid</td>
</tr>
<tr>
<td>Bitter</td>
<td>Alkaloids, phenylpropanoids, terpenoids</td>
<td>Quinine, isocoumarins, limonin</td>
</tr>
<tr>
<td>Umami</td>
<td>Amino acids</td>
<td>Glutamate, aspartate</td>
</tr>
<tr>
<td>Salty</td>
<td>Ions</td>
<td>Sodium, calcium</td>
</tr>
</tbody>
</table>

Measurement of Total Soluble Solids by Refractometer

Soluble solids = sugars, organic acids, soluble pectins, anthocyanins, phenolic compounds, ascorbic acid...

Flavor vs. Sugar/Acid Ratio

<table>
<thead>
<tr>
<th>Acids</th>
<th>Sugars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Insipid, tasteless</td>
</tr>
<tr>
<td>Moderate to High</td>
<td>Sour, tart</td>
</tr>
<tr>
<td></td>
<td>Best flavor combination</td>
</tr>
</tbody>
</table>

Soluble solids measured by a refractometer = sugars, organic acids, soluble pectins, anthocyanins, phenolic compounds, ascorbic acid

Need quick methods of measuring total sugars and titratable acidity
Sensory Methodology

• Analytical tests
  ~ Difference? What is it? How strong is it?
  ~ Descriptive analysis
  ~ Trained judges

Sensory Methodology

• Consumer tests
  ~ Preference, liking, purchase intent
  ~ Attitudes, beliefs
  ~ Ethnography
  ~ Untrained consumers

Objective measurements and Quality prediction

Development on the plant

• Developmental program
• Physiological processes (metabolism)
• Changes in composition
• Genetic/environmental/cultivation factors
→ Harvesting at maximum potential

Postharvest Life (?)

• Altered physiological processes (metabolism)
• Changes in composition
• Genetic/environmental/handling factors
→ Attaining and retaining maximum quality

Sensors for Nondestructive Testing of Produce Quality

• Acoustic impulse transmission
• Aroma sensing technology ("electronic noses")
• Chlorophyll fluorescence
• Electrical and mechanical impedance
• Fruit bounce firmness measurement
• Near infrared (NIR) transmittance
• Nuclear magnetic resonance (NMR) imaging
• X-ray imaging

Volatiles as Sensory Markers for Quality

➤ Testing of rapid methods for volatile analysis for use in commercial setting to monitor flavor quality (pre- and post-harvest)
Volatile profiling in combination with sensory analysis (trained panel/consumer) to identify objective determinants of fruit flavor quality.

Nondestructive Quality Sensing Needs

- Degree of freshness (time since harvest)
- Prior exposure to ethylene
  \[\text{Concentration} \times \text{duration} \times \text{temperature}\]
- Prior exposure of chilling-sensitive commodities to chilling conditions (temperature x duration)
- Internal translucency
- Internal browning
- Mealiness (lack of juiciness)