FRUIT MATURITY AND QUALITY

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KEYWORDS
respiration, ethylene, ripening, color change, starch conversion, soluble solids, titratable acidity, softening, texture, aroma

ABSTRACT
Maturation is the process through which fruit develop marketable appearance and gain the capacity to ripen. Harvest ends the maturation process and maturity stage at harvest determines fruit quality after storage. Maturity has two important definitions. Physiological maturity is attained when fruit have the capacity to ripen after harvest. Horticultural maturity means fruit have developed marketable appearance and edibility. Fruit at physiological maturity typically have a long storage life but may not be horticulturally mature. This is commonly the case for red varieties where red color development lags behind the start of ripening. Physiologically immature fruit ripen poorly, do not develop typical flavor, and can be highly susceptible to shrivel, bitter pit, superficial scald, and external CO₂ injury during storage. Picking late in the maturation process when ripening has begun limits storage life due to softening, low acidity, and high susceptibility to chilling injury and internal CO₂ injury in susceptible varieties. Because maturation and ripening patterns vary among varieties, some varieties are best harvested before the fruit eats well while others should not be harvested until some typical flavor is detected.

Ripening of apples and European pears requires ethylene gas. Ethylene is produced naturally by fruit but can also be applied from an external source to accelerate ripening. Ethylene production increases as maturation progresses and ethylene analysis is a means to assess physiological maturation. Fruit ethylene production is not always easily interpreted in part because the pattern of ethylene production varies considerably with cultivar and ethylene production trends vary from year to year. Other common indicators used to assess maturity include starch loss, peel ground color, firmness, soluble solids, and titratable acidity. Together these maturity indices provide an indication at harvest of where fruit is on its developmental path as well as what quality can be expected after storage. While changes in these attributes occur during maturation in all varieties, the patterns of change vary considerably among varieties. For example, starch index at optimum maturity for Red Delicious is very low compared to Honeycrisp.
Once harvested, the starch remaining is converted to sugar, softening and texture changes occur, chlorophyll breaks down, yellow pigments accumulate, aroma increases, the peel may become greasy, and acidity decreases as acid is used to fuel respiration. Many of these aspects of ripening require ethylene to proceed including softening, chlorophyll degradation, greasiness, and production of volatile compounds responsible for ripe aroma. The rate of acid loss is also an ethylene response. These processes all occur simultaneously but may not progress at the same rate, particularly when ripening is slowed due to use of postharvest technology. The beginning of physiological disorder development also occurs soon after harvest although visual symptoms of some disorders may not develop until months later.

Figure 1. Ethylene production and respiration rate during maturation and ripening of apple fruit.
Fruit Maturity and Quality

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Topics

• Maturity definitions
• Ethylene
• Maturity and quality indicators
• Firmness
• Volatiles
• Greasiness
Apple Fruit Maturation

- Color change
- Starch, firmness loss
- Soluble solids, titratable acidity increase
- Aroma change
- Greasiness development
- Patterns characteristic for each variety, strain
Respiration

- Oxygen
- + malic acid
- Heat
- Chemical energy
- Carbon dioxide
- + Water
Physiological Change During Apple Fruit Maturation and Ripening

- Ethylene production
- Respiration rate

Maturation, ripening

Ethylene, CO₂ production

[Graph showing the increase in ethylene production and respiration rate during apple fruit maturation and ripening.]
Apple Fruit Maturity

- Physiological: will ripen after harvest
- Horticultural: appearance, marketability

‘Starking Delicious’  ‘Scarlet Spur II’
Apple Fruit Maturity

- Physiological: will ripen after harvest
- Horticultural: appearance, marketability

![Graph showing percentage of red color in apples over harvest time for Scarlet Spur II and Starking varieties.](image)
Apple Fruit Maturity

• Physiological: will ripen after harvest
• Horticultural: appearance, marketability
Apple Fruit Maturity

- Physiological: will ripen after harvest
- Horticultural: appearance, marketability

![Graph showing apple fruit maturity metrics over harvest periods. The graph compares % red color, firmness, and ethylene levels across different harvest times.](image-url)
Climacteric respiration and ethylene

Ethylene production

Respiration rate

‘Delicious’ firmness

Days at 68 °F

Fan et al., JASHS, 1999
STARCH PATTERN INDEX FOR APPLES

- This chart accounts for variations between apple varieties and is suitable for assessing all starch patterns after iodine solution soaking.
- Use a 20 mm sample for meaningful results.
- Score fruit based on unstained area, not intensity of staining.
- Refer to ENZAFRUIT Maturity Procedures Manual for further measurement procedures.

0  1  2  3  4  5  6
Apple Fruit Maturation: Ethylene, Firmness, Starch

Ethylene vs. Starch for 'Bisbee Delicious' apples over four years (1-4). The graph shows the relationship between ethylene ppm and starch over time, indicating the maturation process. The data points for each year are marked with different symbols and colors, with year 1 represented by black circles, year 2 by yellow triangles, year 3 by orange circles, and year 4 by green triangles.
Assessing apple fruit maturity

‘Bisbee Delicious’

Harvest date:
- Sep 7
- 13
- 20
- 27
- Oct 4
- 11
- 18
- 25
- 31

Starch levels:
- 1
- 2
- 3
- 4
- 5
- 6

Ethylene levels:
- 0.01
- 0.1
- 1
- 10
- 100

‘Fuji’

Harvest date:
- Aug 3
- 17
- 24
- 31
- Sep 7
- 14
- 21
- 28
- Oct 4
- 12

Starch levels:
- 1
- 2
- 3
- 4
- 5
- 6

Ethylene levels:
- 0.01
- 0.1
- 1
- 10
- 100
Starch Polymers in Apple and Pear Fruit

amylose

amylopectin

http://i.imgur.com/30Tam.jpg
Amylose staining with I$_2$-KI solution

Amylose

Amylose plus iodine


Starch Hydrolysis
Soluble Solids and Starch during ‘Gala’ Maturation

Graph showing the relationship between starch rating, soluble solids content (% SSC), and harvest days after full bloom. The graph illustrates an increase in starch rating and soluble solids content as days after full bloom increase.
Soluble Solids Content at Harvest and after Storage

Harvest Days after Full Bloom

Weeks in Storage
- 0 (at harvest)
- 6
- 12
- 18
- 24

Plotto et al., Fruit Var J, 1995
‘Honeycrisp’ Maturity: grouped by titratable acidity

<table>
<thead>
<tr>
<th>lots</th>
<th>TA %</th>
<th>starch (1-6)</th>
<th>SSC %</th>
<th>color (1-5)</th>
<th>ethylene ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A:1-5</td>
<td>0.522</td>
<td>5.1</td>
<td>13.7</td>
<td>3.5</td>
<td>5.7</td>
</tr>
<tr>
<td>B:6-10</td>
<td>0.451</td>
<td>5.5</td>
<td>13.1</td>
<td>3.5</td>
<td>2.9</td>
</tr>
<tr>
<td>C:11-15</td>
<td>0.400</td>
<td>5.6</td>
<td>12.7</td>
<td>3.2</td>
<td>7.5</td>
</tr>
</tbody>
</table>
‘Honeycrisp’ titratable acidity after storage

![Graph showing the titratable acidity of Honeycrisp apples over weeks in air at 37 °F for different storage conditions.

- **A**
- **B**
- **C**

The x-axis represents weeks in air at 37 °F, and the y-axis represents the percentage of titratable acidity. The graph shows a decrease in acidity over time for all conditions.

**USDA**
Firmness

- Penetrometers measure outer portion fruit
Firmness Change with Distance into Fruit

![Graph showing the relationship between force and distance into fruit](http://epa.oszk.hu/00000/00025/00003/gyumolcs.html)
Firmness

- Softening can be non-uniform within fruit
- Firmness ≠ Texture
Fruit Firmness/Texture

- outer 0.32”
- 0.32” to coreline
- Core boundary
- Crispness
- Visco-elasticity (creep)
- Quality Factor
Fruit Firmness/Texture

- M1=lbs
- M2=lbs
- Co=creep
- QF=quality factor

![Graph showing Fruit Firmness/Texture](image)

QF: 94.9
<table>
<thead>
<tr>
<th>D(in)</th>
<th>P(lb)</th>
<th>T(s)</th>
<th>C(in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13</td>
<td>0.3</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>0.38</td>
<td>0.8</td>
<td>0.50</td>
<td>1.0</td>
</tr>
<tr>
<td>0.63</td>
<td>1.3</td>
<td>0.75</td>
<td>1.5</td>
</tr>
<tr>
<td>0.88</td>
<td>1.8</td>
<td>1.00</td>
<td>2.0</td>
</tr>
<tr>
<td>1.13</td>
<td>2.3</td>
<td>1.13</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Harvest Sep 18</th>
<th>Harvest Oct 26</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QF</strong>: 94.9</td>
<td><strong>QF</strong>: 55.9</td>
</tr>
<tr>
<td><strong>M1</strong>: 15.5</td>
<td><strong>M1</strong>: 15.5</td>
</tr>
<tr>
<td><strong>M2</strong>: 25.2</td>
<td><strong>M2</strong>: 17.5</td>
</tr>
</tbody>
</table>
‘Golden Delicious’

Harvest Sep 13

Harvest Sep 26
5 weeks @ 70 °F

QF: 88.7
M1=15.8
M2=24.0

QF: -59.7
M1=15.8
M2=9.4
Gala: 2 months storage

air: 7 d @ 70 °F

CA: 7 d @ 70 °F

QF: 16.3
M1 = 14.4   M2 = 16.4

QF: 78.0
M1 = 14.4   M2 = 22.2
Apple Fruit Volatiles

• >300, aldehydes, alcohols, esters
• cultivar specific
• harvest maturity
• ethylene regulated
• storage environment
Apple Fruit Volatiles

- Unripe: aldehydes - green, grassy
- Ripe: esters - fruity, sweet
- Ester production regulated by ethylene
‘Delicious’ Volatile Production

August           September

nL kg⁻¹ h⁻¹

10

1

0.1

0.01

0.001

15 22 29 5 12 19 26 3 10

August          September

hexanal

2-methylbutyl acetate
'Delicious' Volatile Production

\[ \text{uL L}^{-1} \text{ h}^{-1} \]

August           September

- hexanal
- 2-methylbutyl acetate
- ethylene
Maturity, ester, and ethylene production

![Graph showing the production of Gala esters, Gala ethylene, Delicious esters, and Delicious ethylene](#)

- **Days after full bloom**: 80, 100, 120, 140, 160, 180
- **Units (μG or μL L⁻¹)**: 0.001, 0.01, 0.1, 1, 10, 100

- **Gala esters**
- **Gala ethylene**
- **Delicious esters**
- **Delicious ethylene**

(Maturity, ester, and ethylene production diagram.)
‘Golden Delicious’ volatile production

![Graph showing total aroma production over days after harvest for different harvests.](image)
Peel Greasiness

- Can be present on mature fruit (Gala, Honeycrisp)
- A sign of ripening
- Fruit resources used to produce
- Prompt management for storage
Summary

• Physiological and Horticultural Maturity
• Ethylene required for ripening
• Starch as a maturity index
• SSC, acidity, firmness as quality indicators
• Disorders incited close to harvest
• Volatiles/aroma maturity dependent
• Greasiness: A sign of ripening
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