Fruit Growth & Development
Fruit Development Stages

- **Cell division**
  Predominates after bloom
  Smaller fruited crops generally have a shorter period of cell division
  Extended some by blossom thinning

- **Pit hardening (stone fruit only)**
  Lignification of endocarp

- **Cell enlargement**
  Predominates later in fruit development (and after pit hardening in stone fruit)

- **Fruit maturation**
  Final weeks (days) of fruit development
Fruit Growth Curves

Apple
- Sigmoid curve

Pear

Peach
- Double sigmoid curve

I: Cell division
II: Pit hardening
III: Cell enlargement

Jackson, 1975
Stone Fruit

- Usually one carpel & seed
- Fruit derived from ovary
Pome Fruit

- Usually 5 carpels & 10 seeds
- Fruit derived from hypanthium
Cell Division Stage

• 2 million cells in flesh of apple at anthesis \(\rightarrow\) requires 21 doublings of cell number

• 40 million cells at harvest \(\rightarrow\) requires only 4.5 doublings

• Most post-anthesis cell divisions occur in first few weeks after bloom, but as long as 100 days
Cell Enlargement Stage

- Begins soon after pollination, continues through cell division stage, then at diminishing rate until harvest
Peach Fruit Growth

Tukey, 1933
Ovule

Integuments → protective
Nucellus → nutritive
Diurnal Apple Fruit Growth

Diurnal gains & losses in size

Faust, 1989
Pre-Bloom Factors & Fruit Size

- **Post-harvest defoliation**
  - Fruit size in following year

- **Spur size & position**
  - Larger spurs bear larger fruits
  - “King bloom” of apple produces largest fruit

- **Age of bearing wood**
  - Larger fruit on 2-year-old spurs than 1-year-old spurs

- **Pre-blossom temperature**
  - Low temperatures → smaller fruit (shorter growing season, greater fruit set & competition, or reduced pre-bloom cell division?)
Previous Crop & Cell Number

'Starking' Apple

![Bar Chart]

- **Heavy crop**
- **Light crop**

**Cell number (X1000)**

<table>
<thead>
<tr>
<th>Date</th>
<th>Cell number</th>
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<tbody>
<tr>
<td>April 16</td>
<td>0</td>
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<tr>
<td>July 2</td>
<td>50</td>
</tr>
<tr>
<td>Aug 20</td>
<td>70</td>
</tr>
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<td>Oct 13</td>
<td>1500</td>
</tr>
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</table>

Winter 1981

Bergh, 1985
Post-Bloom Factors & Fruit Size

• **Seeds**
  Fruit size dependent for first 7 weeks
  Aborted seeds alter fruit shape

• **Light & carbohydrates**
  Controls supply of CHOs → competition between fruit & shoot growth & between fruits
  Most important source of within tree variation in fruit growth

• **Temperature**

• **Water stress**

• **Fruit thinning**
Seed Number & Fruit Size

‘Delicious’ Apple

Williams, 1979
Light & Fruit Growth
‘Cox’s Orange Pippin’ Apple

Palmer et al, 1991
Leaf Number & Fruit Growth

Apple

Magness & Overley, 1929
Temperature & Fruit Growth

For 10-40 days after full bloom

Fruit growth rate (mm/day) vs. Maximum/minimum temperatures (°C)

Delicious
Golden Delicious
Fuji

Warington et al, 1999
Water Stress & Fruit Growth
Apple (England)

Drip irrigated

Non-irrigated

1976

Goode et al, 1978
Cultivar/Rootstock & Fruit Size

• **Cultivar**
  - Crab → triploid apples
  - Polygenic control → primarily cell division after pollination
  - Cell size primarily related to length of growing season

• **Rootstock**
  - Proportion of fruit growing in high light & competition between shoot & fruit growth
  - Other unidentified effects
Fruit Shape
Length:Diameter Ratios

Westwood, 1962
Fruit Shape

‘Delicious’ Apple

Stem & calyx ends change from convex to concave
Heat Units & Fruit Shape

‘Delicious’ Apple

Westwood, 1993
Fruit Shape

‘Delicious’ Apple

South Carolina

Michigan

Wenatchee, Washington
Gibberellins & Fruit Shape

‘Wealthy’ apple

Asian pear

GA app

GA app
Plant Bio-Regulators & Fruit Development

• **50% GA_{4+7} + 50% 6-benzyladenine (BA): Promalin™**
  Stimulates growth of apical portion of apple fruit → increased length/diameter ratio

• **5% GA_{4+7} + 95% BA: Accel™**
  Post-bloom thinner that sometimes increases fruit growth (size) of apple

• **Gibberellic acid (GA₃): Pro-Gibb™**
  Delays maturity & increases fruit size, soluble solids & firmness of cherry fruit
Gibberellins

GA₃ (Gibberellic acid)

GA₄

GA₇
Fruit Density

Reflection of density of cells & air spaces

Westwood, 1962
Fruit Density & Air Space

‘Delicious’ Apple

Westwood et al, 1967
Fruit Maturation

- Fruit growth rate slows
- Pigment synthesis & degradation → color development
- Waxy cuticle formation → retards dehydration
- Starch → sugar conversion
- Respiration declines ("preclimacteric")
- Flavor volatile synthesis & degradation
- Cell wall degradation → reduced firmness
- Pre-mature fruit abscission
Maturation Processes

Westwood, 1993
Pre-Mature Fruit Abscission
‘McIntosh’ Apple

Greene, 2003
Delaying Fruit Ripening

Aminovinylglycine (AVG, ReTain™)

- Naturally occurring amino acid
- Inhibits ethylene biosynthesis
- Registration as ag chemical not pursued until Alar was banned
- Delays maturity (color, firmness loss & starch degradation) for 5-14 days when applied 4 weeks before anticipated harvest
Fruit Skin

- Composed of cuticle (waxes), epidermis (pigments) & hypodermis (strength)
- Cuticular waxes are exuded from epidermal cells to decrease water loss & uptake
- Epidermal cell growth must be synchronized with fruit growth
- Wax & epidermal/hypodermal cell structure relates to susceptibility to russeting & cracking
- GA$_{4+7}$ (Pro-vide™) sprays applied from petal fall through cell division phase can reduce russeting by promoting epidermal cell elongation
Wax Patterns

Platelet wax pattern not susceptible to russet; amorphous wax pattern susceptible

‘Delicious’

‘Golden Delicious’
Epidermal/Hypodermal Structure

- Cuticle
- Epidermis
- Hypodermis
- Cortex (flesh)

‘Gala’ apple
Equator
Factors Affecting Skin Color

- **Cultivar**
- **Rate of maturation**
  Ethephon hastens maturation & color development
- **Light**
- **Temperature**
  Cool nights (2-5°C) followed by warm, sunny days promotes anthocyanin synthesis
- **Nutrition**
  Excess nitrogen and/or insufficient potassium reduces anthocyanin synthesis
‘Bing’ Cherry Color

Green (pit hardening)  Straw to turning

Red  Mahogany
Bagging ‘Fuji’

Until 3-4 weeks before harvest

1 day

3 weeks
Pigment Changes

‘Cox’s Orange Pippin’ Apple

Chlorophyll → green
Carotenoids → yellow/orange
Anthocyanins → red/purple

Knee, 1972
Light & Color

'Cox's Orange Pippin' Apple

Red color intensity (0=green, 8=dark red)

<table>
<thead>
<tr>
<th>Percent sunlight</th>
<th>Red color intensity</th>
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</thead>
<tbody>
<tr>
<td>100</td>
<td>47%*</td>
</tr>
<tr>
<td>37</td>
<td>33%</td>
</tr>
<tr>
<td>25</td>
<td>30%</td>
</tr>
<tr>
<td>11</td>
<td>17%</td>
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</table>

*Percent red skin

Jackson et al, 1977
Anthocyanins & Crop Load

‘Bing’ Cherry

Spayd et al, 1986
Ethephon & Color

Applied 7-10 days before anticipated harvest; risk of reducing storage life

'McIntosh' Apple

Greene et al, 1977
Fruit Firmness
‘Bing’ Cherry

Fruit firmness
(arbitrary units)

Weeks before harvest

Barrett & Gonzalez, 1994
Salt Deposits

High salt concentrations in over-tree irrigation water

Difficult to remove in packing line
Skin Russet of Apples

Formation of protective “periderm” layer, resulting from humid conditions just after fruit set

‘Fuji’

‘Golden Delicious’
Stem Bowl Splitting of Apples
Caused by premature ripening, structural weakness & high internal forces in stem bowl region

![Apples showing stem bowl splitting](image-url)
Cracking of Cherries
Caused by uptake of rainwater on fruit surface just before harvest
Sunscald (Sunburn) of Apples

Caused by intense sunlight when fruit skin is hot
Doubling of Cherry Fruit

Caused by high temperatures during flower bud initiation the previous summer
Bitter Pit of Apples
Calcium-deficiency related disorder

‘Golden Delicious’

‘Newtown’
Cork Spot of Pears

Similar disorder to bitter pit

‘d’Anjou’
Lenticel Breakdown of Apples

Probably related to poor wax coverage & oxidative damage

‘Fuji’
Stain of ‘Fuji’ Apples
Probably related to nutrient imbalance & sun exposure, causing oxidation
Superficial Scald of Apples
Post-harvest oxidative injury unrelated to stain ‘Granny Smith’
Watercore of Apples

Breakdown of cells around vascular bundles & core & accumulation of sorbitol; induced when over-mature fruit are exposed to cold

‘Red Delicious’

‘Granny Smith’
Split Pit (Endocarp) of Peaches

Large fruit on lightly cropped trees of early maturing cultivars are more susceptible
Severe Splitting over Sunscald
Japanese Apples