OPTIMIZING PRE-HARVEST FRUIT QUALITY

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KEYWORDS
training systems, rootstocks, crop load, harvest maturity, light, ripening, dry matter (DM), DA index (IAD).

ABSTRACT
"Fruit quality" can mean different things to different people. Expectations differ depending on the point in the supply chain. In general, fruit quality includes a wide group of external and internal traits like appearance, taste, texture, aroma, nutritional value and lack of defects. Initially, the consumer judges the product by its appearance and then, by its eating quality, although the latter may determine whether a customer will buy the product again.

Once fruit are harvested, they are removed from their final source of water, nutrients and carbohydrates and their future will depend on the available resources. Climacteric fruit, such as apples and pears, are usually harvested before they are ripe in order to better pack, store and ship, where they continue to ripening. The main goal of all the postharvest regimes is to slow or control ripening related processes. Likewise, it is imperative to focus orchard management practices throughout the season to assure the highest fruit quality. Understanding key pre-harvest factors that most significantly influence apple/pear quality becomes fundamental to improve returns and minimize losses. Factors can be grouped as environmental conditions and orchard cultural practices. We will discuss the impacts and potential and realized controls of both environmental conditions such as temperature, light, soil and orchard cultural practices such as training system, planting density, rootstock, crop load, irrigation, fertilization, and plant growth regulators, all of which have a role in storage longevity and final fruit quality.
Figure 4: Relationship between crop load (number of fruit per square centimeter of tree Trunk Cross Sectional Area) and Dry Matter percentage (%) in Honeycrisp apple at harvest 2014 (WA). R-squared value is referred to the logarithmic trend and average values labeled with the same letter are not statistically significant (for Tuckey’s test, p<0.05) (Serra et al., 2015 submitted paper).

Figure 2: Distribution of d’Anjou pears picked from two different positions of an open vase canopy (external and internal) in “IAD ripening classes” accordingly to DA meter classification at harvest 2014. External canopy fruit were more advanced in maturity in comparison to the internal ones.
Optimizing Pre-Harvest Fruit Quality

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Definition of quality:

- “Degree of excellence or superiority” (Kader et al., 1985)

- “Fitness for purpose” (Juran, 1989, Hewett, 2006)

- To meet the expectation of the consumer (Hewett, 2006)

- “Degree of fulfillment of a number of conditions that determine its acceptance by the consumer” (Akhtar, 2015)

- Quality to the specific use, such as "industrial quality", "nutritional quality", "export quality", "edible quality", etc. (Lopez, 2004).
Producer needs:
- Cultivar w/ high productivity
- Cultivar w/ resistance to pests
- Fruit with good appearance
- Few defects
- Easy to harvest and good shipping quality

Consumer needs:
- Fruit with good appearance
- Firmer fruit
- Good flavor
- Nutritional value
- Good eating experience to buy again

(Barman et al., 2015)
• EXTERNAL QUALITY (appearance)

COLOR  SHAPE  SIZE  ABSENCE OF DEFECTS
• **INTERNAL QUALITY** (eating quality)

- TEXTURE
- SWEETNESS
- ACIDITY
- AROMA
- SHELFLIFE
- FLAVOR
- NUTRITIONAL VALUE

![Graph and images related to apple quality and shelf life](image-url)
Fruit quality is influenced by: 

- Sensory properties: appearance, texture, aroma, taste
- Nutritive values
- Mechanical properties
- Safety and defects

Influenced by:

- Environment
- Orchard management
- Picking time/maturity
- Post-harvest storage practices
Pre-harvest factors affecting fruit quality

Environmental factors
- Temperature
- Light
- Soil

Cultural practices
- Training system/planting density
- Rootstock
- Irrigation
- Nutrition
- Pruning
- Crop load/thinning
- Climate-ameliorating techniques
- Girdling
- PGR

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Environmental factors: TEMPERATURE

- Fruit maturity depends on pre-harvest temperature (4-6 weeks) (Palmer et al., 2003)

- Exposed fruit ripen faster than shaded ones (Kliwer and Lider, 1970)

- Peel color development is promoted by low temperatures (Koshita, 2014)

- Firmness higher at lower temp (Sams, 1999)

- High temp + light intensity faint color (Barman et al., 2015)

- Sunburn major cause of fruit losses (Racsko and Schrader, 2012)

- Watercore is associated with temp, dysfunction of carbohydrates physiology (Ferguson, 1999).

- Frost can cause russeting (calyx ring) (Fellman, 1996).
Environmental factors: LIGHT

- Most important signal tree is sensitive to
- Different in color and phenolic contents between exposed and shaded side (Jakopic et al., 2009)

**Low light:** limiting factor for fruit coloration (inner/lower canopy)

- reflective mulches improve anthocyanin synthesis (red color skin)
- best result on red color with material with great % of UV and IR reflectivity (Ju et al., 1995).

**Excess of light:** bleaching of chlorophyll, pigment degradation, up to cellular death and collapse (sunburn)

- Moderate/Severe sunscald showed higher IEC early in the season. Shape and firmness altered by sun exposure (Torres et al., 2013).
Environmental factors: LIGHT

Same maturity???

Same quality???

Same storability???
Considerable variability in fruit maturity exists within the large canopy of an open vase tree [Zhang et al., submitted]
Environmental factors: LIGHT

DA meter measures a new parameter

Index of Absorbance Difference

\( I_{AD} = A_{670\text{nm}} - A_{720\text{nm}} \)
Environmental factors: LIGHT

Anjou, open vase, 2 canopy positions:
fruit distribution in $I_{AD}$ classes (harvest, Sept 2014)

$I_{AD}$ distributions for internal and external
canopy fruit were different at harvest.
**Environmental factors: LIGHT**

<table>
<thead>
<tr>
<th>Canopy position</th>
<th>Weight (g) T0</th>
<th>I\textsubscript{DA} index T0</th>
<th>Hue</th>
<th>Chroma</th>
<th>Diameter (in)</th>
<th>Firmness (lb)</th>
<th>SSC (Brix)</th>
<th>pH</th>
<th>TA (% malic acid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>241 a</td>
<td>1.73 b</td>
<td>112 b</td>
<td>41.5</td>
<td>2.70 a</td>
<td>13.8</td>
<td>13.89 a</td>
<td>3.95 b</td>
<td>0.38 a</td>
</tr>
<tr>
<td>Internal</td>
<td>213 b</td>
<td>1.89 a</td>
<td>115 a</td>
<td>40.5</td>
<td>2.60 b</td>
<td>13.65</td>
<td>12.07 b</td>
<td>4.04 a</td>
<td>0.36 b</td>
</tr>
</tbody>
</table>

**significance**

|                      | ***          | ***          | ***          | ns          | ***          | ns          | ***          | **          | *          |

*p*<0.05, *; p*<0.01, **; p*<0.001, ***; ns, not significant

Arithmetic means are presented; post hoc tests were done with LSMEANS option and the Bonferroni post hoc means comparisons.

**Well-lit fruit:**

- Higher DM, SSC and darker red peel (apple)
- Higher occurrence of bitter pit, internal breakdown and rotting after storage

**Shaded fruit:**

↑ transpiration + shriveling in storage +cracks, disorganization of epidermal waxes in the shade side (Corelli-Grappadelli, 2003).
Cultural practices: climate ameliorating techniques

- Evaporative cooling
- White coating products
- Photo-protective (colored) nets to reduce the incidence of environmental stresses (less sunburn).

Fig. 1. Fruit size distribution of 'Golden Delicious' apple during three successive years. Comparison between the Pearl net, Black net (both of 30% shading) and un-netted control.

(Shahak et al., 2008)
Skin blushed area (%) was not affected by netting.

Netting decreased incidence of sunburn (-12%), bitter pit (-26 %) and fruit fly.

Netting did not affect fruit density, russet severity

(Amarante et al., 2011)
Cultural practices: fertilization

Best result when “nutrients are available in a balanced and timely manner” (Barman et al., 2015)

Understanding nutritional needs...

Alterations in mineral absorption leads to DEFICIENCY or EXCESS physiological disorders + poor fruit quality

- Climatic condition
- Tree age
- Fertilizing system
- Moisture profile of the root zone
- Type of soil
- Macro and micro nutrients

Mineral absorption and assimilation depend on:
Mineral content greatly affects fruit quality

<table>
<thead>
<tr>
<th>Element</th>
<th>Effect on quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess N</td>
<td>Larger, softer, poorer colored fruit, subject to drop, higher ethylene production, prone to develop cork spot, bitter pit, internal breakdown and browning, scald and more susceptible to pathogens</td>
</tr>
<tr>
<td>Low Ca</td>
<td>bitter pit, cork spot...earlier softening, short post-harvest life</td>
</tr>
<tr>
<td>High K</td>
<td>prone to develop cork spot, bitter pit, senescent breakdown and more susceptible to pathogens. Ca antagonist $\rightarrow$ Ca deficiency</td>
</tr>
<tr>
<td>High Mg</td>
<td>Ca antagonist $\rightarrow$ Ca deficiency</td>
</tr>
<tr>
<td>Low P</td>
<td>Susceptibility to low temp and senescent breakdown / uncommon</td>
</tr>
<tr>
<td>High B (micro)</td>
<td>Earlier ripe and can cause pre-harvest drop</td>
</tr>
<tr>
<td>Low B (micro)</td>
<td>Low SSC and acids (Shear and Faust, 1980)</td>
</tr>
</tbody>
</table>

Increasing N fertilization:
• in Anjou ↓ flavor rating, lower N trt had smaller fruit size
• In McIntosh apple increases volatile production
  (Mattheis and Fellman, 1999).
Cultural practices: irrigation

- Key role for fruit development and quality, insufficient moisture reduce mineral absorption -> fruit size ↓ (Bramlage, 1993).
- Water management affects photosynthesis and then quality.

**Water stress**

- Extreme = ↓ yield, ↓ fruit size and ↓ quality
- Mild = ↓ (?) yield + ↑ (?) quality (time dependent)
  - In pre-harvest higher soluble solid content (Crisosto et al., 1994)
  - ‘Braeburn’, -40% late season deficit = fruit quality improved in firmness, SSC and DM (Mpelasoka et al., 2001)
  - ‘Bartlett’: ↑ SSC, ↑ firmness, ↑ yellow color, ↓ fruit size, ↓ vegetative growth; no defects in post-harvest (Crisosto et al., 2002).

**Absent** = ↑ yield + may ↓ postharvest quality

**Water excess**

Increase vegetation -> shaded fruit -> quality ↓ (Lakso, 2003).
Cultural practices: training system

High level of light interception + homogeneous distribution in the canopy lead to a higher productivity and a more consistent product.

How to achieve it (Corelli-Grappadelli, 2003):

- N/S orientation (more uniform illumination)
- Training system with high area/volume ratio (optimal leaf density)
- Narrower canopies (and dwarfing rootstocks), to optimize light interception and photosynthesis → more sugars, more DM.
- Maintaining the shape by pruning.
- > 90% light interception, just 50% quality fruit (Wertheim et al., 2001).

(Source: Baldini, 2001)
Cultural practices: training system

Modi®: Yield (kg/tree) per training systems per bearing wood

<table>
<thead>
<tr>
<th></th>
<th>Bi-axis</th>
<th>Spindle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm</td>
<td>2° year</td>
<td></td>
</tr>
<tr>
<td>Kg/tree</td>
<td>3,030 trees/ha</td>
<td>3,788 trees/ha</td>
</tr>
<tr>
<td></td>
<td>1,226 trees/A</td>
<td>1,534 trees/A</td>
</tr>
</tbody>
</table>

### Spur on branches (2-3-4)
- Bi-axis: 0.29 b
- Spindle: 4.47

### Shoot
- Bi-axis: 2.41 b
- Spindle: 1.42

### Brindilla
- Bi-axis: 0.41 b
- Spindle: 1.56

### Spur on axis
- Bi-axis: 7.36 a
- Spindle: 4.47

### Farm M
- Bi-axis: 70.3%***
- Shoot: 2.8%
- Brindilla: 3.9%
- Spur on branches (2-3-4): 0.29%
- Spur on axis: 70.3%
- Bi-axis: 1.42
- Shoot: 1.56
- Brindilla: 3.15
- Spur on branches (2-3-4): 1.56
- Spur on axis: 4.47

*** ns (Musacchi et al., 2014)
Cultural practices: training system

**Modì®: Comparison between training system**

<table>
<thead>
<tr>
<th>Training system</th>
<th>Avr. fruit weight (g)</th>
<th>% red overcolor</th>
<th>Chroma</th>
<th>Hue</th>
<th>Firmness (lb/cm²)</th>
<th>Soluble solid content (°Brix)</th>
<th>Titratable acidity (g/L malic acid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bi-axis</td>
<td>245</td>
<td>a</td>
<td>79</td>
<td>b</td>
<td>30.6</td>
<td>12.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Spindle</td>
<td>226</td>
<td>b</td>
<td>90</td>
<td>a</td>
<td>27.8</td>
<td>10.8</td>
<td>15.2</td>
</tr>
<tr>
<td>Significance</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

**Modì®: Habit investigation**

> SSC, > \( I_{AD} \)

- Spur on axis
  - Spur on 2-years-old and over braches
  - Spur on 1-year-old shoot
  - Brindilla

(Musacchi et al., 2014)
Cultural practices: rootstock

Rootstock can influence fruit in (apple):
• Mineral composition,
• On-tree disease resistance
• Time of ripening
• Composition of phenols and antioxidant capacity
• Post harvest disorders development

Dwarfing rootstock can affect fruit maturity:
- earlier ethylene production,
- higher SSC
- earlier starch degradation than vigorous rootstocks

(Ferree, 1998)
Cultural practices: rootstock

Yield (metric Ton/A) and average fruit weight (g): comparison between rootstocks for Abbé Fétel

Values characterized by same letters are not significantly different at p≤0.05 (SNK test)

(Musacchi et al., 2011)
Cultural practices: rootstock

**Fruit size classification**

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>&lt;70 (Ø mm)</th>
<th>&gt;70 (Ø mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAMS</td>
<td>40.3</td>
<td>59.7</td>
</tr>
<tr>
<td>BH-MC</td>
<td>48.3</td>
<td>51.6</td>
</tr>
<tr>
<td>MC</td>
<td>44.4</td>
<td>55.6</td>
</tr>
<tr>
<td>MH®</td>
<td>20.3</td>
<td>79.2</td>
</tr>
<tr>
<td>SYDO®</td>
<td>26.4</td>
<td>73.6</td>
</tr>
<tr>
<td>BA29</td>
<td>20.1</td>
<td>79.9</td>
</tr>
</tbody>
</table>

- 4° year

**Fruit quality analyses**

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Firmness (lb/cm²)</th>
<th>Solute solids (°Brix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAMS</td>
<td>9.5</td>
<td>b</td>
</tr>
<tr>
<td>BA29</td>
<td>8.6</td>
<td>c</td>
</tr>
<tr>
<td>BH-MC</td>
<td>10.8</td>
<td>a</td>
</tr>
<tr>
<td>MC</td>
<td>9.7</td>
<td>b</td>
</tr>
<tr>
<td>MH®</td>
<td>9.7</td>
<td>b</td>
</tr>
<tr>
<td>SYDO®</td>
<td>9.3</td>
<td>b</td>
</tr>
<tr>
<td>Significance</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

(Musacchi et al., 2011)

Abbé Fétel on Sydo® at Bi-axis (3.5 x 1m, 2,857 trees/ha)
Cultural practices: rootstock

Anjou (central leader, yr planting 1998): comparison between
fruit distribution for 3 different rootstocks at
pre-harvest (27 August) and at harvest (2 Sept 2014).

PRE-HARVEST

Δt= 7 days

HARVEST
### Cultural practices: crop load

#### HC crop load trial: yield 2014 (harvest August 28, 2014)

<table>
<thead>
<tr>
<th>Target number of fruit/tree</th>
<th>Number of fruit (actual)</th>
<th>kg fruit/tree</th>
<th>lb fruit/tree</th>
<th>fruit weight (g)</th>
<th>number efficiency (number of fruit/TCSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-40</td>
<td>34.3 d</td>
<td>6.6 c</td>
<td>14.6 c</td>
<td>196.3 a</td>
<td>4.7 c</td>
</tr>
<tr>
<td>50-65</td>
<td>55.7 c</td>
<td>8.5 c</td>
<td>18.7 c</td>
<td>151.8 ab</td>
<td>7.5 c</td>
</tr>
<tr>
<td>75-85</td>
<td>83.7 b</td>
<td>12.0 b</td>
<td>26.5 b</td>
<td>143.7 b</td>
<td>11.3 b</td>
</tr>
<tr>
<td>90-100</td>
<td>95.0 b</td>
<td>14.0 b</td>
<td>30.9 b</td>
<td>147.7 ab</td>
<td>12.5 b</td>
</tr>
<tr>
<td>125-135</td>
<td>130.0 a</td>
<td>17.0 a</td>
<td>37.5 a</td>
<td>130.8 b</td>
<td>16.0 a</td>
</tr>
</tbody>
</table>

Significance

| *** | *** | *** | * | *** |

#### Fruit size distribution at harvest 2014

[Serra et al., submitted]
Lower $I_{AD}$ values were more frequent in the lowest crop load indicating advanced fruit ripeness. 

[Serra et al., submitted]
<table>
<thead>
<tr>
<th>Crop load</th>
<th>Blushed color (%), firmness, titratable acidity, soluble solids content were all higher in the lowest crop loads.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7 fruit/cm²</td>
<td></td>
</tr>
<tr>
<td>7.5 fruit/cm²</td>
<td></td>
</tr>
<tr>
<td>11.3 fruit/cm²</td>
<td></td>
</tr>
<tr>
<td>12.5 fruit/cm²</td>
<td></td>
</tr>
<tr>
<td>16.0 fruit/cm²</td>
<td></td>
</tr>
</tbody>
</table>
Higher the fruit Dry Matter (DM), greater the consumer acceptability (Palmer et al., 2010).
DM suggested as a fruit final quality predictor.

[Serra et al., submitted]
Conclusions:

- **Quality** is a subjective concept. From the grower to the consumer, needs and perceptions are different.

- Not all the varieties perform well in all environments; a *variety* is suitable for a site when both internal and external quality are achieved.

- **Environmental factors** affecting fruit quality can be mitigated by some protection techniques.

- **Cultural practices** must be planned in advance starting with orchard design and maintained by careful management.

- Any practice inducing *vegetative growth* is likely to negatively affect fruit quality. Low Ca in fruit leads to post-harvest disorders.

- Increasing density over certain limits is not always beneficial.

- Find a **compromise** between yield and fruit size and external/internal quality......
Acknowledgment: Stefano Musacchi, Rachel Leisso, Jingjin Zhang, Lee Kalcsits, Luca Giordani

THANKS FOR YOUR ATTENTION!