Precision Harvest Management

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Each season, apple fruit growth and development is affected by the climate that year, the crop load on the tree, and the nutrient content of the fruit. In areas with variable summer climates such as New York State, this results in variable fruit quality from year to year. Various fruit quality characteristics measured at or just before harvest may be useful for predicting the quality of apple fruits post-storage.

With favorable weather and the use of precision orchard management, we can produce a high quality apple. However, fruit must be picked at the optimum maturity for that quality to be realized and for growers to capture high returns for their fruit. For 50 years, we have used fruit maturity measurements to guide decisions on when to pick (color, background color, firmness, soluble solids, starch degradation pattern and internal ethylene). The regional fruit maturity programs run by extension educators have helped guide growers on when to pick. Fruit samples are collected from various orchards and analyzed for firmness, soluble solids, starch pattern and ethylene once per week. Buyers, consultants and fieldmen work with growers to decide when to pick each block and each variety. These harvest maturity evaluations have been invaluable in helping fruit growers know when to pick each variety.

Assessing Quality of the Fruit at Harvest

It is important to distinguish between fruit quality measurements and fruit maturity measurements. Measurements such as sugar content, firmness, dry matter concentration, and fruit mineral concentration are all fruit quality measurements, while ethylene evolution, change in color and background color, and starch degradation pattern are fruit maturity measurements. Using fruit maturity measurements helps us pick the fruit at the correct maturity to ensure good postharvest performance, but the internal quality (what is in the package) is also important to assess at or just prior to harvest to guide decisions on what to do with the fruit. The internal quality of the fruit varies from year to year and from orchard to orchard, but we do not assess it and use the information to make better decisions about what should be done with the fruit (sell immediately, short term storage or long term storage). Some of the variability in fruit quality at harvest can be explained by light distribution within the tree canopy. One of the reasons for the move towards intensive production on dwarfing rootstocks was to improve fruit quality by removing the shaded region in the lower, central parts of large trees. However, even on a well-grown Tall Spindle tree, fruit internal quality can still vary considerably. More recent studies by John Palmer in New Zealand have shown that fruit dry matter concentration is a measure of fruit quality that integrates many of the events that occurred during the growing season into one measure of quality.

Fruit Dry Matter Concentration

Palmer et al. (2010) has recently shown that apple fruit dry matter concentration (DMC) can not only predict soluble solids concentration after storage, but also, and more importantly, consumer acceptance. In their research, fruit DMC was a more reliable predictor of total soluble solids (TSS) after 12 weeks of air storage at 0.5°C than TSS at harvest for both Royal Gala and Scifresh. Fruit DMC was also positively correlated with flesh firmness, although this relationship was not as strong as that seen with soluble solids, and was more dependent on cultivar. Consumer studies showed that consumer preference was positively correlated with fruit DMC of Royal Gala apples.

Fruit DMC at harvest can therefore be used to predict the sensory potential for the fruit after many months of storage. In contrast, measurements such as firmness and titratable acidity are more dynamic and can change during maturation. The dynamic nature of these latter indices makes it difficult to predict storage responses from their measurement at harvest. However, this does not mean that the traditional harvest indices are useless, as they are indicators of harvest maturity; instead, DMC can be viewed as a supplementary quality index. Fruit DMC can be used to compare and contrast the future eating quality for different orchard blocks at harvest, while firmness and other quality indices can be used to monitor the progression of the fruit during the harvest window to pick at the optimum time so that the sensory potential is realized after storage. For example, a high DMC fruit will only achieve its high sensory potential if it is harvested at the correct stage of maturity and then stored in a manner in which firmness and acidity are optimally conserved. It is very unlikely that a high DMC will compensate for poor firmness from late picking.

Over the harvest period, fruit dry matter concentration changes little, while other fruit characteristics such as soluble...
solids concentration, flesh firmness, starch content, skin red color, and background color can change quite rapidly. This allows DMC to be determined (one week) before harvest to be used to make decisions on the destiny of the fruit. Also, this measure of fruit quality is easy to determine. It is done by cutting 2 longitudinal slices from opposite sides of the fruit on each of a 10-fruit sample, and then determining the fresh weight of the wedges before drying and the dry weight of the wedges after drying in a forced air oven for several hours at 65°C (Figure 1).

Dry matter concentration can be influenced by cultivar, rootstock, season, crop load, water stress, and position within the tree, and can vary from 8 to 19%. One of the most important factors affecting fruit DMC is crop load, which is negatively correlated to fruit DMC (high crop load=low fruit dry matter content). With very high crop loads, the carbohydrates from the tree must be divided among many more fruits, thus each fruit receives less dry matter. This is especially important with Honeycrisp, which, when overcropped, does not develop good color or flavor due to low DMC.

A second important factor that influences DMC is light level and temperature during the season. Shading studies with Cox’s Orange Pippin showed that a shade of 66% post-bloom reduced fruit DMC at harvest from 19.4% to 17.1%. Cloudy summers have a negative effect on fruit DMC and will result in lower fruit soluble solids and quality after storage. This may also help explain differences in fruit quality from year to year and from sunny production regions to humid and cloudy production regions. A third important factor that influences DMC is water supply. Reduced water supply due to drought can increase DMC because it is a ratio of dry matter to water content.

We envision the use of fruit DMC as a way to segregate fruit below a certain quality standard. The measurement of fruit DMC will be most useful in comparing fruit from different blocks of the same cultivar. With such comparisons, blocks with high dry matter fruit of any cultivar will prove to be more acceptable to the customer than fruit from blocks with low dry matter.

**Fruit Mineral Concentration**

Another measure of the internal quality of an apple at harvest is fruit mineral concentration. Work done in the 1980s showed that some fruit disorders such as bitter pit could be predicted from concentration of fruit minerals such as calcium. Later studies have shown the ratios of various elements in the fruit can be useful indicators of storability, post-storage fruit quality, or susceptibility to disorders.

In our studies with Honeycrisp (Robinson and Lopez 2009), crop load had a dominant effect on fruit quality, but fruit mineral nutrition also had a significant effect. High nitrogen soil fertilization increased fruit size but reduced fruit color, storage quality, and crop value, while vegetative shoot growth was increased. In contrast, potassium fertilization improved yield, fruit size, storage quality, and crop value, while reducing the incidence of storage disorders and storage rots. Thus, we recommend a moderate level of nitrogen fertilization (20–50 lbs N/acre) and a relatively high level of potassium fertilization (80–100 lbs K₂O/acre). Although nitrogen helps push growth, it results in poorer color, more rots, and storage disorders. High potassium results in increased yield, fruit color, fewer storage disorders and rots, and greater crop value.

Total water supply (irrigation amount plus rainfall amount) was related to the incidence of bitter pit and fruit rot incidence. The early season (mid-May to mid-June) was related to increased incidence of bitter pit and fruit rot incidence. This was likely due to poor Ca uptake in the early season of years with dry May and June weather. Thus, in dry years, irrigation should be applied during the early season to ensure adequate Ca is absorbed by the plant and provided to the young fruitlets.

In our studies, there was no relationship between fruit Ca concentration and fruit firmness, incidence of disorders or storage rots. This is in contrast with other work on Honeycrisp and other cultivars. We also could not show a benefit of Ca sprays on fruit Ca levels or bitter pit incidence. Other foliar nutrient sprays (N, Mg, Zn, B) had little effect on yield, fruit quality, crop value, storage disorders, or storage rots. However, we did find a consistent relationship between fruit P concentration and incidence of disorders (primarily bitter pit). We also found a consistent relationship between fruit P:S ratio and fruit red color.

Perhaps fruit mineral analysis will prove beneficial in determining fruit storability. We suggest examining fruit P, S, Ca and P:S ratio, which is correlated with bitter pit and storage rot incidence. A system of sampling fruit from each block and each variety one week before harvest and getting fast laboratory service to measure both fruit DMC and fruit mineral concentrations would allow both fruit DMC and fruit mineral levels and ratios of minerals to be used to segregate fruit at harvest, so that poor quality fruit is not put in the fresh market or stored for long periods with poor results and storage disorders.

**Determining When to Pick the Fruit**

**Block-Specific Maturity Tests.** The regional fruit maturity programs conducted by extension educators give variety-specific maturity data for a region, but they do not provide block-specific information growers can use to determine when to harvest each variety in each block. Some farms already do extensive block-by-block maturity testing and use the information to determine when to pick each block. Others rely on the regional information from extension programs. An increase in block-specific maturity testing by growers (or their consultants) could significantly improve fruit quality after storage. This information can then guide how long the fruit should be stored.
The DA Meter. An alternative method of evaluating fruit maturity is to use differential absorbance (DA) of near-infrared radiation applied to the surface of the fruit to measure chlorophyll levels in the fruit, developed by Dr. Costa of the University of Bologna. He developed a hand-held device called the DA meter, which is an instrument that allows the measurement of chlorophyll content in the fruit skin as a precise index of a fruit’s ripening state (Figure 2). The DA meter allows a quick measurement of ripeness by growers or their consultants during the harvest period, to identify the best time for the picking, and for selecting representative fruits to show the pickers to guide them in the fruit selection process when doing multiple picks.

The DA meter gives values from 0–1, called a DA index. The values obtained from the DA meter are not dependent on the season like other parameters such as soluble solids concentration. Sugar content is dependent on climatic conditions during the year. Poor light levels during the summer prevent fruit from reaching a high sugar level, even at complete ripeness. As a consequence, the soluble solids index can indicate if the fruit tastes good, while the DA index indicates when the fruit, either good or bad tasting, has actually reached the optimal ripeness level. In favorable years, the exclusive use of soluble solids to decide when to pick the fruit would anticipate the harvesting too much, resulting in picking sweet fruits but not as sweet as they could be if picked at the optimal point of ripeness. In a bad season, the opposite would occur; i.e., delaying harvest until sugar content improved, but with over-maturity and negative consequences for storability, and in many cases without ever reaching a satisfactory sugar level. The DA index allows fruit to be picked at the optimal ripeness level – that is, when the fruit has reached the best sugar level possible given the climate that year, but before losing storability. The DA index varies through the whole season, which allows DA index measurements to begin weeks before harvest, and then charting changes in the index to provide a reliable indicator of fruit ripeness long before the moment of picking.

The measurement of chlorophyll content with the DA meter is not affected by fruit red color (different wavelengths). Thus, with highly colored cultivars or strains that get red before they are ripe, the DA meter provides a reliable indicator of the ripeness stage of the fruit itself. The measurement is non-destructive and allows measurements of fruit directly on the tree. To fully implement this machine in the northeast, more testing by researchers and growers will be required. However, it offers the potential to increase the precision of block-specific harvest maturity decisions.

Getting the Fruit Picked on Time

Even if growers can more precisely pinpoint when to pick each variety in each block, having the labor to do the picking on time is a significant challenge for many growers. Managing labor during the picking season to always harvest each plot and each variety on time should be a very high priority for growers. Sometimes weather delays harvest or labor shortages affect the timeliness of harvest. However, precision orchard management requires better labor management so the job always gets done on time. In the case of harvest maturity, this can make the difference between successfully capturing a high fruit price after a full season of precision orchard management, or in losing the high fruit price at the last moment after investing significant effort to produce a high quality product.

Efforts and Summary

Precision harvest management includes assessing the quality of the fruit by measuring fruit dry matter content and fruit mineral concentration, then identifying the optimum fruit maturity for each variety and each block by using traditional fruit maturity indices or the new DA meter, and then having the labor resources to harvest the fruit at the optimum moment. This is not an easy task, but will help growers capture the high crop values they have generated from a season-long effort of precision orchard management, to not leave “money on the table”.

Our previous research indicates that crop load is an important variable in determining Honeycrisp apple fruit quality, both at harvest and after storage. When crop load is too high, the tree cannot supply sufficient carbon and other nutrients to give optimum fruit quality (taste, appearance, and storability). Similarly, if weather conditions are cloudy, tree carbon supply for fruit growth is limited, resulting in less than adequate resources for optimum fruit growth and quality.

Our current research is attempting to identify measurable fruit characteristics at harvest that integrate the effect of crop load and climate that could be used to predict fruit quality after storage. Based on the work of Dr. John Palmer in New Zealand in 2013, we have begun a study to determine if Honeycrisp orchards can be evaluated at harvest for storage potential using fruit dry matter content, fruit mineral content and the DA meter.

We have sampled 90–120 Honeycrisp orchards from the main apple-growing region in New York State. Fruits were sampled weekly until the end of harvest. Fruits sampled right before harvest were evaluated for dry matter content and fruit mineral content of macro- and micronutrients. Apples from each orchard were harvested, and fruit red color, flesh firmness, starch index, sugar content, and DA meter readings were evaluated. Half of the fruits from each sample were treated with MCP, or left untreated and then stored until early February at 0°C in air and evaluated for fruit quality – flesh firmness and sugar content, external and internal apple disorders, and appearance and taste by an untrained panel (Figures 3 and 4). An assessment of potential fruit storability for each block has been made based on fruit dry matter content and fruit N, Ca and N/Ca ratio. The results after storage will be correlated to preharvest measures to determine if we could predict fruit quality and storability at harvest to assist farmers in segregating fruit for long- and short-term storage.
From this study, we want to develop guidelines for precision harvest management of Honeycrisp apples.

**Expectations**
1. One week before harvest, take a fruit sample from each block and assess fruit quality by measuring fruit dry matter concentration and fruit mineral concentration.
2. Use the results of fruit quality assessment to segregate fruit for long-term or short-term storage, immediate sales, or juice.
3. Identify the optimum fruit maturity for harvest of each block with the DA meter and firmness and starch ratings.
4. Manage labor resources to pick the fruit at the optimum maturity.

**Figure 3.** Some of the physiological storage disorders evaluated in this project (from left to right – soft scald, soggy breakdown and bitter pit.

**Figure 4.** Sensory panel members evaluate Honeycrisp apples sampled weekly from several orchards throughout the NY State.

**Literature Cited**
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