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Whether selling at a farmers' market, to a wholesaler, for processing, or considering regular or controlled atmosphere storage, harvesting apples at the optimal maturity for the target market is vital to ensure a high-quality product. Fruit harvested too early may have poor flavor and color and will be prone to postharvest disorders (e.g., storage scald and bitter pit). However, waiting too long to harvest can result in soft,

overripe fruit with limited storage life.



Determining the optimal apple harvest date

There are several maturity indices that can be used to establish a time frame for harvesting apples. Identifying when and where the fruit will be marketed is a starting point for selecting the most relevant indicators. For example, color and flavor are more relevant for apples that will be marketed at a farmers' market or farm stand. However, for apples that will be stored for an extended time, either in regular or controlled atmosphere storage, starch conversion and fruit firmness are typically better indicators of optimal harvest date.

This publication details how to collect a representative sample of fruit and provides an overview of some of the most common apple maturity indices used in commercial apple production.

Collecting representative samples

Regardless of which index is used to measure maturity, the most important step is to collect a representative and accurate sample of fruit from the orchard block. Use the following strategies to collect a representative sample:

- Sample each cultivar and each block separately. Maturity can vary within the same orchard block and even within the same tree.
- Select 5 to 8 trees per block per cultivar and rootstock. These trees should be representative of the rest

of the trees in the block in terms of crop load and vigor. Mark the trees so that you can collect samples from the same trees weekly. Avoid sampling from trees located at the edge of any block.

- Sample 2 to 4 fruit per tree. Because apples on the tree's periphery tend to ripen earlier, collect samples from outer branches rather than from the inside of the canopy.
- Samples should be collected in a consistent way throughout the ripening period, considering the side of the trees (both east and west) and height in the canopy where fruits are being collected.
- Avoid fruit with visible disease or insect damage.
- Begin sampling 4 to 5 weeks before normal harvest is anticipated. Days after full bloom (DAFB) is a good indicator of when fruit might mature. For example, researchers in Michigan determined an average of 143 DAFB for first harvest of 'Red Delicious'.
- Sampling can initially take place once per week. As apples near maturity, sample several times per week if time allows.
- Try to consistently sample at the same time of day, as sugar levels can change throughout the day.
- Process samples as quickly as possible after harvesting, ideally within 2 hours of picking.

Apple maturity indices

Fruit firmness

As an apple matures, the flesh softens. This can be measured with a penetrometer, which determines the amount of pressure required to puncture of the flesh of the fruit. Many factors affect firmness readings; for example, apples that have watercore will give higher firmness readings, and bigger apples will be softer than smaller ones. Make sure to test apples that have similar sizes and are representative of the block you are sampling.

To measure apple firmness, use a penetrometer with a plunger tip that is $\frac{7}{16}$ -inch in diameter. A plunger tip that is $\frac{5}{16}$ -inch in diameter is used for softer fruit crops, but will not give meaningful readings if used on apples. Some common brands are Wagner Fruit Test FTX, Magness-Taylor, and McCormick. These can be purchased at farm supply stores.

Because the flesh, and not the skin, changes as the apple matures, the penetrometer should be used on a section of the apple that has been peeled (figure 1). Using a potato peeler, remove the skin on both the blush and non-blush sides of the apple at a point halfway between the calyx and the stem. Measure both sides and average the readings. To get accurate readings, it is critical to adjust the speed with which the plunger tip is inserted in the flesh. It should take 2 seconds to push the plunger in at a consistent speed. Stop when the entire head of the plunger has been inserted (about $\frac{1}{3}$ -inch).

Flesh firmness highly correlates to storage quality and is an especially important measurement for fruit destined for long-term storage. In

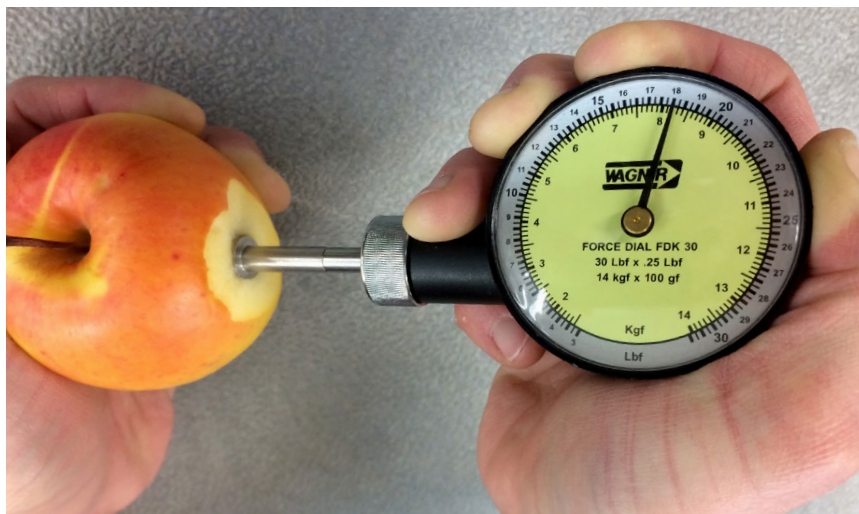


FIGURE 1. A penetrometer is inserted to full depth in the blush side of an apple.

Photo courtesy of Beth Workmaster.

general, apples slated for long-term storage (3 to 8 months) should be harvested at no less than 15 lb. firmness. For short-term storage (1 to 2 months), 13 to 16 lb. firmness is appropriate. However, for short-term storage or immediate consumption, firmness should be used in combination with other maturity indices.

Starch index (SI)

As apples ripen, starch in the flesh is converted to sugar. This process can be measured using the starch-iodine test, which provides a visual assessment of the conversion of starch into sugar. Iodine binds to the starch molecules in the apple flesh, turning them a dark purple or blue-black color. As the fruit matures the starch concentration decreases, causing less dark coloration of the flesh in a starch-iodine test.

To measure the SI of an apple, cut the fruit in half around the equator. Next, dip it into or spray it with iodine dye solution (figure 2). Wait at least two minutes for the stain to react with the apple flesh. This will take longer under cold conditions.

Iodine solution can be purchased ready-made or can be prepared using ingredients available at a chemical supplier. To make an iodine solution, mix 10 grams of iodine crystals, 25 grams of potassium iodide, and 1 liter of water. This must be stirred for several hours until the crystals dissolve completely. The iodine solution will fade if exposed to light, and should be kept in a well-labeled opaque container or in a container wrapped in aluminum foil.



The iodine solution is highly poisonous.

Gloves should always be worn to avoid skin contact with the solution.

Dispose of tested apples in an area inaccessible to livestock.

Specific starch conversion patterns can be found online for many cultivars (e.g., 'Honeycrisp' and 'McIntosh' in figure 3). Rating systems vary, but often run from 1 to 8 where 1 is full starch and 8 is starch-free. Optimal harvest values differ by cultivar and rating system. As a general reference, on a 1 to 8 scale, 5.5 to 7.0 SI values are recommended for fresh market, and 3.0 to 5.0 for processing or storage.

SI can be a reliable tool to measure maturity in cultivars such as 'Empire', 'Jonathan', 'Golden' and 'Red Delicious', 'McIntosh', and 'Macoun'. However, some cultivars, such as 'Gala', 'Honeycrisp', and 'Fuji' do not lose starch in as uniform a pattern, making the results difficult to interpret.



FIGURE 2. An apple is dipped in iodine solution.

Photo courtesy of Beth Workmaster.

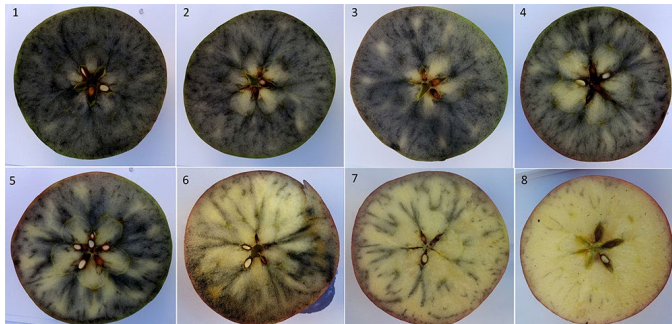
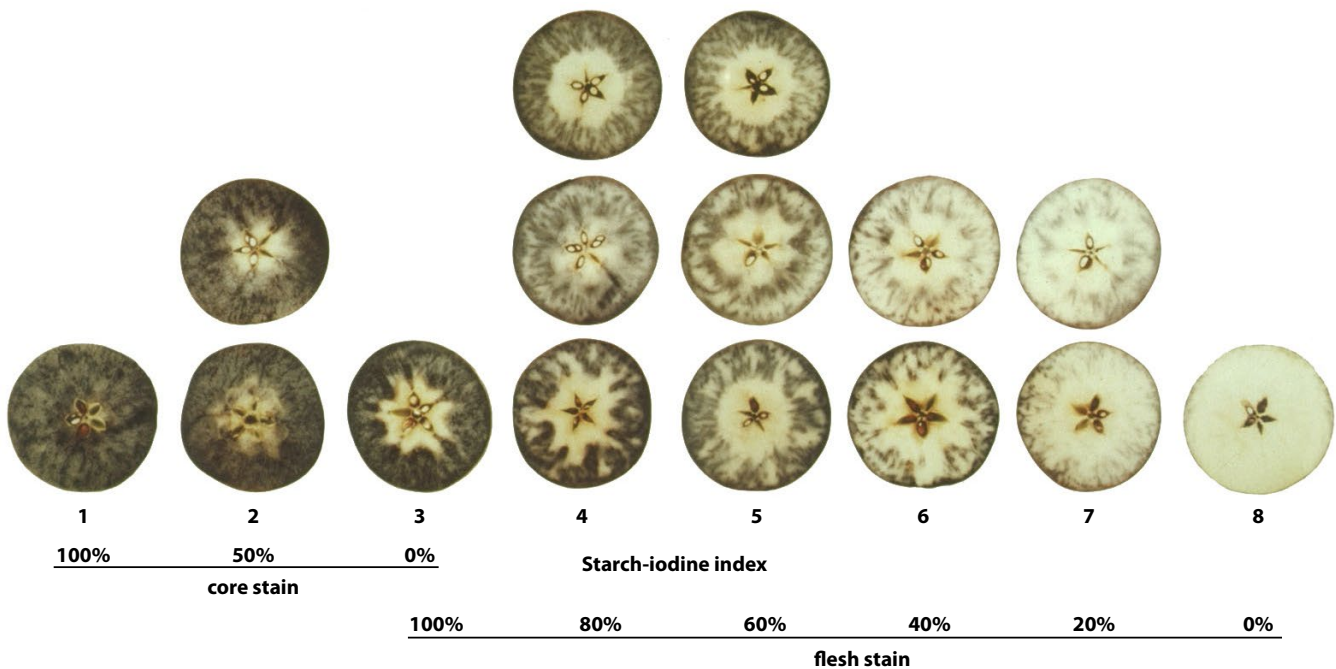


FIGURE 3. Iodine stain conversion pattern for Honeycrisp (left) and McIntosh (bottom) apple varieties. The McIntosh ripening pattern can be used for many apple varieties, including Gala.

Photos courtesy of the University of Maine Cooperative Extension (left) and Blanpied and Silsby, 1992 (bottom).



Soluble solids concentration (SSC)

As discussed in the context of the iodine-starch test, the sugar content of an apple increases as it matures (i.e., as starch is converted to sugar). A soluble solids concentration (SSC) reading provides a different measure of this starch-to-sugar conversion. In apple fruit, the SSC consists not only of sugar, but also of organic acids and inorganic salts. However, soluble solids are easier to measure than sugar and can be used as an effective approximation of sugar content.

SSC can be calculated using a digital or optical refractometer with a small amount of juice (figure 4). Juice can be obtained as a by-product of the

flesh firmness measurement or can be produced using a juicer, a garlic press, or a potato press.

SSC will vary depending on many factors, including where the apple is on the tree, the crop load of the tree, and the growing conditions throughout the season. In particular, SSC increases in apples in areas of the tree that receive more sunlight, where leaf photosynthetic rates (the rate at which the sun's energy is turned into sugar) are higher. SSC decreases due to dilution when there is a high crop load or excessive rain or irrigation. The SSC maturity index can be highly variable, making seasonal comparisons difficult.

It is recommended to harvest apples around 12 to 14% SSC. However, the SSC target varies by cultivar. In particular, 'Honeycrisp' apples

require higher sweetness values to be considered a good-quality product. SSC is best used in combination with another maturity index.

Acidity

The tangy flavor of an apple can be partially attributed to its acidity, consisting mainly of malic acid. The total acidity of an apple decreases as it ripens, and will continue to decrease postharvest. However, acidity is infrequently used as a maturity index for apples for several reasons. First, the rate at which apples lose acidity and the optimal acidity for consumption vary widely by cultivar, making it difficult to give concrete recommendations for a minimum or optimal harvest acidity level. Additionally, measuring



FIGURE 4. A hand-held refractometer (left) or a digital refractometer (bottom) can measure the soluble solids of an apple juice sample.

Photos courtesy of Annie Deutsch (left) and Beth Workmaster (bottom).

acidity requires more specialized laboratory equipment compared to other maturity indices. Acidity can be measured through a titration process in which a base solution of sodium hydroxide is added to a juice sample obtained from the fruit. Small amounts of sodium hydroxide are added until the acids in the juice are neutralized. The titration process can be done using an automated titration system, or with a color indicator dye (phenolphthalein) and pH meter to determine when the acids in the juice have been neutralized.

Measurements of acidity are most useful when repetitive measurements are made on a single tree, as acidity drops around the time the apple reaches maturity. Therefore, rather than setting a target acidity at which to harvest apples, the rate of acidity change is more frequently used as a measure of apple maturity. Acidity levels begin to drop as optimal harvest time nears.

Color changes

Changes in the background color (the part of the skin not colored red) from green to yellow can be a good indicator of fruit maturity, in particular on cultivars like 'Gala' and 'Fuji'. Fruit should be harvested for long-term storage when background color changes from green to yellow, and for short-term storage when background color changes from yellow to cream.

Changes in fruit maturity can also be assessed with a DA (difference of absorbance) index, which measures levels of chlorophyll-a in the flesh of the fruit just under the skin. DA index values decline as the fruit ripens and the chlorophyll degrades. These values correlate to the fruit's ethylene production while ripening, which is cultivar specific. DA index measurements can be obtained with nondestructive instruments such as the DA meter, currently available for growers. DA index readings of 0.60 are recommended for harvesting apples slated for long-term storage. Once the index reaches 0.35, fruit should be harvested for short-term storage.

Summary

Several indices can help measure apple maturity, including starch index, fruit firmness, soluble solids concentration, acidity, and background color. Because each maturity index has advantages and disadvantages, a good strategy is to combine a couple of indices and wait to harvest until all reach optimal maturity values. For example, collecting starch-iodine, flesh firmness, and SSC data will give more information about fruit maturity when all are taken together versus any one index alone. In addition, each orchard block and cultivar will vary in terms of maturity values, so careful observation of individual orchard trends will allow for assessment of the factors most important to an operation.

Further reading

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