Whether apple fruits will be sold for immediate fresh market consumption, will be stored for wholesale under regular or controlled atmosphere storage or will be sold for processing, estimating optimum harvest dates is critical for scheduling labor, but also to ensure an optimum high-quality product.

Fruits that are harvested too early will generally present insufficient red skin coloration, low sugar contents (soluble solids), high acidity levels, will be too firm, small-sized, lacking flavor, and/or be susceptible to physiological disorders such as bitter pit or storage scalds. If fruit are harvested too late, they will become overripe, leading to off-flavor development, high softening rates, highly prone to damage and pathogens, a very short postharvest life as well as increased potential development of physiological disorders.

There are several tests that are used to determine apple fruit maturity, and these will be described throughout this article. But before performing any measurement, the first step is to know how to collect a representative fruit sample from the orchard block.

How to Collect a Representative Apple Fruit Sample?

Each cultivar or strain and each orchard block should be sampled separately; as fruit maturity can vary within the same orchard block as well as within the same tree.

The first step consists of selecting 5 to 8 trees per each block per cultivar/strain and rootstock. These trees should be representative of the rest of the trees in the same block regarding crop load and vigor. Try to avoid choosing trees located in the borders of any block. Proceed to mark the trees as you will weekly collect samples from these.

Ideally, you should begin collecting samples around 4 to 5 weeks before the anticipated normal harvest date. For this purpose, days after full bloom (DAFB) can be used as an estimator of anticipated harvest dates. To use DAFB as a reference guide, record the data of full bloom by orchard block and cultivar/strain in the spring. Do this yearly considering that full bloom may vary annually throughout different sites of your farm. It's important to consider that DAFB is only a general reference to indicate when the fruit will reach its maturity, thus there might be a 5- to 20-day difference between the estimated harvest date and the optimal harvest date for a specific cultivar/strain.

Initially sample once per week, but as the fruits advance in their maturity, consider sampling several times per week if time allows.

Sample 2 to 3 fruits from the periphery of each marked tree, as this fruit generally tend to ripen earlier than fruit in the inner part of the canopy. When sampling fruit avoid fruits with any visible disease or insect damage, make sure fruits of the same size, and be consistent in your sampling method (consider both sides of the tree and canopy height from where fruits are collected). Always collect your samples at the same time of the day.

Once you have collected your samples, measure them within 2 hours after picking, as results can be affected due to temperature changes.
Apple Fruit Maturity Indices

As apple fruits ripen there will be a series of physicochemical changes taking place in the fruit. Some of these changes include: decrease in chlorophyll levels, increase in red skin coloration, seeds turn into a darker color, fruit respiration and ethylene production increases, flesh begins to soften, the starch in the flesh is converted to sugars, and acidity levels decrease. Most of these changes can be easily quantified by using different maturity tests, with the exception being the measurement of ethylene production rates which need to be quantified using a lab-based gas chromatograph. The importance of each indicator will be determined by the fruit's target market/consumer.

Color Changes

The requirements of fruits coloration will differ depending on the cultivar/strain (solid red, striped red, green, or yellow). Changes in the surface (part of the skin-colored red) and background (part of the skin not colored red) color are important maturity indices.

Surface color measurements

Generally, for red-colored cultivars, the indicator for its commercial-grade will be based on the percentage of the surface of the fruit that has a good shade of red color (more color, better grade). For example, in the case of Honeycrisp, the acceptable minimum color for the retail sector is of 50% to 60% red coloration with no hard green.

Background color

Changes from green to yellow in the background color of apples can be a good indicator of fruit maturity. This is especially important in cultivars such as Gala and Fuji. In general, fruit destined for long-term storage should be harvested when there is a change in background color from green to yellow; while changes of background color from yellow to cream should be targeted for fruits with short-term storage.

Chlorophyll's content quantification using a DA (difference of absorbance) meter: the DA meter is a device that measures the Index of Absorbance Difference (IAD) which relates to the actual content of chlorophyll-a in the fruit skin and to ethylene evolution during fruit ripening. The DA meter is a hand-held device that shines LED light into the apple and a sensor measures how much light reflects back out. It can be used for fruits that are still attached to the tree as well as on detached fruits. Values of IAD will decrease as the fruit ripens and the chlorophyll degrades. For each apple cultivar, a characteristic DA index can be developed. In general, DA index readings of 0.60-0.70 are recommended for long-term storage apples; while 0.35 index values are targeted for harvesting fruit for short-term storage (Figure 1).

Figure 1. Using a DA meter to quantify the Index of Absorbance Difference (IAD) which relates to the actual content of chlorophyll-a in the fruit skin. Photo: Dr. Macarena Farcuh, University of Maryland.

Fruit Firmness Changes

As the fruit matures and ripens, the flesh will become softer and thus fruit firmness/pressure testers or penetrometers have been developed to measure these changes. These instruments determine the amount of pressure required to puncture the flesh of the fruit (without skin). Some common brands include Effegi firmness tester and Magness-Taylor pressure tester.

To measure firmness in apples, use a firmness tester/penetrometer with a 7/16-inch diameter plunger (usually the larger one of the two that are provided). Before testing remove a disk of skin between the size of a nickel and a quarter (using a potato peeler) on both the blush and the non-blush sides of the apple at a point midway between the stem and blossom end (avoiding sunburned areas). Then, hold the fruit against a stationary, hard surface, and force the tip of the plunger into the fruit to a depth of 7.9 mm (scribed line on the plunger) of the exposed fruit flesh (not through the skin) (Figure 2). To get accurate readings it is critical to adjust the speed with which the plunger tip penetrates the fruit flesh. It should take 2 seconds to push the plunger at a consistent speed. Applying pressure too fast can result in an inaccurate reading. Measure both sides and finally average the readings to determine the single fruit value. For consistency, the same person should perform the tests for each fruit lot.
Several factors can affect firmness readings; such as for example the presence of watercore, which will give erroneous higher readings; or fruit size, as larger apples will usually be softer than smaller ones. Thus, select fruit that are homogenous in size and representative of the orchard block for accurate measurements.

As flesh firmness highly correlates with postharvest storage quality, firmness is a key aspect to measure for long-term storage fruit. In general, apples that are destined for long-term storage (>3 months) should be harvested with a firmness of at least 15 lbs; while fruit for shorter-term storage (1-2 months) a firmness of 13-15 lbs is appropriate.

**Starch Content Changes**

Starch in the fruit flesh will be converted to sugars as apple fruits mature and ripen. Therefore, the stage of maturity of apple fruits can be determined by performing a simple starch-iodine test. As iodine binds to the starch molecules in the apple flesh, it turns them into a blue-black coloration; while cells that contain sugars will have no color change. This test records the degree of starch disappearance in the flesh, as starch concentration decreases as the fruit matures and ripens.

Iodine solution can be purchased ready-to-use or can be prepared by mixing 10 grams of potassium iodide and 2.5 grams of iodine crystals and in 1 liter of water (proceed to stir for several hours until the crystals completely dissolve). The iodine solution must be kept in a well-labeled opaque container or wrapped with aluminum foil as it will fade if exposed to light. The cap should be non-metallic as the solution will disintegrate metals. Avoid contact with the solution as it is highly poisonous! Gloves should always be worn to avoid skin contact and tested apples should not be used as compost or for animal feed.

To perform the starch-iodine test, cut an apple in half horizontally around its equator, and apply iodine solution to the cut surface of one of the halves (holding the apple half by the stem), and drain off any excess solution (Figure 3). Set the treated side up and wait for 2 minutes for the solution to react with the apple flesh (under cold-conditions the reaction can take longer).

The pattern for starch disappearance is specific for each apple cultivar/strain. For example, Golden Delicious, Gala, Honeycrisp and Fuji do not lose starch in a uniform pattern; while Delicious loses its starch in a moderately even ring. The common starch index rating system is on a scale from 1 to 8 where 1 is full starch (all blue-black) and 8 is starch-free (no stain) (Figure 4). However, not all apples are scored according to this scale. For example, a specific starch chart for Honeycrisp apples, which ranges from 1 to 6 (Figure 5) has also been developed.

The aim of this test is to compare the pattern of each stained apple-half with the pictures on the specific chart that you are using and choose the picture that most closely represents what you are observing. Calculate the average to the nearest one-tenth of an index number.

Optimal harvest values for the starch test will vary depending on the cultivar/strain and by rating system used. In general, on
a 1 to 8 scale, values ranging from 3-5 are recommended for harvesting apples for long-term storage, while 6–7 for fresh market.

Figure 4. The starch iodine test chart on a scale from 1 to 8 developed for McIntosh apples. This chart was developed by Blanpied and Silsby, 1992 and can be used for many apple cultivars. It is often referred to as the “Cornell chart”. Photo: Predicting Harvest Date Windows for Apples, Information Bulletin 221

Figure 5. The starch iodine test chart on a scale from 1 to 6 developed for Honeycrisp apples. Source: Washington State Tree Fruit Research Commission

Soluble Solids Contents (SSC) or Sugar Content Changes

The sugar content of apples will increase as the fruit matures and ripens (as previously discussed for the starch-iodine test). To measure the percentage of soluble solids contents (SSC) of an extracted fruit juice sample, a manual or digital refractometer is used (Figure 6). It is important to mention that in fruits, the SSC measurement consists of sugars, organic acids, and inorganic salts. Nevertheless, soluble solids are simpler to measure than sugars, and SSC has been shown to work as an effective approximation to the percentage of the sugar content of the fruit.

Measurements are performed by squeezing a small amount of juice into the device's prism. Fruit juice can be obtained as a by-product of the flesh firmness testing or by using a garlic or potato-press. If using a manual instrument, hold it up towards the light and look through the lens to read the percentage of SSC from the scale. In the case of digital refractometers, these have an internal light source and sensor that delivers the reading and are temperature-compensated (as differences in temperature can affect the readings). After each juice sample, the prism surface should be rinsed with distilled water and carefully wiped with a soft tissue to prevent contamination between samples. The refractometer can be calibrated by zeroing with distilled water and by then using a 10% sucrose solution.

Readings of SSC can be affected by several factors that can make it highly variable and difficult to compare between
seasons. SSC will increase in fruits in years with high temperatures and high sunlight (due to increased photosynthesis); while SSC will decrease with excessive rain or irrigation and when there is a high crop load in the tree. Fruits within the same tree can also vary in their SSC readings as fruits that are located in heavily shaded areas or on weak spurs will have lower SSC values in comparison to fruit located in sun-exposed areas.

It is expected that as the fruit matures and ripens, SSC readings will increase. In general, it is recommended to harvest apples with readings around 12% to 14% SSC; nevertheless, SSC targets will vary by cultivar/strain and target markets for the fruits.

**Acidity Changes**

The major acid present in the juice of apples is malic acid, and it contributes, together with sugars and aroma volatiles to apple fruit flavor. As fruits mature and ripen, their total acid contents decrease. In general, apple acidity is not a frequently used maturity index as there is a lack of guidelines for maturity based on acid contents. This is a consequence of the wide variation among cultivars in terms of the rates at which they lose acidity and their optimal acidity contents for consumption, which makes it challenging to develop concrete recommendations.

Generally, acidity measurements need to be performed using specialized laboratory equipment, such as a titrator. The measurement of fruit acidity is attained by a process in which a base solution of sodium hydroxide is added to a fruit juice sample in small amounts until the acids in the juice are neutralized. Nevertheless, there are handheld refractometer-type instruments that have been developed that can measure SSC and total acidity in the same instrument for apple fruits (Figure 7).

![Figure 7. ATAGO pocket Brix-Acid meter to determine total soluble solids and titratable acidity for apples. Photo: ATAGO Pocket Brix-Acidity Meter](image)

As a decrease in acidity contents is an indicator of advancing maturity, measurements of acidity are most useful when frequent measurements are made on the same tree. Instead of defining a target acidity range for optimal harvest, it is more effective to use the rate of acidity changes as a measurement of the apple maturity. If acidity patterns and guidelines want to be developed, acidity contents should be recorded over a number of harvests.

**Summary**

Determination of apple harvest maturity and optimal harvest dates can be achieved by using different maturity indices, which include changes in background and surface color, fruit firmness, starch contents, soluble solids contents and acidity levels. A good strategy is to take into account several indices when making harvest and storage decisions, especially under the unusual weather conditions of this growing season. This is important as none of the individual maturity indices can alone explain the true maturity status of an apple.

Furthermore, the relative importance of the specific maturity indicators and their measurement value ranges will be defined by the cultivar/strain, orchard block, as well as by the fruit target market. As each cultivar/ strain and orchard block will vary on their maturity indices, it is of crucial importance to collect a representative sample of apple fruits from each to conduct these maturity tests and start monitoring fruits weekly around 4 to 5 weeks before the anticipated normal harvest date. Careful observation of the results and trends in each cultivar/ strain and orchard block will allow for the identification of the main indices for an optimal fruit harvest date determination.

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Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

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Code: ART-6655