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There are three major species of squash that are grown worldwide – *Cucurbita pepo*, *C. maxima*, and *C. moschata*. The species *C. moschata* includes calabaza or tropical squash, round to oval pumpkins grown in the Midwest for pie processing, and the popular butternut varieties, highly regarded for excellent shelf life. The species *C. maxima* includes the large show pumpkins, Golden Delicious type processing squash, Hubbard varieties, and buttercup/kabocha varieties, the latter esteemed for their exceptional eating quality. Lastly, *C. pepo* is the species having the greatest variation in type, including hard-shelled gourds, summer squash, ornamental pumpkins, and squash. In North America, acorn is the most popular *C. pepo* squash, but striped Delicata and Sweet Dumpling varieties are known for having good eating quality. Cultural methods for the above species of squash are similar; however, harvesting schedules and post-harvest handling may vary considerably.

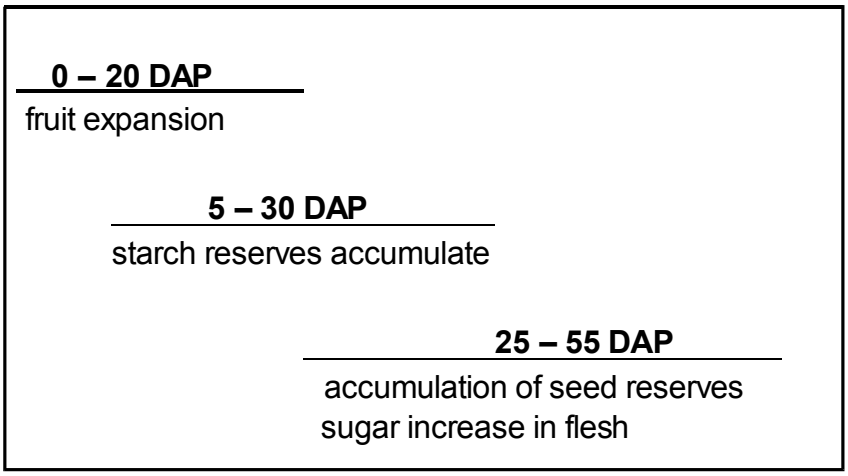
Components of eating quality:

People differ in their preference for flavor components and degree of moisture in squash. Nonetheless, connoisseurs of squash usually prefer a relatively dry squash that has a pasty, slightly moist texture after cooking and a high level of sweetness. High sugars not only contribute to a desirable sweet taste, but also mask undesirable flavor components associated with certain varieties and that may be acquired during cooking. Sugar levels can be estimated easily by freezing small tissue samples and then pressing a drop of clear juice from the thawed samples, and measuring soluble solids in the juice with a hand-held refractometer. Relative sugar content is given in units of percent soluble solids (or ^{o}Brix). Soluble solids levels of 10% are passable, but generally levels of 11% or greater are considered necessary for good eating quality in squash. The pasty texture of squash is attributable to starch. At harvest starch comprises about 45 to 55% and sugars about 10 to 15% of the dry matter of squash, so a squash with high dry matter also has high starch content. Other minor constituents of the dry matter (dried flesh) are proteins, fats, cell wall constituents (crude fiber), and minerals (called ash). Starch provides substrate for conversion to sugars during the latter stages of squash maturation and during subsequent storage. Squash with low dry matter, generally less than 16%, lack sufficient starch levels to produce a combination of pasty texture and degree of sweetness for acceptable eating quality. In varieties with low dry matter, starch is depleted during storage by conversion to sugars, and the texture of the squash becomes excessively moist and fibrous.

Stages of squash development:

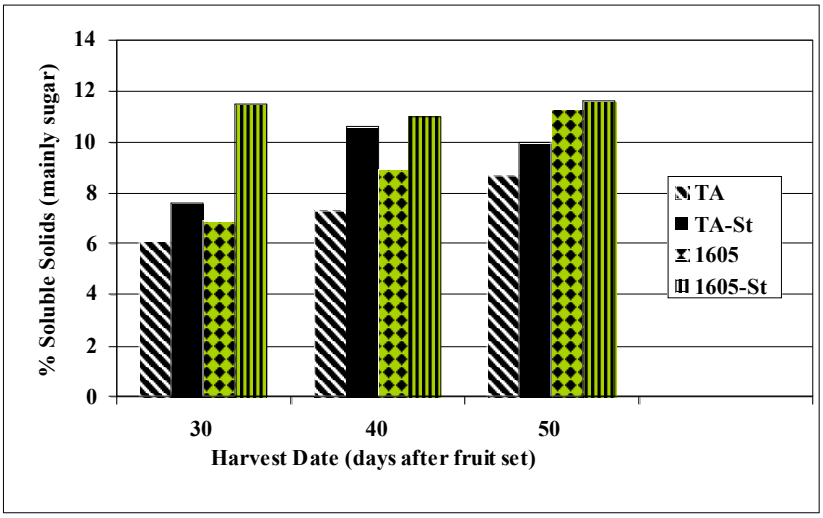
To understand how harvest period, storage and variety selection can affect eating quality, it is necessary to understand basics of squash development and maturation. This process includes not only the development of flesh quality, but also the effect of seed development on maintaining flesh quality. A general outline of development is shown in Figure 1. Small-fruited varieties of squash, such as acorn, reach close to full size within 15 to 20 days after pollination (DAP). Dry matter and starch accumulation begins shortly after fruit set, but is most rapid between 10 and 20 DAP and reaches a maximum content at 30 to 35 DAP. In acorn and other related squash

Figure 1. Stages of fruit development in squash, given as days after pollination (DAP).



in *Cucurbita pepo*, sugar levels begin to increase rapidly between 25 to 30 DAP, and usually reach a maximum between 50 to 60 DAP (Figure 2). Increases in sugar content and maximum sugar content will vary among varieties. In varieties with low dry matter, sugar levels usually

Figure 2. Percent soluble solids for Table Ace (TA) and NH1605 Acorn Squash with and without storage (St) for 20 days at 56 °F.



accumulate slowly and maximum levels are lower than in varieties with high dry matter and therefore higher starch content. In kabocha and buttercup squash (*Cucurbita maxima*) sugars will usually reach acceptable levels (11% soluble solids) between 60 and 70 DAP. In butternut squash, the situation is more extreme. Soluble solids levels are often only 8 to 9% at 60 DAP, and storage at room temperature for 25 to 40 days may be necessary to elevate sugar levels.

Even though the dry matter of the flesh (mesocarp tissue) peaks at about 30 days after pollination, seed development takes much longer. If a squash is cut open at 20 DAP, the seeds appear to be full size. This is because the seed coat, the leathery covering over the embryo, reaches full size by this time. But if the seed is cut in half, the embryo is actually barely visible at this time, being about an eighth to a quarter of an inch in length. The embryo expands rapidly and largely fills the seed coat cavity by 35 days after pollination. However, dry seed biomass (seed fill) continues almost linearly until about 55 DAP. Thus, a squash fruit can be considered to reach full maturation when seed development is complete at about 55 days after pollination.

Post maturation changes occur in stored fruit. There is a progressive moisture loss during storage, so fruit fresh weight decreases. Respiration consumes carbon in the form of sugars, and starch conversion to sugar continues to replace the sugar consumed by respiration. The eating quality of squash varieties with low sugar at harvest will initially be enhanced in storage because sugar levels increase. Eventually, however, long storage time will deplete starch levels to a point where the texture of the squash is compromised.

<u>Harvest period and eating quality:</u>

Because seed maturation is not complete until 7 to 8 weeks after fruit set, it is important to maintain a healthy plant until at least the earliest harvest date or about 50 days after fruit set. This insures a continuous supply of photosynthates (organic carbon source produced from photosynthesis) to the developing fruit. Seeds are the primary sink for assimilates such as sugars and nitrogen compounds, so if photosynthesis is impaired by disease or insect feeding, nutrients required for the developing seed are withdrawn from the flesh, depleting starch levels and lowering eating quality. If fruit are picked immature, seed development continues in stored fruit at about the same rate as in fruit left on the plant. Seed development in an immature, detached fruit occurs at the expense of depletion of nutrient reserves in the fleshy tissue, thereby reducing dry matter (mostly starch) and lowering eating quality.

Because fruit and seed development are similar in all three species of squash, their recommended harvest periods are somewhat similar. However, with kabocha or buttercup varieties, it is actually desirable to harvest them before complete seed maturation, about 40 to 45 days after fruit set when the fruit are still bright green. New Zealand studies indicate that rind hardness is maximum around 40 DAP, so fruit harvested at 40 days suffer less damage to the fruit surface, and in turn, less chance for disease entry during subsequent storage, than fruit picked during later stages. Kabocha squash are also susceptible to sunburn damage as leaf canopies senesce (die back), resulting in changes in rind color from green to brownish and bronze colorations. Extreme sunburn and heat damage can cause the rind to turn white. Therefore, it is best to harvest the squash before fruit are exposed to direct sun as the vines die down. Kabocha squash have a high dry matter content, usually 20 to 30%, and a small seed cavity, so that any seed maturation following harvest has a minimal effect on depleting starch

reserves in the flesh. If kabocha squash are harvested between 40 and 50 DAP, they will need to be stored for 10 to 20 days at room temperature to allow for elevation of sugars to acceptable levels for good eating quality.

Acorn squash present the most difficult problem with respect to determining harvest time. Most modern acorn varieties not only reach near full size within two weeks after fruit set, but also develop a dark green to black mature color. For this reason, acorn squash harvested for the large wholesale markets are often picked immature. Immaturity can be easily recognized by observing rind color on the ground side of the squash. Immaturity is indicated if the ground color is light green or light yellow rather than having the dark orange coloration of mature fruit. If these immature squash are sampled, they are found to have low sugar levels and may have low starch levels as well. If such immature squash are left in storage, sugar content will increase, but starch will be depleted both by respiration and remobilization of sugars from the flesh to the developing seed. This has a negative impact on eating quality. The problem of poor quality in prematurely harvested squash is further exacerbated because many commercial acorn varieties and many of the newer striped varieties have inherently (genetically determined) low dry matter and starch levels.

In contrast to acorn squash, butternut squash do not reach their characteristic tan color until relatively late in development (35 or more days after fruit set), so premature harvest before starch accumulation and seed fill are complete is generally not a serious problem. The biggest problem in butternut squash is that sugar levels are usually not sufficient for good eating quality when squash are harvested, especially in parts of New England where the growing season is marginally short for butternut squash. This year, for example, we harvested fruit from six breeding lines and three open pollinated cultivars, Ponca, Puritan and Waltham butternut, at 60 to 62 days after pollination. Levels of soluble solids were mostly 8 to 9%, with a few as low as 7%. In an adjacent trial, experimental hybrids and some standard varieties were harvested and sampled between 67 to 78 days after fruit set. Other than one sample at 10.6% soluble solids, the levels ranged from 7.4 to 9.8%, well below the 11% or higher preferred for good eating quality. To increase sugar levels sufficiently for satisfactory consumption, butternut squash harvested at 55 to 60 DAP may have to be stored at room temperature for another 30 or more days. Can this process by accelerated? Studies with kabocha squash have shown that storing squash for short periods at high temperatures (ca. 80-85 ^{o}F) can accelerate post-harvest increases in sugar levels. In preliminary studies at UNH, we harvested butternut squash at about 55 to 60 days after pollination and stored squash for three weeks in a greenhouse where daytime temperatures ranged from 75 to 85 ^{o}F. Out of 28 fruit sampled, 20% had soluble solids between 10 to 11% and 80% had soluble solids between 11 and 14%. Eating quality ranged from good to excellent for most samples. It would have been preferable to store the squash under shaded conditions, because some light discoloration of the rind was observed on some fruit.

For long term storage, temperatures between 50 and 60 ^{o}F and relative humidity (RH) between 50 to 70% are recommended. Higher temperature and lower humidity result in more weight loss of fruit and can accelerate the development of hollow neck in butternut squash. The higher temperature also increases respiration rate and loss of dry matter. Even though some squash, particularly butternut varieties, may store reasonably well beyond three months without

disease problems, the texture and overall eating quality of the squash will be compromised after long storage.

How do you determine when to harvest?

Most acorn varieties are semi-bush and set most of the crown fruit within about a week period. Modern hybrids tend to produce some female flowers before male flowers appear and these usually abort unless there are other varieties of *C. pepo* nearby supplying pollen. But this is shortly followed by a period of both male and female flowering and fruit set. Some later fruit sets will occur on runners, but these fruit are usually undersized and lack quality, and so should not be harvested and sold. These late set fruit are a drain on photosynthates, and pruning these fruit off of the plant can actually increase quality of the crown set fruit.

By noting the initial flush of male and female flowers on a semi-bush squash cultivar, a grower can estimate the approximate time when most fruit set occurs, and delay harvest until about 50 days or more from the fruit set period. Another approach is to check the ground spot on the fruit, and not harvest fruit until the spots turns orange. Some of the newer striped varieties of *C. pepo* will show some color changes with maturation, but the color change, say from white to tan between the stripes or stripes changing from green to orange, may occur well after the fruit are ripe enough to harvest. In addition, some varieties may have a dark yellow rather than dark orange ground spot at maturity. So with these, I think that it is better to keep track of the approximate date of fruit set. However, if you observe a color change that correlates with maturity in a particular variety, then you can use that as a harvest indicator.

How about variety selection? That is a tough call. I have found that most modern hybrids being commercially sold lack the eating quality of a good Sweet Dumpling or Delicata squash. UNH has developed some high quality acorn and sweet dumpling type varieties that are being released to the seed industry. High Mowing Organic Seeds offers a UNH-developed, sweet dumpling hybrid, Sugar Dumpling, which also has intermediate resistance to powdery mildew. Johnny's Selected Seeds is in the process of producing seed of one of my PMR mini-acorns, and currently sells an acorn hybrid, Tip Top, that has good eating quality. Cornell Bush Delicata is another variety in this class with good eating quality and powdery mildew resistance. There are several other varieties available that have reasonably good eating quality, so growers will just have to evaluate them to determine if they fit into their particular farm and marketing situation.