Post-harvest Changes in Nutrition and Eating Quality of Squash

Brent Loy and Jennifer Noseworthy,
Department of Biological Sciences,
University of New Hampshire, Durham, NH, USA
Emails: jbloy@unh.edu; jennifer.noseworthy@unh.edu

Introduction

There are three major species of squash that are grown worldwide for their mature, edible fruit – *Cucurbita pepo*, *C. maxima*, and *C. moschata*. The species *C. moschata* includes tropical cultigens and round to oval to long neck pumpkins grown in parts of North America for processing. However, the major fresh market type grown in the northeast is the popular dumbbell-shaped butternut. The species *C. maxima* includes the humongous show pumpkins, Golden Delicious-type processing squash, Hubbard varieties, and the green to gray, 2 to 3 pound buttercup/kabocha varieties, the latter esteemed for their exceptional eating quality. Within *C. pepo*, acorn varieties predominate in supermarkets, but markets are expanding for 0.8 to 1.5 kg, striped, ribbed squash in the 'Sweet Dumpling' class. Although cultural methods for the above species of squash are similar, harvesting schedules and post-harvest handling may vary considerably, along with the development of traits that relate to eating quality and nutrition.

What are the key nutrients in winter squash?

Carbohydrates in the form of sugars and starch are the major constituents of squash flesh (mesocarp), comprising between 50% to as much as 70% of the dry biomass (solid portion after elimination of water) at harvest (Table 1). Varieties with a high content of dry matter (18-26%)) have better eating quality than those with low dry matter content because of high starch content and a lower proportion of fibrous cell wall material. Starch not only contributes to a desirable pasty texture of cooked squash, but also generates sugars during enzymatic breakdown.

Table 1. Percentage dry weight composition of the edible portion of buttercup and butternut squash at harvest (adapted from T.G. Phillips, 1945).

	Percent of Total	
Component	**Harvest**	**3 Months**
Carbohydrates	62-68	57-62
Starch	52-53	14-19
Sugars	10-15	43
Cell wall (cellulose, pectin)	9-10	13-17
Protein	5-6[z]	6-8[z]
Ash (mineral elements)	5-6[y]	5-6[y]
Other	10-16	8-19

[z]Values overestimated because of high soluble N content.

[y]Data obtained from other sources.

In cooking tests, high sugar content is strongly associated with high consumer rating of eating quality. The sugar content at harvest can vary from over 20% in some acorn varieties to around 10% or less in some kabocha and butternut varieties. The relative sugar content can be estimated using a hand-held refractometer, with values given in % soluble solids (SS). Acceptable eating quality is generally attained when SS values are 11% or higher. In most varieties, sugar content will increase steadily increase during several weeks of storage as long as starch is not depleted. With longer storage times, fibrous cell wall matter comprises an increasingly larger portion of the constituents (Table 1), so texture eventually deteriorates, becoming more watery and fibrous and less pasty. This is especially true in low dry matter varieties because starch is rapidly depleted during storage.

Other than providing carbohydrates, the major nutritional benefit of squash is the high content of carotenoids, the yellow to orange, fat-soluble pigments. Beta-carotene, an abundant carotenoid in several varieties of squash, is an important precursor to vitamin A, an essential vitamin for normal eye development and function. Numerous epidemiological studies have implicated carotenoids in a protective function against several cancers, cardiovascular disease and cataracts, and also enhancing immune responses. Lutein, a carotenoid prevalent in large amounts in some squash varieties, is one of the two principal pigments in the macular region of the retina, and increased dietary intake may reduce incidence of age-related macular degeneration. Growers can and should identify nutritional benefits of their produce as a marketing tool. Jennifer Noseworthy has been studying carotenoid content and carotenoid profiles in squash and sweet potato as part of her doctoral degree at the University of New Hampshire. She has found that the popular butternut variety 'Waltham,' not only has relatively high carotenoid levels, but a large proportion (30 to 40%) of the carotenoid content is comprised of lutein. Zeaxanthin is another carotenoid important in eye health. It is absent in most fruits and vegetables, but found in ample supply in leafy brassicas such as kale. Among the kabocha/buttercup varieties analyzed, carotenoid levels were higher than butternuts and two kabocha varieties developed at UNH (Eclipse and Thunder) and the variety Sunshine (Johnny's Selected Seeds) have high levels of β-carotene and lutein and about 5% zeaxanthin.

When is a squash mature?

With many fruits and vegetables a mature fruit is defined as one that is ripe, and displays certain color, firmness and odor changes associated with ripeness. Squash maturity is more difficult to define. Most of the popular edible varieties of squash have relatively small fruit size, and near full size is attained by 20 days after fruit set. Whereas the change in rind color from green to orange can be a useful trait in ornamental pumpkins to determine harvest time, changes in rind color in edible winter squash do not relate well to squash maturity. For example, acorn squash turn a dark green, mature-looking color within two weeks of fruit set, 40 to 50 days before they should be harvested! By the same token, butternut squash turn a fairly mature tan color by about 35 to 40 days after pollination, some two to three weeks before they should be harvested. Harvest time should be based on compositional changes and maturation of the fruit. In most varieties the accumulation of flesh dry matter and therefore starch content peaks between 30 to 35 days after pollination. As mentioned above, high starch content is strongly associated with good eating quality. Peak dry matter, however, does not coincide with maturation of seeds within the fruit, and because the fruit is the reproductive organ of the plant, it is reasonable to define a squash as being mature when the seeds are mature. Seed fill in most squash grown in

the Northeast is not complete until about 55 days after pollination and fruit set. Most people do not eat the seeds of squash, so delaying harvest until the seeds are completely filled may not always be necessary, but maintaining a healthy plant and delaying harvest until about two months after fruit set is a good general recommendation. Seeds require photosynthates (carbon compounds produced from photosynthesis) to complete development. If the fruit is harvested before the seed is fully developed, then assimilates for seed fill are remobilized from the flesh to the seeds during subsequent storage. Under conditions of poor plant health or premature harvest, movement of carbohydrates from the fleshy mesocarp tissue to seeds can reduce flesh quality substantially, especially in varieties with inherently low dry matter.

Keeping track of when fruit set occurs may not realistically fit into a grower's crop schedule, so a reasonable rule of thumb for kabocha and acorn squash is to begin harvesting squash when the ground color of the fruit reaches a dark orange color. Acorn squash reach near full size and a dark green color by about two weeks after fruit set, so to the casual observer, the squash may appear to be mature. However, the ground spot on squash between 15 to 40 days after fruit set will vary from light green early on to dark yellow. Butternut squash does not show orange ground color, so harvest should not begin until at least two weeks after squash turn tan color. Maturity dates listed in seed catalogs are often in error, especially for acorn squash, where maturity is often stated as being between 70 to 76 days when in reality the actual maturities are probably closer to 90 to 100 days. Kabocha and buttercup varieties have very high dry matter content, and late seed fill in harvested squash does not appreciably detract from quality. Studies in New Zealand suggest that squash harvested at 40 days after fruit set may have a harder rind and be more resistant to storage diseases than squash harvested later. However, the sugar content is low in immature kabocha squash, so I recommend harvesting prior to 55 days only when vines have begun to go down, so as to minimize sunburn damage and fruit discoloration.

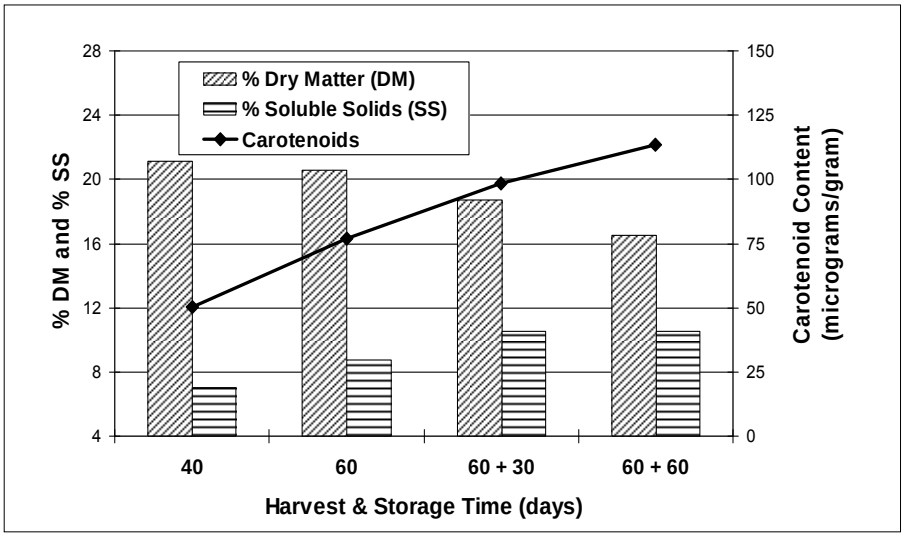
Post-harvest changes in eating quality and nutrition

In acorn and related varieties, starch to sugar conversion occurs relatively early in fruit development, and a soluble solids content of 11% or greater in the best culinary varieties may be attained within 45 to 55 days after fruit set. Therefore, acorn squash can be sold at harvest and recommended for immediate consumption, even though optimum eating quality may not be attained until a few weeks after harvest. Buttercup and kabocha used to be considered as the consummate varieties for connoisseurs of squash, but the recently introduced varieties of acorn and 'Sweet Dumpling' types of squash with high dry matter, such as 'Honey Bear' and Sugar 'Dumpling,' are being touted by many as having the most outstanding eating quality.

Given the popularity of butternut squash, there is a surprising lack of information on changes in eating and nutritional quality during storage. Most such studies were published in the 1960s and lacked good experimental design. In butternut squash harvested at about 55 days after fruit set, we have found that about 60 days of storage at 56 to 60 ^{o}F is required for soluble solids levels to reach minimum acceptable levels. Carotenoid content often increases even more than soluble solids with storage (Figure 1), so squash has more nutritional value in terms of carotenoid content if stored. Kabocha and buttercup varieties fall in between the butternuts and acorns in terms of edibility at harvest. Our results suggest that most varieties have sufficient sugar levels at a 60-day harvest, but not if harvested at 40 days after fruit set. Sugar content in kabocha will increase with additional storage time as will carotenoids. Occasionally a kabocha variety will

have an excessive dry matter at harvest (over 30%), and in such cases, additional storage is needed for depleting starch and raising sugar levels.

Figure 1. Harvest date and storage time affects eating quality and nutritional content of 'Waltham' butternut squash.



Post-harvest changes can be accelerated with increased storage temperature, but this in turn can adversely affect storage life. Studies with kabocha squash have shown that storing squash for one week at a high temperature (85 ^{o}F) can accelerate post-harvest increases in sugar levels following subsequent storage at 54 ^{o}F. In 2008, 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. Based on our results, we would recommend that growers store butternut squash at a high temperature for one to two weeks for customers wanting to purchase butternut squash ready to consume.

Conclusion

The three major classes of winter squash - acorn, kabocha/buttercup, and butternut – have different attributes associated with maturation and post-harvest changes in eating quality and nutrition. It is important for growers to understand these differences so as to provide information to customers that will guide them in purchasing and utilizing squash for optimum culinary and nutritional benefits. In addition to species differences in maturation, there are also considerable varietal differences with respect to eating quality. It behooves growers to become more aware of varieties which exhibit good eating quality so that their customers are satisfied with their purchases, and realize the benefits of purchasing their produce at roadside retail markets.