

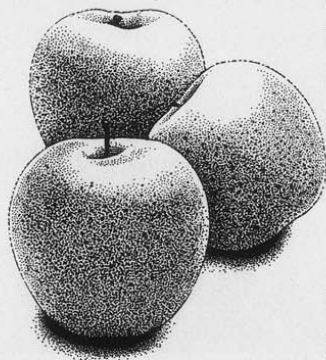
Effect of Postharvest Handling and Storage on Apple Nutritional Status Using Antioxidants as a Model

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SUMMARY. With the development of improved postharvest technology, the shelf life of fruit and vegetables has increased dramatically in many parts of the world. Presently, dietary recommendations for these commodities are based on the bioavailability of essential nutrients at the time of optimum harvest. Few people, however, are fortunate enough to have available freshly harvested produce all year and, therefore, must consume fruit and vegetables that have been stored under the best conditions available. The question, then, is whether nutritional quality changes with storage method and length. Little is known concerning the effects of storage on nutrient content or bioavailability. Furthermore, if levels of these antioxidants do indeed change, perhaps dietary recommendations should reflect this as well. The data in this study indicate that there are significant changes in the levels of natural antioxidants in two apple cultivars at harvest and after an extended period in cold storage.

The objective of industrial raw food storage is to provide sufficient quantities of product to satisfy the increasing demand worldwide. In addition to the primary consideration of safety are those issues related to consumer acceptability and nutritive value, both of which are affected by pre- and postharvest treatment. The most common methods of raw food preservation are 1) short-term heat treatment (i.e., blanching or pasteurization), 2) reducing respiration by lowering temperature, 3) chemical additives to reduce oxidation, 4) changes in atmospheric gas composition, and 5) irradiation for disinfestation and growth inhibition (Mueller, 1990). Unfortunately, nutrient loss occurs during all of these processes and depends on the physical nature of the product as well as on the length and strength of the treatment (Thompson, 1982). Thus, a comparison of published data originating from similar commodities with differing or otherwise unknown histories would be tenuous and could be quite damaging (Bender, 1978; Mueller, 1990). Further, defining daily dietary allowances (Hansen et al., 1979, USDA, 1984) based on unknown postharvest history could be potentially misleading.



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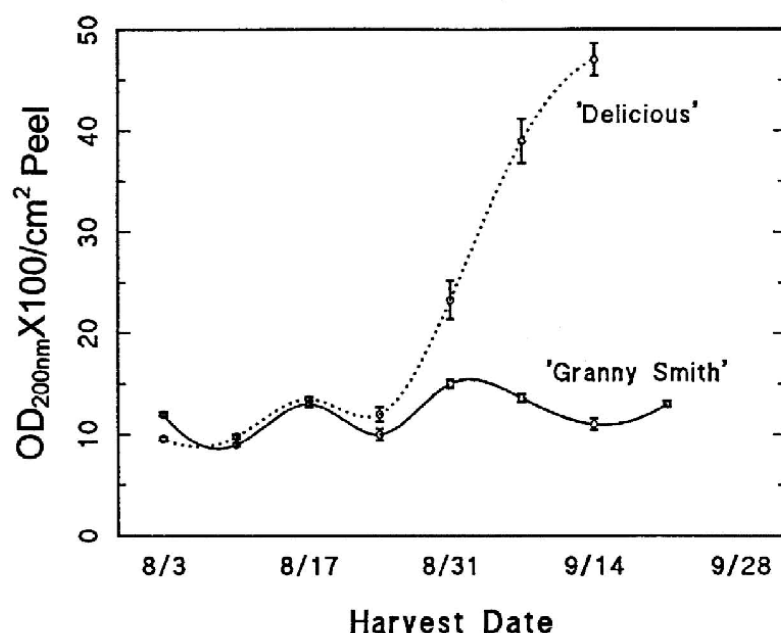


Fig. 1. Antioxidant level (OD_{200 nm} × 100)/cm² peel) as a function of date of harvest in 1993 for 'Delicious' (---) and 'Granny Smith' (-----) apples. Each point represents the mean of 20 fruit. Bars represent ± SE.

Materials and methods

Fruit for this study was taken from mature, commercial orchards within the environs of the USDA Tree Fruit

The apple has been recognized conceptually as a "healthy" food. Vitamins, minerals, simple and complex sugars, as well as the content of cellulosic fibers and pectic substances have been emphasized. In addition, appearance, convenience, variety, flavor, and acceptance by young and old consumers have contributed to this image. Interestingly, what once may have been considered as nutritionally insignificant compounds within the fruit, because of the improved technology of nutrient detection and nutritional studies throughout the world, have become more important in the eyes of a more health conscious and educated public. Interest has mounted in such categories as plant pigments and antioxidants and their effects upon disease prevention and health maintenance.

With properly managed temperature and storage atmosphere, apples can be stored for as long as 12 months. As well, irradiation and short-term heat treatment are gaining acceptance either commercially or experimentally as necessary additions to the list of prestorage treatments. Thus, the bioavailability of nutrients within the total pool will depend on a number of factors before and after harvest. This experiment examined how apple skin antioxidants may vary according to cultivar, harvest date, and storage regime.

Research Laboratory in Fall 1993. In July 1993, 20 each of 10-year-old Red Chief 'Delicious'/M106 and 'Granny Smith'/M106 apple trees with similar architecture, vigor, and fruit load were flagged for periodic sampling. Beginning on 3 Aug., four similar fruit from each tree, excluding those on the south side, were selected and taken immediately to the laboratory. One fruit from each tree was placed in each of four trays, resulting in four trays of 20 matched fruit. One tray at harvest was used for extraction of antioxidants from the peel (cuticle + 2 mm). The others were placed in regular storage at -1 °C. At 2, 4, and 6 months in storage, a single tray was removed from storage and placed in the dark for 24 hours at 23 °C. Following this, apple peel was removed for extraction and analysis of fruit skin antioxidants.

Quality evaluations included color, starch conversion, firmness, soluble solids, and acidity. Color was evaluated with the Color Machine (Pacific Scientific, Seattle) using the

Table 1. Mean values for starch rating, fruit firmness, soluble solids, and acidity of 'Red Chief Delicious' and 'Granny Smith' apples harvested at weekly intervals in 1993.

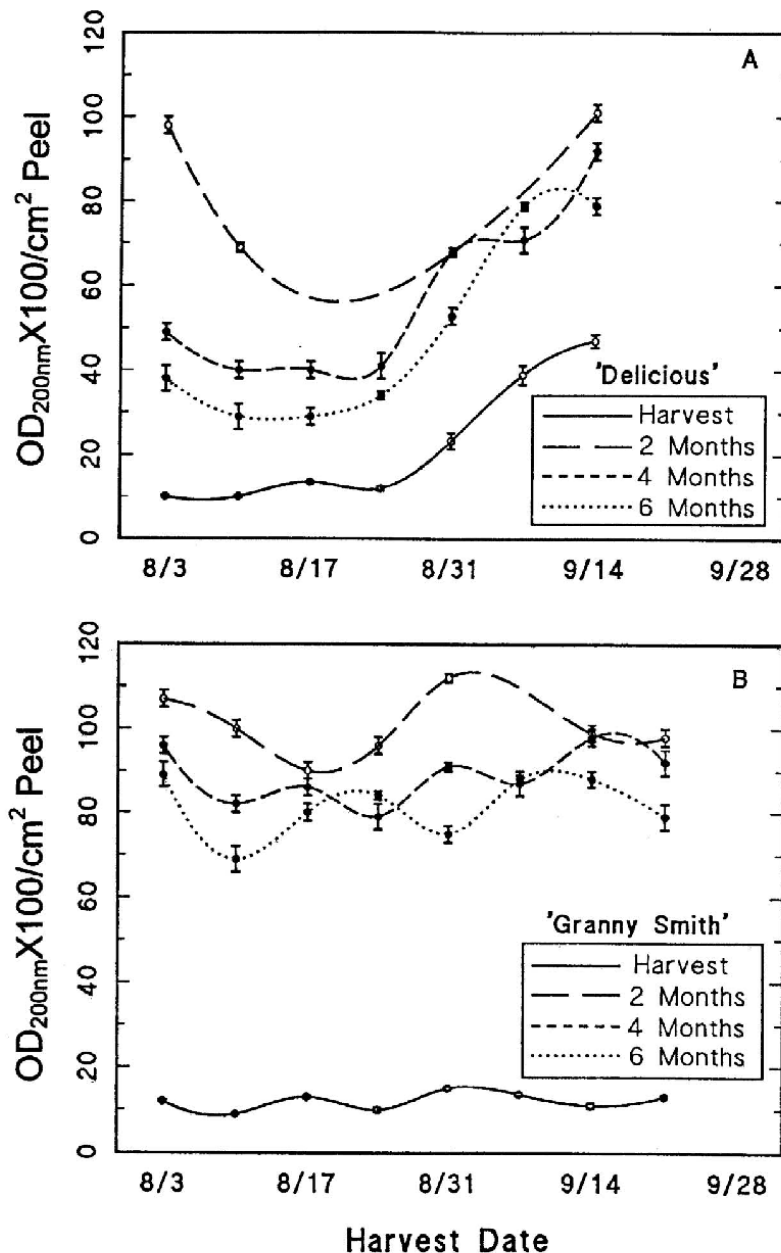
Date	Starch ² (1-6)	Firmness (N)	Soluble solids (%)	Acidity (% malic acid)
Granny Smith				
9/15	1.4 ^y	74.5	10.0	1.02
9/21	1.4	73.1	11.6	0.86
9/28	2.0	75.8	11.0	0.86
Delicious				
9/6	1.3	75.4	9.7	0.35
9/14	1.5	73.5	10.0	0.36
9/20	1.6	70.8	10.4	0.30

²Starch rating based on a scale of 1 = no starch conversion; 6 = complete starch conversion.

^yEach value is the mean of 20 apples.

Hunter "L", "a", "b" scale calibrated with a white CM536 plate. Triplicate color values were determined around the circumference of each apple. Starch conversion was determined on a scale of 1 to 6 (1 = no conversion; 6 = complete conversion) using the middle cross-section of an apple. A model EP1 pressure tester (Lake City Technical, Kelowna, B.C., Canada) equipped with a 1.27-cm head was used to determine firmness. Soluble solids were measured using a digital refractome-

Fig. 2. Antioxidant level ($OD_{200nm} \times 100/cm^2$ peel) as a function of date of harvest in 1993 at harvest and after 2, 4, or 6 months storage at $-1^\circ C$ for 'Delicious' (A) and 'Granny Smith' (B) apples. Each point represents the mean of 20 fruit. Bars represent $\pm SE$.



ter (model PR-1; Atago Co., Ltd, Tokyo). Titratable acidity was measured with a titrator (model TTT8s; Radiometer, Copenhagen, Denmark) and acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as a percent malic acid.

Poststorage exam was performed 24 hours (at $23^\circ C$) after removal and included all those parameters measured at harvest.

Tissue extraction for analysis of antioxidants was performed as previously described (Mcir and Bramlage, 1988) with the following minor changes. Instead of whole apples extracted, three disks, each 2 cm in diameter, were individually extracted with 10 mL HPLC grade hexane for 24 hours in the dark at $22^\circ C$. The samples were filtered through a 0.45- μm filter and an aliquot was placed in a 0.5-mL quartz cuvette and measured for UV absorbance at 200 nm with a Shimadzu UV-VIS 2101 PC Scanning Spectrophotometer (Shimadzu, Corp., Tokyo). These values were expressed as $OD_{200 nm} \times 100/cm^2$ tissue.

In addition to the previous samples, two trays each of 20 'Golden Delicious', 'Fuji', and 'Braeburn' were collected at the time of their respective commercial harvest and placed in regular storage at $-1^\circ C$ with the fruit described above. This fruit was extracted for antioxidants at harvest and after 6 months as described above.

Results and discussion

Fruit tissue extracted weekly showed that, at the time of commercial harvest (last date sampled), the level of antioxidants was quite different between cultivars. The OD_{200} for 'Delicious' fruit was more than four times higher than that of 'Granny Smith' (Fig. 1). It may be important to note the 'Delicious' fruit were more mature than the 'Granny Smith' fruit, with starch levels of 3.6 and 1.1, respectively (starch scale is 1 to 6, with 1 being no conversion of sugar, and 6 being complete conversion—Table 1). Fruit sampling began several weeks in advance of commercial harvest to establish a baseline level of the compounds of interest. Because the last sampling occurred at commercial harvest in each particular orchard, it is possible that stage of maturity affected the total amount of antioxidants in the tissue. This may be a significant factor and quite important if one bases the level of the antioxidant bioavailability on harvest date and, therefore, harvest maturity.

The data indicate that, in fruit stored (untreated) for 2 months, the level of antioxidants in 'Delicious' increased 2 to 10 times (Fig. 2A). Also, as the length of time in storage at $-1^\circ C$ increased from 4 to 6 months, levels generally decreased regardless of harvest date. In 'Granny Smith' apples, the antioxidant level

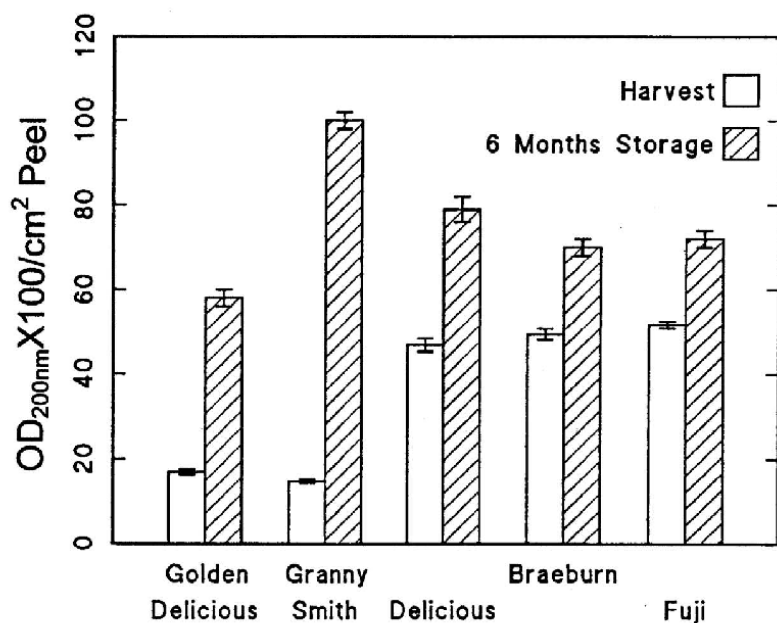


Fig. 3. Antioxidant level (OD_{200nm} × 100/cm² peel) of five major apple cultivars at harvest (open bars) and after 6 months regular storage (hatched bars) in 1993. Each point represents the mean of 20 fruit. Bars represent ± SE.

also increased almost 10-fold when examined 2 months after initiation of cold storage (Fig. 2B). Fruit that stayed in storage for another 4 to 6 months also showed reduced levels of antioxidants relative to fruit held for 2 months. Again, the trend was that, the longer the fruit was held, the less antioxidant was extracted.

A comparison of antioxidant content in five cultivars, each picked at a maturity level suitable for immediate consumption, showed about a 2-fold variation among cultivars regardless of whether measured at harvest or after 6 months at -1 °C (Fig. 3).

There is a wealth of information regarding the effects of long-term storage on edible quality for apples as well as other fruit and vegetables. Most of the attention has been devoted to first defining, and then maintaining those characteristics that define consumer acceptability.

These data show quite well that the amount of nutrient varies with cultivar, time of harvest, and length of storage. Perhaps the nutritional status, especially for such a storable commodity as apple, should be defined as well, taking into consideration the history of the fruit. Alternatively, nutritional status could be defined at commercial harvest, noting that changes could occur depending on how fruit were treated and stored after this point (Karmas, 1988; Karmas et al., 1962). Physicochemical properties such as solubility, chelation, hydration, stability, inhibition or catalysis by or of other compounds, poly-

merization, and oxidation will all contribute to the levels of the particular compound of interest and, although not mutually exclusive, are separate issues that are often treated no differently.

Distinguishing between stability and bio-availability for every nutrient would be a formidable task. On the other hand, data concerning certain key nutrients could be developed and data extrapolated to other raw food products. This type of work needs to be pursued.

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