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Mineral, Fiber, and Total Phenolic Retention in Eight Fruits and Vegetables: A Comparison of Refrigerated and Frozen Storage

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ABSTRACT: Minerals, total phenolics, and fiber were analyzed in several fruit and vegetable commodities to evaluate the differences between fresh and frozen produce. Magnesium, calcium, iron, zinc, and copper were evaluated in corn, carrots, broccoli, spinach, peas, green beans, strawberries, and blueberries. Each commodity was harvested fresh and split into two batches. Half of each commodity was kept fresh, and the other half was frozen. The nutrient content was analyzed over three storage times per treatment. The retention of nutrients was highly dependent on the commodity, but the majority of the commodities showed no significant difference between fresh and frozen for all analytes ($p \leq 0.05$).

KEYWORDS: *fiber, minerals, total phenolics, fruits, vegetables, refrigerated storage, frozen storage, nutrients*

INTRODUCTION

To maintain good overall health, The World Health Organization recommends that individuals consume a minimum of 400 g of fruits and vegetables per day.[1] In addition to the functional benefits of the various essential vitamins and minerals found in these foods, many studies have been published suggesting the benefits of dietary fiber and various phenolic compounds that are found in abundance in fruits and vegetables.[1,2]

Since the advent of modern food processing technology and practices, preserved foods have served as a source of nutrition having the added advantage of longer shelf stability. This helps to overcome the large distances of many populations from agricultural areas, where food must often travel several days to weeks after it is harvested, during which time nutrient degradation can occur.[3] It has been found that the nutritive losses resulting from mild heat treatments required for blanching prior to freezing fruits and vegetables may be less severe than those of a fresh product that is subjected to a long postharvest holding period prior to consumption.[4,5]

In this study we seek to carry out an in-depth evaluation of the effects of freezing as well as frozen versus fresh storage on the nutrient content of six vegetables, e.g., peas, green beans, spinach, corn, carrots, and broccoli, and two fruits, strawberries and blueberries. In contrast to many previous studies that relied on produce obtained from local markets or large suppliers, the commodities in question were harvested by the authors directly from the location in which they were grown, and the entire processing and storage chain was carried out by the authors to ensure a controlled experimental design. In addition, the same initial raw material was used for both fresh and frozen storage studies.

In contrast to the highly sensitive nature of both water- and fat-soluble vitamins to a variety of processing and storage conditions which may impart oxidative and thermal damage, minerals are much more stable. The primary reason for a decline in mineral content of a product during processing is leaching during washing and blanching, which can be extensive—up to around 9–22%.[4,6,7] Increases in the content for some minerals such as calcium have been reported in cases where mineral-rich "hard" water was used for blanching.[8] Perceived decreases in mineral levels during storage are most likely due to differences in the ease with which different minerals are extracted from the food matrix during analysis rather than any actual biochemical or physical loss of the analyte. In studies where results are presented on a wet weight basis, minerals and other nutrients may appear to increase or decrease due to loss or gain in moisture; for this reason dry weight reporting is more accurate.

The term "fiber" describes a variety of plant polysaccharides that contain constituents that cannot be readily digested and absorbed by the human digestive system. These constituents therefore contain no caloric value but have been shown to be integral to a variety of digestive issues, such as fostering helpful intestinal microbiota.[9] Changes in fiber content during processing and storage of most produce have been reported to be miniscule in most cases. Apart from processing steps that require physical removal of tissue such as peeling, few processing and storage conditions are severe enough to alter the highly stable compounds that comprise dietary fiber.[4]

Phenolics are actually a large class of hundreds of compounds that are found in plant tissues, and their incidence in foods is often reported as a value of total phenolic content, rather than quantifying specific compounds. While phenolic compounds are not considered an absolutely vital dietary component in most situations, the antioxidant effects of phenolic compounds have been correlated favorably with reduction of incidence of various diseases.[4,10,11] Like the other water-soluble analytes, phenolics are susceptible to leaching during blanching processes prior to freezing. While some phenolic compounds may be lost during this processing step, the thermal treatment during blanching has also been found to inactivate oxidative enzymes that are normally responsible for the degradation of

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these compounds. Freezing has been shown as an effective method of minimizing the oxidative degradation of these compounds during storage.[4,10]

MATERIALS AND METHODS

Raw Materials. Vegetable seeds were donated by the Seminis Vegetable Seed Co., Inc., Woodland, CA. Six replicate samples were harvested from different randomly selected points along linear rows for each commodity. Commodities were harvested according to the times and locations listed in Table 1.

Table 1. Harvest Times and Locations for Each Commodity Studied

commodity	month and year	harvest location
spinach	December 2012	Full Belly Farm (Guinda, CA)
carrots	November 2012	UC Davis (Davis, CA)
broccoli	February 2013	UC Davis (Davis, CA)
blueberries	March 2013	California Coastal Blueberry Farms (Oxnard, CA)
peas	April 2013	Iacopi Farm (Half Moon Bay, CA)
green beans	June 2013	UC Davis (Davis, CA)
strawberries	July 2013	Driscoll's (Watsonville, CA)
corn	August 2013	UC Davis (Davis, CA)

All commodities were harvested at uniform maturity as determined by both color and approximate size, as recommended by the grower. All commodities were transported to the UC Davis (University of California, Davis) Food Science and Technology pilot processing plant in refrigerated Styrofoam coolers (Lifoam Industries, Hunt Valley, MD) and processed immediately.

Processing. Throughout the processing and storage chains, each of the six field replicates was maintained as discrete samples. All commodities were given a preliminary rinse with water prior to entering the pilot plant to avoid unnecessary contamination of the facilities. Commodities were then submerged in a flume wash (Food Science and Technology Machine Shop, Davis, CA) filled with water and rinsed thoroughly to remove any surface dirt. Some commodities received additional processing steps prior to blanching: carrots were diced into 1.5 cm cubes using an Urschel G-A dicer (Urschel Laboratories, Inc., Valparaiso, IN), strawberries had their crowns removed by hand, green beans and peas were destemmed by hand, broccoli was cut into 3−5 cm florets by hand, and individual corn kernels were removed from the cob by hand using a Zyliss corn stripper (Zyliss, Irvine, CA).

For each field replicate of each commodity, cleaned, prepared samples were randomized and separated into two parts. Half of each field replicate was then marked for fresh storage, while the other half was blanched and frozen. The samples to be blanched were loaded onto the steam blanching line (Food Science and Technology Machine Shop) in stainless steel baskets for the specified amount of time and temperature (Table 2). Following blanching, the samples were transferred onto wire mesh racks and placed immediately into a −32 °C walk-in freezer (Estes Refrigeration, Inc., Richmond, CA). After 1 h, the frozen commodity was divided into three 300 g storage samples which were packaged in UltraSource 3 mil polyethylene pouches (UltraSource LLC, Kansas City, MO) and stored at −27.5 °C (18 °F) for up to 90 days. Blueberries and strawberries were not blanched prior to freezing, in accordance with industry practices.

Table 2. Blanching Protocols for Each Commodity

commodity	blanch time (min)	blanch temp (°C)	commodity	blanch time (min)	blanch temp (°C)
blueberries	N/A	N/A	corn	3.5	93.3
strawberries	N/A	N/A	green beans	3.5	93.3
broccoli	1.5	90.5	peas	2	93.3
carrots	2	96.1	spinach	3	93.3

Stability Study. The fresh half of each field replicate was divided into three 300 g storage samples which were stored in breathable Tuf-R low-density polyethylene bags (U.S. Plastic Corp., Lima, OH) at 2 °C (35.6 °F) in a walk-in refrigerator (Estes Refrigeration, Inc.) for up to 10 days. The frozen half of each field replicate was divided into three 300 g storage samples which were packaged in UltraSource 3 mil polyethylene pouches (UltraSource LLC) and stored at −27.5 °C (18 °F) for up to 90 days. For each field replicate, one frozen pouch and one fresh pouch were analyzed within 24 h of harvest (day 0) and after each storage time: 3 and 10 days for fresh; 10 and 90 days for frozen. Upon completion of each storage period, samples were removed from storage and transported in refrigerated coolers to the UC Davis Analytical Laboratory facilities for analysis.

Minerals. *Acid Digestion.* A 0.5 g portion of dried, homogenized sample was weighed and transferred to a Teflon PFA double-wall digestion vessel with a 200 psi relief seal (CEM Corp., Matthews, NC). A 1 mL volume of nitric acid and 2 mL of hydrogen peroxide (Fisher Scientific Co., Pittsburgh, PA) were added and gently mixed with the sample. The vessel was capped tightly and allowed to predigest for 10−15 min. Samples were digested for 5 min at 40% power and 8 min at 90% power in a CEM MDS 2000 microwave digestion system (CEM Corp.). After cooling, the digest was transferred to a 15 mL centrifuge tube using deionized water to rinse the vessel. The volume was adjusted to 15 mL with deionized water. The test tube was mixed by being shaken vigorously and allowed to sit overnight to allow particles to settle out. A 1 mL aliquot of the digest was diluted with 3 mL of deionized water and analyzed on a Thermo iCAP 6500 inductively coupled plasma atomic emission spectrometer (Thermo Fisher Scientific, Hudson, NH).

Fiber. *Reagents.* Acid detergent solution was prepared by thoroughly mixing 2 L of Ankom acid detergent liquid (Ankom Technology, Macedon, NY) with 8 L of deionized water. Sulfuric acid solution was prepared by diluting 650 mL of concentrated sulfuric acid (Fisher Scientific Co.) to 2 L with deionized water.

Acid Digestion. Approximately 1 g of dried, ground sample material was weighed into an aluminum weigh dish (Fisher Scientific Co.). The sample was washed into a 600 mL refluxing beaker using acid detergent solution. Additional acid detergent solution was added to fill the beaker to the 100 mL mark. The sample solution was heated under reflux for 60 min and then filtered using a coarse porosity fritted glass crucible (Corning, Tewksbury, MA). The sample was rinsed twice with 90−100 °C water and twice with acetone, then dried for 3 h at 105 °C, cooled, and weighed.

Total Phenols. *Reagents.* Sodium carbonate solution consisted of 75 g of sodium carbonate (Fisher Scientific Co.) diluted in 1 L of deionized water. Gallic acid standards of 40, 100, and 2500 mg/L concentrations were prepared by mixing gallic acid (Arcos Organics, Geel, Belgium) with acetone to the appropriate concentration. Folin and Ciocalteu's phenol reagent (2 N) was obtained from Sigma-Aldrich, Buchs, Switzerland.

Folin−Ciocalteu Treatment. Samples were homogenized with 60% water by weight of sample. A 6.4 g mass of each of the blended samples was weighed into a 50 mL plastic centrifuge tube. Samples were homogenized with 27.6 mL of 76% (v/v) aqueous acetone (Fisher Scientific Co.) for 30 s using an Ultra Turrax T25 basic homogenizer (IKA Works, Inc., Wilmington, NC). After being shaken for 10 min, the samples were centrifuged at 2000 rpm for 10 min. To 1 mL of extract was added 0.36 mL of 2 N Folin reagent. The solution was vortexed and allowed to stand for 5 min, then 6 mL of sodium carbonate was added, and the solution was vortexed again. Deionized water (2.64 mL) was added, and the solution was vortexed and incubated at 50 °C for 5 min. After the solution was cooled to room temperature for 1 h, the absorbance was read at 760 nm and compared to a calibration curve of derivatized gallic acid.

Statistical Analysis. Statistical analysis was performed using JMP statistical software version 9.0.0 (SAS Institute Inc., Cary, NJ). A blocked analysis of variance (ANOVA) was run with storage time point and processing treatment as the treatments. Tukey comparisons

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Table 3. Mineral, Fiber, and Total Phenolic Content of Eight Commodities Stored under Either Refrigeration or Frozen Conditions for Three Storage Times[a]

	storage time (days)	calcium content (%)	magnesium content (%)	zinc content (mg/kg)	copper content (mg/kg)	iron content (mg/kg)	fiber content (%)	phenolics content (mg GAE/g)
				Peas				
fresh	0	0.325 bc (0.018)	0.186 b (0.004)	29.9 bc (0.3)	2.8 bc (0.0)	55.0 c (1.0)	8.3 a (0.5)	3.78 c (0.10)
fresh	3	N/A	N/A	N/A	N/A	N/A	8.4 a (0.3)	3.97 b (0.15)
fresh	10	N/A	N/A	N/A	N/A	N/A	8.4 a (0.4)	4.13 a (0.13)
frozen	0	0.308 c (0.011)	0.173 c (0.004)	28.3 d (0.3)	2.7 bc (0.1)	54.5 c (1.4)	6.0 b (0.0)	3.22 d (0.11)
frozen	10	N/A	N/A	N/A	N/A	N/A	5.9 b (0.0)	3.17 d (0.13)
frozen	90	N/A	N/A	N/A	N/A	N/A	6.3 b (0.3)	2.93 e (0.06)
				Spinach				
fresh	0	0.719 a (0.073)	1.126 a (0.030)	79.8 a (5.2)	11.7 a (0.8)	777.6 a (169.7)	8.9 a (0.5)	7.71 b (0.29)
fresh	3	N/A	N/A	N/A	N/A	768.6 a (154.0)	10.5 a (0.5)	8.90 a (0.39)
fresh	10	N/A	N/A	N/A	N/A	761.7 a (168.4)	10.1 a (0.5)	9.12 a (0.35)
frozen	0	0.705 a (0.066)	0.928 b (0.071)	71.4 a (5.2)	11.7 a (1.5)	448.3 b (61.5)	9.6 a (0.5)	8.00 b (0.53)
frozen	10	N/A	N/A	N/A	N/A	414.8 b (58.6)	8.8 a (0.5)	9.58 a (0.81)
frozen	90	N/A	N/A	N/A	N/A	421.5 b (74.0)	8.6 a (2.2)	9.19 a (0.44)
				Green Beans				
fresh	0	0.542 a (0.0.047)	0.267 ab (0.014)	34.0 a (1.5)	8.1 a (0.5)	72.3 a (4.0)	15.9 ab (0.7)	2.23 ab (0.06)
fresh	3	N/A	N/A	N/A	N/A	N/A	15.9 ab (0.7)	2.09 b (0.09)
fresh	10	N/A	N/A	N/A	N/A	N/A	16.8 a (0.9)	2.19 ab (0.10)
frozen	0	0.532 a (0.056)	0.259 b (0.017)	33.1 ab (3.3)	7.9 a (0.8)	76.6 a (7.0)	15.3 bc (1.0)	2.22 ab (0.20)
frozen	10	N/A	N/A	N/A	N/A	N/A	15.0 bc (1.2)	2.17 ab (0.13)
frozen	90	N/A	N/A	N/A	N/A	N/A	14.6 c (1.3)	2.31 a (0.20)
				Broccoli				
fresh	0	0.292 a (0.049)	0.251 b (0.020)	39.6 a (5.5)	4.7 a (0.5)	91.2 ab (18.3)	11.3 b (0.6)	8.04 c (0.29)
fresh	3	N/A	N/A	N/A	N/A	N/A	11.8 b (0.5)	8.73 c (0.40)
fresh	10	N/A	N/A	N/A	N/A	N/A	13.7 a (0.9)	11.09 a (0.41)
frozen	0	0.302 a (0.038)	0.251 b (0.017)	39.7 a (6.0)	4.4 a (0.4)	70.4 b (9.5)	11.2 b (0.8)	7.99 c (0.36)
frozen	10	N/A	N/A	N/A	N/A	N/A	10.8 b (1.1)	9.57 b (0.43)
frozen	90	N/A	N/A	N/A	N/A	N/A	11.4 b (0.5)	8.29 c (0.36)
				Carrots				
fresh	0	0.32 a (0.015)	0.228 a (0.021)	17.7 ab (0.7)	6.9 a (0.8)	71.1 a (12.3)	12.6 a (1.7)	1.08 ab (0.15)
fresh	3	N/A	N/A	N/A	N/A	N/A	12.0 a (0.6)	1.05 b (0.13)
fresh	10	N/A	N/A	N/A	N/A	N/A	13.5 a (1.5)	1.05 b (0.16)
frozen	0	0.306 a (0.010)	0.223 a (0.016)	18.5 a (0.5)	6.5 a (0.8)	60.5 a (7.4)	12.3 a (0.5)	1.33 a (0.26)
frozen	10	N/A	N/A	N/A	N/A	N/A	12.2 a (0.8)	1.22 ab (0.21)
frozen	90	N/A	N/A	N/A	N/A	N/A	9.2 b (0.3)	1.12 ab (0.26)
				Corn				
fresh	0	N/A	0.119 ab (0.005)	23.6 ab (1.1)	2.1 a (0.4)	16.6 a (1.2)	2.7 c (0.2)	2.42 a (0.07)
fresh	3	N/A	N/A	N/A	N/A	N/A	2.9 bc (0.2)	2.28 a (0.06)
fresh	10	N/A	N/A	N/A	N/A	N/A	2.9 bc (0.0)	1.97 b (0.16)
frozen	0	N/A	0.106 c (0.006)	21.8 b (1.0)	2.0 a (0.2)	14.6 a (1.3)	3.3 a (0.3)	2.45 a (0.12)
frozen	10	N/A	N/A	N/A	N/A	N/A	3.2 ab (0.1)	2.29 a (0.08)
frozen	90	N/A	N/A	N/A	N/A	N/A	3.1 ab (0.3)	1.76 c (0.07)
				Blueberries				
fresh	0	0.102 a (0.008)	0.061 b (0.000)	4.7 b (0.2)	2.8 a (0.3)	26.1 a (2.7)	7.0 a (0.3)	21.31 d (0.69)
fresh	3	N/A	N/A	N/A	N/A	N/A	7.1 a (0.4)	21.48 d (1.14)
fresh	10	N/A	N/A	N/A	N/A	N/A	6.8 ab (0.4)	22.07 cd (1.43)
frozen	0	0.102 a (0.006)	0.060 b (0.001)	4.8 b (0.1)	2.5 a (0.2)	24.7 a (4.1)	6.4 bc (0.3)	23.39 bc (0.74)
frozen	10	N/A	N/A	N/A	N/A	N/A	6.3 c (0.4)	24.57 ab (0.72)
frozen	90	N/A	N/A	N/A	N/A	N/A	6.9 ab (0.0)	26.13 a (0.61)
				Strawberries				
fresh	0	0.306 a (0.011)	0.170 a (0.013)	14.1 ab (0.6)	6.1 ab (0.5)	56.3 a (5.1)	8.8 a (0.5)	22.21 a (1.34)
fresh	3	N/A	N/A	N/A	N/A	N/A	8.8 a (0.5)	23.22 a (1.31)
fresh	10	N/A	N/A	N/A	N/A	N/A	8.7 a (0.7)	22.60 a (0.99)
frozen	0	0.290 a (0.036)	0.153 a (0.007)	14.0 ab (0.7)	5.6 ab (0.5)	46.6 b (2.2)	8.8 a (0.5)	21.91 a (0.40)
frozen	10	N/A	N/A	N/A	N/A	N/A	9.1 a (0.6)	22.43 a (0.78)
frozen	90	N/A	N/A	N/A	N/A	N/A	8.3 a (0.5)	22.03 a (1.49)

[a]Each data point represents the mean of six field replicates and is followed by the standard deviation for those replicates in parentheses. Significantly different values between storage points for a given commodity and nutrient are followed by different letters.

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were used to determine the significance of differences between both fresh and frozen treatments and storage time points for each commodity and nutrient.

■ RESULTS AND DISCUSSION

The results of this study are presented in Table 3. The content of five minerals as well as fiber and total phenolics was evaluated in eight different commodities stored under either refrigeration (fresh) or frozen conditions over three storage points.

Minerals. Rickman et al.[4] and previous authors have found that minerals are unaffected by the thermal treatments implemented during conventional food processing.[12,13] In fact, leaching of minerals during blanching is the only significant cause of loss of minerals that has been reported that is relevant to the conditions of this study. Water-soluble minerals can be extracted into the water used during the blanching process, causing losses in mineral content of food blanched before further processing.[4,6,14]

While all commodities were washed and scrubbed thoroughly prior to sampling, it is possible that some soil may have remained on the samples, which would have artificially augmented the baseline fresh values and would have caused an apparent decrease in frozen values due to the fact that the mineral-rich soil had been removed during blanching. To evaluate this possibility, an extra set of carrot samples was analyzed. The carrots were peeled after washing and sampled according to the same experimental protocol as the other samples in this study. Half of the peeled carrot samples were stored fresh, and the other half were blanched and frozen. There were no significant differences in mineral content between the fresh and frozen peeled carrots. This suggests that some of the difference in mineral content of samples immediately after blanching is due to removal of residual soil particles.

Calcium. Calcium was one of the best-retained nutrients in the fresh and frozen stored commodities evaluated over the course of this study. In all commodities, there were no significant differences between the frozen samples and those that were stored fresh (Table 3). These results were consistent with the findings of Wills et al.[15] and Maklouf et al.,[16] who found that the calcium content of frozen vegetables was highly conserved, if not higher than in fresh-stored produce.

Magnesium. Magnesium was largely well conserved over both fresh and frozen storage in most commodities. Broccoli, carrots, blueberries, and strawberries showed no significant difference in magnesium content between fresh and frozen samples (Table 3).

Frozen peas, spinach, and corn contained between ~7% and 18% less magnesium when compared to fresh samples (Table 3). These changes were apparent immediately following processing, indicating that minor losses were most likely caused by leaching of magnesium into the blanching water.[16,17]

Zinc. The trends in retention of zinc in frozen fruits and vegetables were similar to those of magnesium. Broccoli, carrots, strawberries, green beans, corn, blueberries, and spinach showed no significant difference between fresh and frozen treatments, while peas showed small losses (~5%) in frozen samples (Table 3).

Copper. Copper, like calcium, was well retained in frozen as compared to fresh produce. In all commodities, there were no significant decreases in the frozen samples (Table 3). This indicates that there were no losses due to leaching of nutrients during blanching, which is the only reason cited in the literature for loss of minerals during the freezing process where no tissue is removed.[4,12,13]

Iron. Two general trends were apparent in the retention of iron in frozen and fresh produce. In green beans, broccoli, carrot variety B, blueberries, strawberries, and peas, there were no significant differences in the iron content between the two treatments. However, in spinach and carrot variety A, the frozen samples had between 10% and 45% less iron than the fresh samples (Table 3). This could be due to leaching of iron during blanching,[14,16,17] since as illustrated with spinach, the loss occurs immediately after blanching and freezing. It may also have been due to small traces of soil left on the surface of products that was washed off during blanching. The amount of surface area exposed to blanching may have also contributed, since the carrots were diced prior to blanching and the spinach had high surface area naturally.

Acid-Digestible Fiber (ADF). Most of the commodities (blueberries, strawberries, green beans, peas, spinach, and corn) showed no significant change in fiber content over the course of fresh or frozen processing and storage (Table 3); however, some commodities showed increases during storage or declines as a result of either blanching or frozen storage. Broccoli showed an increase (21.2%) in fiber content during fresh storage (Figure 1). This could be due to continued respiration

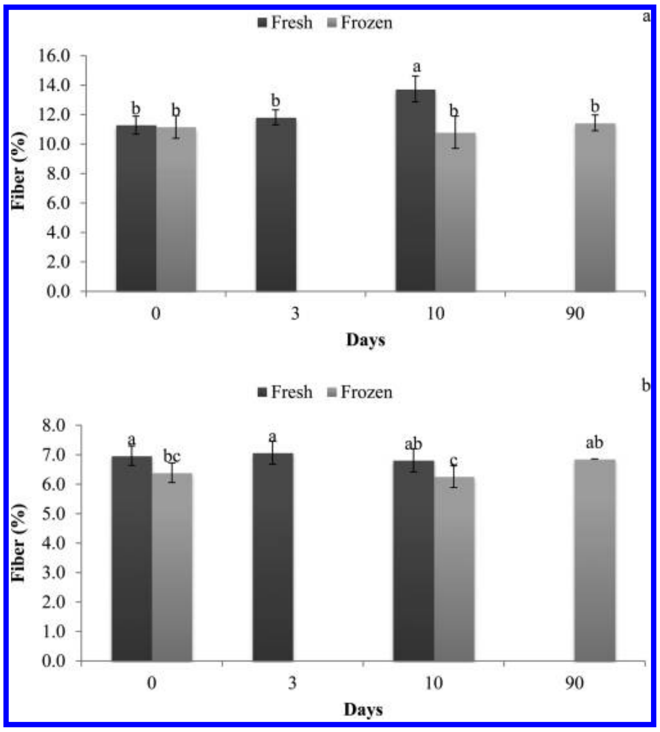

Figure 1. Fiber content of (a) broccoli and (b) blueberries during fresh and frozen storage. Values reported on a dry weight basis. Values that share the same letter (a, b, c) are not significantly different ($p \leq 0.05$).

and thickening of cell walls within broccoli tissue during storage.[18] Some commodities, such as bamboo shoots, have been known to exhibit such behavior during postharvest storage as a stress response.[19] It should be noted that while increases in fiber content were found in vegetables such as onions in previous studies,[20] the increases occurred over much longer periods of fresh storage than in this study. Onions respire

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slower than broccoli, so that may be the reason for the difference. This increase in fiber content during fresh storage caused fresh broccoli to appear to have higher fiber content than frozen broccoli, even though the fiber content of frozen broccoli was unaltered during processing and storage.

Both varieties of carrots lost fiber (~25%) during frozen storage. This could be due to degradation of cell wall components such as cellulose, hemicellulose, pectin, and lignin, which is known to occur during frozen storage of some commodities.[21] Degradation of these polysaccharides in these tissues could have caused the apparent decrease in fiber over storage time.

Fiber losses in peas appear to be due to physical losses during the blanching and freezing process, as the decline occurs immediately after these processes on day 0. According to Kunzek et al.,[22] thermal processing can cause changes in the solubility of plant carbohydrates, which could account for the losses seen in peas, which were among the commodities blanched before freezing. This seems to be corroborated by the fact that two of the commodities with the best retention of fiber were strawberries and blueberries, the two commodities that received no blanching treatment prior to freezing.

Some variability in the method of analysis of fiber, or variability in the raw material, may have had an impact on these results, as frozen blueberries showed slight decreases in fiber levels initially (~8%), but by the end of the 90 day frozen storage period, the frozen product was not significantly different from the fresh product (Figure 1). Previous studies indicated little to no loss of fiber for any commodities during processing apart from methods that involved peeling or otherwise removing plant tissue.[4,14]

Phenolics. Overall, phenolics were well retained in both fresh and frozen produce, and some commodities retained higher concentrations with frozen storage. Spinach, green beans, and carrots showed no significant differences between fresh and frozen produce, while broccoli, corn, and peas had lower levels of phenolic compounds in frozen samples (Figure 2). This could be due to either oxidation of phenolic compounds or leaching of water-soluble phenolic compounds during blanching.[14,23] The decline in phenolic content of peas during frozen storage may be due to oxidation of sensitive phenolic compounds, which can occur nonenzymatically even at temperatures encountered in frozen storage.[4,14] The increases in phenolics in broccoli and peas over the fresh storage period contrast with the findings of Vallejo et al.,[23] who found large losses in phenolic content of fresh broccoli over a period of 10 days, but are supported by Olivera et al.,[24] who proposed that rupture of cellular compartments such as vacuoles during processing could lead to increased availability of phenolic compounds. Blueberries showed higher values of phenolics in frozen compared to fresh samples. This may be due to high oxidative enzymatic activity in fresh blueberries, which would have been minimized by frozen storage.[24,25]

Conclusions. With regard to the nutrients studied, frozen fruits and vegetables represent nutritionally viable alternatives to fresh produce subjected to typical postharvest holding times. Total phenolics, fiber, and minerals were for the most part well conserved in frozen samples as compared to fresh, and when there were decreases in frozen samples, they were usually small and may have been due to some variability in the raw material.

In this study we sought to evaluate the nutritional quality of fruits and vegetables as they arrived to the consumer. A logical progression to future studies would include evaluation of what happens to that nutrient content during preparation for consumption in the home. Knowledge about basic culinary practices involved in preparation of these commodities for consumption in the home would provide useful insight into how they can best be preserved.

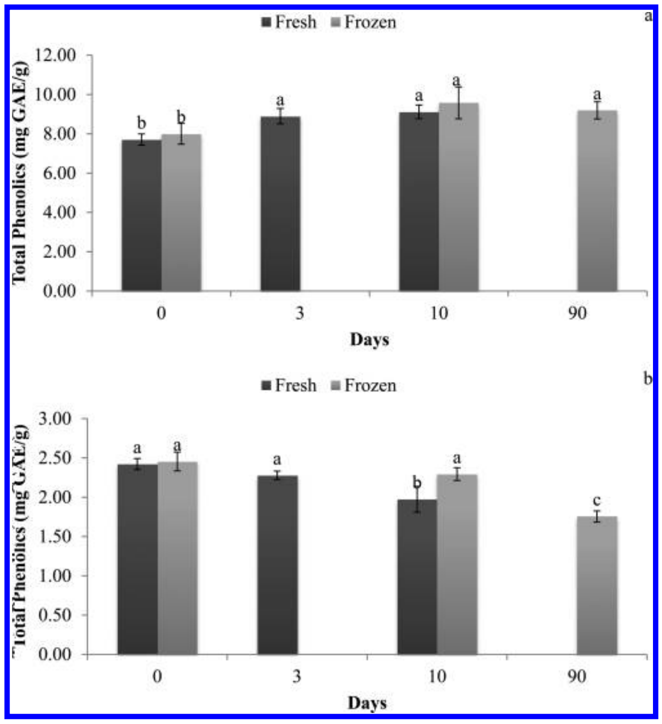

Figure 2. Phenolics content of (a) spinach and (b) corn during fresh and frozen storage. Values reported on a dry weight basis. Values that share the same letter (a, b, c, d, e) are not significantly different ($p \leq 0.05$).

AUTHOR INFORMATION

Notes

The authors declare no competing financial interest.

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