Effect of Canning and Freezing on the Nutritional Content of Apricots

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Abstract: The effect of commercial canning and freezing on the nutritional content of fresh apricots was investigated. Processed samples were analyzed post-processing and after 3 months of storage and compared directly to fresh apricots from the same source. Vitamin C, beta-carotene, total phenols, and antioxidants were quantified. Compared to fresh, canned apricots initially exhibited similar levels of antioxidants, a 17% increase in beta-carotene, and a 48% increase in phenols, while vitamin C was reduced by 37%. After 3 months of storage, antioxidant levels were 47% higher than fresh. Vitamin C did not change significantly following storage and beta-carotene decreased by 15%. The canned apricot fruit packed in light syrup did not have higher total soluble solids (TSS) levels indicating no increase in fruit sugar content. Frozen apricots exhibited large increases in antioxidants (529%), beta-carotene (35%), vitamin C (3,370%), and phenols (406%) compared to fresh. After 3 months of storage, frozen apricots decreased in vitamin C (29%) and phenols (17%), but remained 2,375% and 318% higher than fresh, respectively. Beta-carotene increased during storage, reaching levels 56% higher than fresh while antioxidant activity was unchanged. This study demonstrates that key nutrients in canned and frozen apricots are retained or amplified upon processing, with the exception of vitamin C in canned apricots. The routine addition of citric and ascorbic acid to fruit prior to freezing resulted in significantly higher antioxidants, vitamin C, and phenols. Consumers eating canned or frozen apricots can feel confident of similar or superior nutritional content as compared to fresh apricots.

Keywords: antioxidant, beta-carotene, total phenolic content, processing, vitamin C

Practical Application: The apricot industry is limited by the short shelf life of the fruit and consumer belief that processed produce is not as nutritious as fresh. Assessing the nutritional content of canned and frozen apricots and determining that processed apricots can deliver nearly comparable nutrient levels to fresh apricots provides the evidence needed to dispel these misconceptions and potentially increase demand for processed apricots among consumers.

Introduction

Increasing consumption of fruits is beneficial for human health. In recent years, increases in obesity, cancer, heart disease, and diabetes has led nutritional and health professionals to attempt to curtail the onset of these conditions through preventative dietary means. Increased consumption of fresh fruits, although encouraged, is often difficult to achieve. Short growing seasons, limited geographic spread of production regions, and short shelf lives resulting in deterioration in home refrigerators make year-round consumption of fresh fruit challenging or impractical for some consumers. Processing (canning, drying, jarring, freezing) has long been a method to increase distribution and longevity of produce. Although the 2015 to 2020 Dietary Guidelines, published by the United States Dept. of Agriculture (USDA) and the Dept. of Health and Human Services (DHHS), explicitly includes "fresh, frozen, canned, and dried" fruit in the recommendation of 2-cup equivalents per day, many consumers believe that fresh produce delivers superior nutrient content (USDA and DHHS, 2015). This public belief can limit the sale of processed produce and may not be based in fact (Rickman, Barrett, & Bruhn, 2007a). For example, Li, Pegg, Eitenmiller, Chun, and Kerrihard (2017) found that fresh broccoli, cauliflower, corn, green beans, spinach, blueberries, and strawberries do not have significantly higher nutrient levels than frozen, especially when taking into account consumer behaviors to store fresh produce at home before consumption, leading to decreased nutrient content.

Apricots are a climacteric fruit in the Rosaceae family with a short storage life of 3 to 5 days at ambient conditions and 2 to 4 weeks with cold storage (Agar & Polate, 1995; Egea, Martinez-Madrid, Sanchez-Bel, Murcia, & Romojaro, 2007). Apricots undergo rapid degradation and senescence upon harvest, which limits the availability of fresh apricots to consumers. According to USDA and the National Agricultural Statistics Service (NASS), 63% of apricots sold in California in 2015 were processed and 68% were processed in 2014 (USDA and NASS 2016). Apricots contain many health promoting properties: antioxidants, fiber, provitamin A carotenoids, organic acids, vitamins (vitamin C, thiamin, riboflavin, niacin, pantothenic acid, folic acid, and vitamin B6) and minerals (potassium, calcium, and magnesium), making them an attractive addition to a healthy diet (Tomás-Barberán, Ruiz, Rivera, Sánchez-Roca, & Gil, 2013).

The objective of this study was to determine if processed apricots (frozen and canned) retained nutrient levels comparable to that of fresh apricots and to assess the retention of these nutrients after 3 months of storage in the processed forms. As the majority of apricots are processed due to a limited fresh shelf life, it is

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important to quantify changes in nutrient content. A similar study showing nutrient levels in fresh and canned peaches discovered that canned peaches retained comparable nutrient levels and changed minimally over time (Durst and Weaver, 2011), increasing the duration that peaches can be consumed past the fresh season.

Materials and Methods

Samples – canned

Six boxes of fresh apricots (*Prunus armeniaca* var. Patterson), each from a separate harvested bin sourced from the same orchard in Westley, Calif., U.S.A., were collected and delivered to the University of California Postharvest Pilot Plant (Davis, CA, U.S.A.) on June 16, 2016 and held overnight at 0 °C. Each box was considered a replicate. The following day, 18 apricots were selected from each box and analyzed for TSS and antioxidant activity. A second sample of 18 apricots from each box were analyzed for vitamin C, beta-carotene, and total phenols as described below.

The same harvested bins were delivered to Pacific Coast Producers (Lodi, CA, U.S.A.) for commercial canning. Apricots in extra light syrup were sealed in 454 g (16 ounce) cans and heated at 93 to 96 °C for 8 to 12 min. Approximately 21 g of sucrose was added to each can (6 g sucrose per serving of apricot). After 3 months, canned samples were delivered to the Univ. of California Postharvest Pilot Plant and analyzed using the same methodology as the canned samples analyzed immediately following canning.

Samples – frozen

Six boxes of fresh Patterson apricots from three bins in one orchard and three bins from a second orchard (both in Westley, CA, U.S.A.) were harvested and delivered to the Univ. of California Postharvest Pilot Plant on June 16, 2016, and held overnight at 0 °C. The following day, the fresh apricots were analyzed as described above for canned apricots.

Fresh apricots from the same bins were delivered to Del Mar Food Products (Watsonville, CA, U.S.A.) on the same day as harvest to be Individually Quick Frozen (IQF) and stored at –17.8 °C. Apricots were cut in half, dipped in a 3.5% acid solution made of 1.75% ascorbic acid and 1.75% citric acid to prevent browning, and dewatered prior to freezing. This step leaves minimal residual acid on the apricots, but enough to prevent browning of the fruit. One week after IQF processing, six 6.4 kg boxes of frozen apricots were delivered to our UC Davis laboratory for analysis. Thirty-six halves of frozen apricots were used for analysis of total soluble solids (TSS) and antioxidants and another 36 frozen apricot halves were analyzed for vitamin C, beta-carotene, and total phenols using the methods outlined below. Frozen apricots were thawed before analysis.

Another six 6.4 kg boxes of frozen apricots were stored at Del Mar Food Products for 3 months at –17.8 to –23.3 °C and then delivered to our laboratory for analysis following the same methodology as the samples analyzed immediately after freezing.

Compositional analysis

Eighteen apricots were selected from each of the 6 bins. A wedge including one quarter of each fruit was cut and a composite juice sample consisting of the 18 quarter wedges was extracted together using a hand press. The juice from each of the replications was analyzed for TSS using a temperature compensated refractometer (Reichert, Depew, N.Y., U.S.A.).

A second wedge including one quarter of the apricot was cut from the same 18 fruit analyzed for TSS. Antioxidants were analyzed using the ferric reducing ability of plasma (FRAP) method (Benzie & Strain, 1996) and reported as mM Fe/100 g. Vitamin C and beta-carotene were analyzed by HPLC (Bouzari, Holstege, & Barrett, 2015) and reported on a dry weight basis. Total phenols were measured using the Folin-Ciocalteu colorimetric assay (Singleton & Rossi, 1965; Waterhouse, 2003) and reported in mg gallic acid equivalents (mg GAE/g) on a dry weight basis.

Statistical analysis

For each analyte, unpaired *t*-tests were used to determine significant differences between the means of fresh and processed samples without storage. Paired *t*-tests were used to compare means of processed without storage and processed after 3 months of storage. Two sets of fresh samples were analyzed, one for each processing type, to account for differences in composition due to orchard management, variety, and growing location. Canned samples were compared to fresh samples from the six bins in the orchard that supplied the apricots to be canned, and frozen samples were compared to fresh samples from the three bins in each of two orchards that supplied the apricots to be frozen. Differences were considered significant when the *P*-value was <0.05.

Results and Discussion

Canned apricots

Beta-carotene. There was a slight increase in beta-carotene immediately after canning, but after 3 months in the can there was no difference from the at harvest values (Table 1). Canned apricots retained beta-carotene levels comparable to fresh apricots after 3 months in the can. Provitamin A carotenoids are lipid soluble, making them less prone to leaching into canning mediums than water soluble nutrients (Rickman, Bruhn, & Barrett, 2007b). Lessin, Catigani, and Schwartz (1997) found an increase in provitamin A carotenoids in thermally processed collards, broccoli, sweet potatoes, spinach, and carrots which they hypothesized to be due to the deactivation of enzymes capable of degrading carotenoids and increased extraction efficiency.

Antioxidants. Antioxidant activity was not significantly changed immediately after canning of apricots, but increased after 3 months in the can compared to both freshly harvested and just-canned apricots (Table 1). Canned peaches were found to have >1.5 times higher antioxidant activity than fresh peaches, with no significant decrease after 3 months of storage in the can (Durst and Weaver, 2011). The authors hypothesized an increase in solubility of phenolic compounds or deactivation of enzymes that degrade phytonutrients. Increases in antioxidant activity have also been reported in thermally processed sweet corn (Dewanto, Wu, & Liu, 2002a) and tomatoes (Dewanto, Wu, Adom, & Liu, 2002b; Gahler, Otto, & Böhm, 2003). The reason why we did not observe an immediate increase in antioxidant activity in apricots is unknown.

Vitamin C. There was a 37% decrease in vitamin C immediately after canning; however, there was no further decrease in vitamin C content during 3 months' storage in the can (Table 1). Vitamin C is water-soluble and heat sensitive, making it extremely prone to oxidation during the canning process (Kalt, 2005). Losses in ascorbic acid during canning have been reported for broccoli (Murcia, López Ayerra, Martínez Tomé, Vera, & García Carmona, 2000), carrots (Howard, Wong, Perry, & Klein, 1999), sweet corn (Dewanto et al., 2002a), and tomatoes (Dewanto et al., 2002b; Gahler et al., 2003), among others due to the duration of exposure to severe heat and leaching into the canning medium. In

Table 1–Comparison of fresh apricots with canned apricots at canning and after 3 months of storage in the can.[a,b]

Analyte	Fresh	Canned	Canned 3M storage	Fresh compared with canned	Fresh compared with canned 3M	Canned compared with CANNED 3M
Beta-Carotene (mg/kg)	100.28 ± 13.97	117.72 ± 7.91	100.20 ± 7.35	S*	NS	S**
Vitamin C (mg/kg)	234.3 ± 12.6	147.5 ± 43.1	126.0 ± 20.6	S**	S***	NS
Phenols (mg GAE/g)	1.633 ± 0.151	2.412 ± 0.512	2.808 ± 0.366	S**	S***	NS
Antioxidant activity (mM Fe 100 g^{-1})	1.070 ± 0.328	0.772 ± 0.300	1.573 ± 0.320	NS	S*	S**
Total Soluble Solids (%)	13.83 ± 0.66	12.58 ± 0.55	12.50 ± 0.39	S**	S**	NS

[a]Results are stated as the mean ± standard deviation.
[b]Significance was compared using 2-sample t-test. NS, not significant ($P \geq 0.05$); S, significant ($P < 0.05$).
*Significant at $P < 0.05$; **Significant at $P < 0.01$; ***Significant at $P < 0.001$.

contrast to these findings, Durst and Weaver (2011) observed an increase in vitamin C content in canned peaches, but in agreement with our study, vitamin C content in peaches did not change significantly during 3 months of canned storage. Despite initial losses upon thermal treatment, ascorbic acid is relatively stable during storage of canned products (Rickman et al., 2007a).

Phenols. Total phenol content increased 48% with canning, and remained unchanged during 3 months of storage (Table 1). Chaovanalikit and Wrolstad (2004) discovered a slight increase in total phenols and anthocyanins following canning of cherries, which they attributed to increased phenolic extraction due to increased membrane permeability of the fruits. Increases in phenolic content with thermal processing have also been reported in sweet corn (Dewanto et al., 2002a) and tomatoes (Gahler et al., 2003).

Total soluble solids. Total soluble solids decreased significantly with canning from 13.83% to 12.58% and did not change significantly during storage in the can, indicating that despite the addition of light syrup, the apricot fruit itself did not absorb sugars (Table 1).

Frozen apricots

Beta-carotene. The fresh apricots harvested for the frozen experiment had very similar levels of beta-carotene to those from the canning experiment (Table 1 and 2). After freezing, there was an immediate 35% increase in beta-carotene, and after 3 months of storage, beta-carotene levels were 56% greater than the at harvest levels (Table 2). Scott and Eldridge (2005) reported higher beta-carotene values for frozen corn and comparable levels for canned corn. Increased levels of phytochemicals after processing may be due to degradation of cellular matrices, making them more bioavailable and detectable (Barrett, 2007; Howard et al., 1999; Leong & Oey, 2012; Rickman et al., 2007b).

Antioxidants

The apricots harvested for the frozen experiment had similar antioxidant activity to those harvested for the canning experiment (Table 1 and 2). Frozen apricots had 6-fold higher antioxidant activity compared to fresh apricots and there was no further change during 3 months frozen storage (Table 2). The large increase in antioxidant activity was likely due to the addition of ascorbic and citric acid to the apricots before freezing. The addition of ascorbic acid (an antioxidant itself) was found to increase antioxidant activity in lettuce (Altunkaya and Gokmen 2008). Hunter and Fletcher (2002) found that frozen peas and spinach had similar antioxidant levels compared to their fresh equivalents higher than the canned or jarred equivalent. When citric acid was used as a prefreezing treatment on strawberries, they maintained higher levels of vitamin C and anthocyanins than without citric acid (Abd-Elhady, 2014).

In contrast with our study, Jimenez and others (2008) observed a decrease in antioxidant activity after freezing of apricots. A prefreezing, antibrowning treatment of ascorbic and citric acids was also used on their samples, but with a concentration of 0.1% each, significantly lower than the 3.5% each that was used prior to freezing of our apricots. In agreement with our findings, Jimenez and others (2008) found that antioxidant activity in frozen apricots did not change during 5 months of frozen storage.

Vitamin C

The vitamin C content of the apricots sourced for the frozen experiment were higher than in the apricots used for the canned experiment. The vitamin C content of the frozen apricots was 34-fold higher than the fresh apricots (Table 2). The high increase in vitamin C in frozen apricots can most likely be attributed to the processing method in which the apricots were dipped in the ascorbic acid and citric acid solution. While freezing generally does not result in a decrease in vitamin C content (Rickman et al., 2007a), the direct effects of freezing cannot be differentiated from the effects of adding ascorbic and citric acids as a prefreezing treatment. In strawberries, a prefreezing treatment of citric acid, used as an antibrowning agent, led to a corresponding increase in ascorbic acid content at increasing concentrations of citric acid (Abd-Elhady, 2014), indicating a protective effect. Hunter and Fletcher (2002) found the ascorbic acid content of frozen spinach and frozen peas to be greater than or equal to their fresh counterpart. During 3 months of frozen storage, vitamin C content of apricot samples decreased 29%, but remained 25-times higher than the fresh samples (Table 2). Howard et al. (1999) observed a linear loss of ascorbic acid in frozen broccoli over 1 year of freezer storage with losses as high as 48%. Minimal losses in ascorbic acid content were observed throughout storage in frozen green beans, carrots, and spinach (Favell, 1998) and in corn, carrots, broccoli, spinach, peas, green beans, strawberries, and blueberries (Bouzari et al., 2015).

Phenols

Total phenol content in fresh apricots was similar between those used for the canned and frozen experiments. Total phenols increased 406% in frozen apricots compared to the fresh product at harvest, and decreased 16% during 3 months of storage (Table 2). Ascorbic acid is used as a competitive inhibitor of polyphenol oxidase (PPO) (Altunkaya & Gökmen, 2008), the enzyme responsible for browning reactions (Martinez & Whitaker, 1995). Browning reactions are induced by oxidation of phenolic compounds to quinones by PPO (Martinez & Whitaker, 1995); therefore, inhibition of PPO by ascorbic and citric acids will prevent losses of total phenols. Ascorbic acid has been found to aid in retention of phenolic compounds in lettuce (Altunkaya &

Table 2–Comparison of fresh apricots with frozen apricots at freezing and after 3 months of frozen storage.[a,b]

Analyte	Fresh	Frozen	Frozen 3M storage	Fresh compared with frozen	Fresh compared with frozen 3M	Canned compared with frozen 3M
Beta-Carotene (mg kg^{-1})	99.68 ± 6.09	134.82 ± 4.26	155.92 ± 3.75	S***	S***	S***
Vitamin C (mg kg^{-1})	399.8 ± 49.2	13876.0 ± 1274.2	9898.7 ± 778.0	S***	S***	S***
Phenols (mg GAE $g^{-1)}$	1.452 ± 0.294	7.352 ± 1.198	6.075 ± 0.528	S***	S***	S*
Antioxidant activity (mM Fe 100 g^{-1})	1.033 ± 0.493	6.498 ± 0.913	6.773 ± 1.467	S***	S***	NS
Total Soluble Solids (%)	14.05 ± 1.11	13.42 ± 1.24	15.55 ± 1.25	NS	S*	S*

[a]Results are stated as the mean ± standard deviation.
[b]Significance was compared using 2-sample *t*-test. NS, not significant ($P \geq 0.05$); S, significant ($P < 0.05$).
*Significant at $P < 0.05$; **Significant at $P < 0.01$; ***Significant at $P < 0.001$.

Gökmen, 2009). Ali, El-Gizawy, El-Bassiouny, and Saleh (2015) found that ascorbic acid at concentrations less than 1.5% behaved as an enzyme competitive inhibitor, but at higher concentrations was also able to act as a quinone reducer. Citric acid is used to suppress PPO activity by decreasing the pH and chelating copper at an active site of PPO (Martinez & Whitaker, 1995). Ascorbic acid was demonstrated to prevent degradation of anthocyanins (phenolic compounds) in lychee (Jiang, 2000). The addition of ascorbic and citric acids likely influenced the high phenol content, but cannot explain such a large increase. In frozen peaches, the total phenols were found to increase significantly and remain unchanged after 3 months of storage. This increase may have been due to an increase in extractability due to disruption of cellular matrices during the freezing process (Asami, Hong, Barrett, & Mitchell, 2003). de Ancos, González, and Pilar Cano (2000) observed an increase upon freezing in the total phenolic contents in 2 varieties of raspberries, which remained unchanged after a year of frozen storage. The increase in total phenol content in frozen apricots may be due to a combination of increased extractability due to freezing and decreased PPO activity by the addition of the acid solution, but the singular effect of either cannot be determined alone.

Total soluble solids

There was no immediate change in total soluble solids immediately after freezing, but after 3 months of storage, the total soluble solids increased significantly (2.5% higher than at harvest) (Table 2).

Due to the addition of ascorbic and citric acids as a prefreezing treatment to prevent browning, the effects of freezing cannot be completely differentiated from the effects of the acid addition. While the addition of ascorbic acid, an antioxidant, directly increased the vitamin C content and antioxidant activity, the prevention of enzymatic browning by both citric and ascorbic acids also contributed to the high level of total phenols. Chen, Kao, and Lin (2008) found that increasing pH led to a decline in phenolic content and decreased antioxidant activity in yams. Golubitskii, Budko, Basova, Kostarnoi, and Ivanov (2007) found that vitamin C was more stable in an acidic medium. Anthocyanin and total phenol levels decreased in cherries frozen without the addition of a prefreezing acid treatment, likely due to continued PPO activity (Chaovanalikit & Wrolstad, 2004). The pH was decreased due to the addition of the acids, which could also result in more stabilization of nutrients.

Conclusions

Due to their very short shelf life, many apricots are processed to increase the duration of the marketing season and availability to consumers. Canning or freezing apricots allows for greater market reach by stabilizing the products, and provides comparable or superior nutritional content compared to fresh apricots. For example, beta-carotene, phenols, and antioxidant activity were higher in canned and frozen products. Vitamin C content was much higher in frozen product, but significantly reduced in canned apricots. Canning and freezing can allow for increased extractability or solubility of nutrients while prefreezing treatments can enhance nutrient content. Consumers eating canned or frozen apricots can feel confident of similar or superior nutritional content as compared to fresh apricots.

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Author Contributions

Claire Adkison conducted the data analysis and wrote the first draft of the manuscript; Bill Biasi planned the experiments and assisted with sample collection and analysis; Veronique Bikoba conducted the antioxidant activity assay; Dirk Holstege conducted the phenol and vitamin C assays, and Elizabeth Mitcham planned the experiments, assisted with data analysis, and revised the manuscript.

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