Calcium ascorbate treatments to control the fresh-cut apple quality reduction when stored at high temperature

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Abstract

Previous studies have demonstrated that apple slices dipped in 20% calcium ascorbate (CaAsc) reduced the browning, allowing a shelf life of 28 d when stored at 4°C, and storage at 0°C is best practice. However, the use of low storage temperatures for fresh-cut fruit could be difficult to implement in some countries, markets or in the home refrigerator. For that reason, the effect of storage temperature (0, 4 and 8°C) in 'Braeburn' apple slices dipped in CaAsc (0 and 20% w/w), stored in air for up to 28 d was studied. Changes in antioxidant levels were measured using reducing activity (FRAP) and ascorbic acid content (AA). Changes in browning and sensorial quality were measured to indicate eating quality. CaAsc dips increased the initial levels of AA from 0.19 g kg^{-1} in the untreated slices to 3.94 g kg^{-1} for the 20% CaAsc treatment. After 28 d of storage, the AA reduction in treated slices was 33% when stored at 0 and 4°C and 74% at 8°C. For FRAP, the antioxidant activity decrease was 42, 65 and 69% for slices stored at 0, 4 and 8°C, respectively. In terms of overall quality, untreated slices did not achieve acceptable quality at a shelf life of even 7 d for any temperature studied. However, treated apples extended the shelf life to less than 21 d when stored at 8°C, and 28 d when temperature of 0 or 4°C was used. Thus, the use of CaAsc dips in apple slices can moderate the overall quality reduction when high storage temperatures are used, but a temperature of 0 to 4°C is the optimum storage temperature.

Keywords: ready to use, minimal processing, vitamin C, antioxidant capacity, appearance

INTRODUCTION

There has been a rapid growth of fresh-cut produce industry worldwide in recent years to a multi-billion dollar sector, mainly because of increasing consumer demand for healthy, freshly prepared, convenient fruits and vegetables (Qadri et al., 2015). Mixed fruit, apples, pineapple and watermelon account for the largest dollar and unit share of fresh cut fruit sales in US grocery retail (Cook, 2012). In addition, apples have been shown to have beneficial effects on vascular function, blood pressure, lipids, inflammation and hyperglycaemia. The cardio protective effects of apples, and other fruits, have been primarily ascribed to their high polyphenol content (Bondonno et al., 2017). One way to increase fresh fruit consumption is processing fruit into a fresh-cut product which is convenient. However, fresh-cut processing results in major tissue disruption of surface cells and injury stress of underlying tissues (Toivonen, 2004).

The main problem for fresh-cut apple is oxidation caused by polyphenol oxidase (PPO) that exists in particularly high amounts in apple (Whiteker, 1972). The resulting undesirable browning makes the product undesirable to the consumer. A range of treatments has been applied to extend the shelf life of fresh-cut apples such as dipping in solutions of a wide range of anti-browning agents such as calcium ascorbate (CaAsc).

Application of exogenous CaAsc significantly increases the antioxidant status of apple

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slices and is increases shelf life (Aguayo et al., 2015). Fresh-cut 'Braeburn' apple slices dipped in 6 or 12% CaAsc and stored in modified atmosphere packaging (MA) or dipped in 20% CaAsc and packaged in air or MA had a shelf life of 21-28 d (Aguayo et al., 2010). On the other hand, to delay loss of quality and guarantee product shelf life, control of storage temperature is important. In a recent research, temperature was demonstrated to dramatically affect not only quality and hygiene indicators of fresh-cut salad, but also consumer acceptance and the tendency of consumers to waste the product at the domestic level. The cold chain (below 5°C) should be maintained during production, distribution, retail and during domestic storage until use. However, low temperatures may be difficult to implement in countries, markets or even in at the consumer level (Marklinder and Eriksson, 2015).

In this work, the protective effect of CaAsc dips (0 and 20% w/w) in 'Braeburn' apple slices were evaluated when product was storage under three different storage temperatures -0, 4 and 8°C.

MATERIALS AND METHODS

Raw material and treatments applied

New Zealand grown 'Mahana Red' apples (*Malus domestica* Borkh., a sport of 'Braeburn') were sourced from coolstores of a commercial supermarket and transported to the laboratory and stored at 0°C for 12 h. The apple boxes were opened in a food-grade processing room (10°C) and the fruit sorted to remove those damaged or with significant variation in background color. Whole apple surfaces were sterilised by dipping in cold water (4°C) with 5 mg L^{-1} chlorine dioxide (Oxine™, Australasia Marketing Pty Ltd Sydney, NSW, Australia) for 15 min. The apples were then manually cored and cut into 8 slices (sing a hand-held slicer. Slices were dipped in cold water (0°C) with 2 mg L^{-1} chlorine dioxide for 2 min, and the slices drained. CaAsc solution was prepared using water at 0°C pre-treated with 2 mg L^{-1} chlorine dioxide then made up to a concentration of 20% (w/w) using CaAsc (99.9% purity, Wolf Canyon Asia Pacific Ltd) or 0% (control), and dipped for 2 min then drained. Apple skins were not removed prior to treatment, since apple slices are currently marketed with skin intact.

Apple slices were randomized across packages of 15 apple slices (350±20 g) per aluminum bag (25×18 cm, 80 μm thickness, Caspak, New Zealand). To maintain near-ambient oxygen concentration in the air treatment bags, a 5-mm hole was punched through both sides of each bag. Three replicate bags per treatment were stored at 0, 4 and 8°C per storage duration: 0, 7, 14, 21 and 28 d.

Sensory evaluation

A panel of five people were trained to recognize and score the quality attributes of the treated slices. All assessments were compared to slices freshly cut from whole air-stored apples of the same variety and purchase date. Appearance, taste and texture were scored on a nine-point scale where 1 = complete lacking or soft, to 9 = fully characteristic of fresh. A similar scale, where 1 = inedible, 3 = poor, 5 = fair (limit of marketability), 7 = good and 9 = excellent was used for the evaluation of the overall acceptability. Only overall acceptability data are presented.

Analysis of bioactive compounds

Fruit pieces were flash frozen in liquid nitrogen and stored at -80°C for a maximum of 2 months. To ensure uniformity, frozen samples (200 g) were either homogenized in 100 mL of distilled water in a commercial blender (Sunbeam Model PB7600, Type 504, 230-240V, Auckland, New Zealand) to produce a juice extract (for the antioxidant activity analysis), or 150 g ground to a fine powder in a Cryomill in liquid nitrogen (for ascorbic acid content (AA) analysis).

1. Ascorbic acid evaluation.

A 0.2 g sample of powdered apple tissue was suspended in 1 mL of 6% metaphosphoric

acid, 2 mM EDTA and 1% PVPP containing 4 mM TCEP (tris[2-carboxyethyl] phosphine hydrochloride). The slurry was vortexed for 20 s, and incubated in a heating block for 2 h at 40°C to ensure full reduction of any dehydroascorbate. The extract was clarified by centrifugation at 4°C for 10 min, and 20 µL of the supernatant was injected into a 7.8×300 mm Aminex HPX-87H HPLC column (Bqsio-Rad, Merck, Darmstadt, Germany). The column was run with 2.8 mM H_2SO_4 as the mobile phase, at a flow rate of 0.6 mL min^{-1}. The amount of AA was detected using a Waters 996 photodiode-array detector set at 245.5 nm for absorbance using AA (Sigma, St. Louis, MO) as a standard. The peak was authenticated as AA by showing that it was completely degraded by ascorbate oxidase at pH 5.5.

2. Antioxidant activity.

The reducing activity was measured using the FRAP assay according to Benzie and Strain (1996) with some modifications. FRAP reagent contained 25 mL of 0.3 M acetate buffer (pH 3.6), 2.5 mL of 10 mM TPTZ (2,4,6-tris 2-pyridyl-s-triazine) solution in 40 mM HCl and 2.5 mL of 20 mM ferric chloride ($FeCl_3$ $6H_2O$). This reagent was freshly made up each d. The assay was performed using 198 µL of warmed (37°C for 2 h) FRAP reagent mixed with 6 µL of the corresponding juice homogenate and incubated for 20 min at 20°C. The ferric reducing ability of apple extracts was measured by the increase of absorbance at 593 nm. It was expressed as AA equivalent antioxidant activity per g fresh weight of apple tissue.

Statistical analysis

To determine the effect of storage temperature with or without CaAsc dips on each dependent variable, a one-way analysis of variance (ANOVA, $P<0.05$) was carried out (Statgraphics Centurion, version XV.II software (StatPoint, Inc., USA). This statistic analysis was performed for each d of analysis. Mean values were compared by LSD (multiple range least significant difference test) to identify significant differences among treatments.

RESULTS AND DISCUSSION

Antioxidant activity was measured using FRAP method. The antioxidant activity of untreated apples slices on d 0 was 1.01 g AA kg^{-1} (Table 1). However, slices dipped in 20% of CaAsc resulted in 7.21 g AA kg^{-1}, seven times more antioxidant activity than the control. Antioxidant activity decreased with time of storage, especially at the highest temperature - 8°C. After 28 d, a significant reduction was found - 50, 65 and 69% reduction for 0, 4 and 8°C, respectively.

Table 1. Antioxidant activity (FRAP as g ascorbic acid kg^{-1} f.w.) of fresh-cut apple dipped into 0 or 20% of calcium ascorbate solution, packaged in air and stored for 28 d at 0, 4 or 8°C.

Temperature of storage (°C)	CaAsc (%)	Time of storage				
		0 d	7 d	14 d	21 d	28 d
0	0	1.01 b	1.01 d	0.87 c	0.80 c	0.80 d
	20	7.21 a	6.20 a	4.90 a	4.18 a	3.66 a
4	0	1.01 b	1.04 d	0.81 c	0.76 c	0.87 d
	20	7.21 a	5.64 b	4.68 a	3.77 a	2.54 b
8	0	1.01 b	0.92 d	0.82 c	0.76 c	0.85 d
	20	7.21 a	4.19 c	3.02 b	2.07 b	2.22 c

Data represents means of 3 replicates. Different letters within the same column denote a significant difference ($P<0.05$).

A similar trend to that of antioxidant activity was found for AA content, the initial level of untreated apple slices was of 0.19 g kg^{-1} and immediately after treatment, AA content was 21-fold higher for the 20% CaAsc treatment (Table 2). Ascorbic acid was also decreased with time of storage. At the end of the experiment, a lower reduction of AA in apple slices was measured in apple stored at 0°C. In contrast, a higher but similar decrease was obtained when temperatures of 4 and 8°C was used.

Table 2. Ascorbic acid content (g kg^{-1} f.w.) of fresh-cut apple dipped into 0 or 20% of calcium ascorbate solution, packaged in air and stored for 28 d at 0, 4 or 8°C.

Temperature of storage (°C)	CaAsc (%)	Time of storage				
		0 d	7 d	14 d	21 d	28 d
0	0	0.19 b	0.22 c	0.22 c	0.22 c	0.19 c
	20	3.95 a	3.72 a	2.74 a	2.32 a	2.61 a
4	0	0.19 b	0.23 c	0.23 a	0.22 c	0.22 c
	20	3.95 a	2.70 b	2.73 a	2.61 a	1.59 b
8	0	0.19 b	0.22 c	0.22 c	0.22 c	0.20 c
	20	3.95 a	2.63 b	1.78 b	1.40 b	1.05 b

Data represents means of 3 replicates. Different letters within the same column denote a significant difference (P<0.05).

Sensory evaluation showed that the appearance of slices was improved by dipping in CaAsc solutions (data not shown). After 7 d of storage at any temperature, slices not treated with CaAsc were scored under the limit of marketability. The shelf life was extended to 28 d when apples were dipped in 20% CaAsc treatment and stored at 4°C, and best quality was observed at 0°C. However, the storage at 8°C, reduced the shelf life to less than 21 d (Table 3).

Table 3. Overall quality (1 to 9) of fresh-cut apple dipped into 0 or 20% of calcium ascorbate solution, packaged in air and stored for 28 d at 0, 4 or 8°C.

Temperature of storage (°C)	CaAsc (%)	Time of storage				
		0 d	7 d	14 d	21 d	28 d
0	0	8.0 a	4.5 c	4.0 b	3.7 b	3.7 c
	20	8.0 a	8.3 a	8.0 a	7.0 a	7.0 a
4	0	8.0 a	4.3 c	3.7 b	2.3 c	2.0 d
	20	8.0 a	7.3 b	7.1 a	6.3 a	5.3 b
8	0	8.0 a	4.3 c	3.0 b	1.0 d	1.0 d
	20	8.0 a	7.0 b	6.7 a	3.0 c	3.0 cd

Data represents means of 3 replicates. Different letters within the same column denote a significant difference (P<0.05). Data based on hedonic scale where 1 = unusable, 3 = poor, 5 = fair (limit of marketability), 7 = good and 9 = excellent.

These results demonstrate the strong anti-browning potential of CaAsc in fresh-cut apples as other authors have previously reported (Luo and Barbosa-Cánovas, 1996; Mola et al., 2016). In addition, an optimal concentration of antioxidant levels in tissue ensures long storage periods. The retention of overall quality in apple slices have been correlated with the retention of antioxidant levels (Aguayo et al., 2010). Storage temperatures higher than recommended are responsible for a rapid reduction in bioactive compounds and overall quality of fresh-cut fruits and is likely to be associated with greater waste. It has been estimated that lowering home refrigerated temperature from 7 to 4°C could annually save 32,000 t of leafy salad waste in UK (Brown et al., 2014). Temperature is an important factor known to influence quality of fresh-cut fruits and vegetables. However, temperature varies considerably in the distribution chain of different food companies, or it is too high in home refrigerator or difficult to implement in many countries. This will have an impact on product quality, shelf-life and food waste (Nunes et al., 2009). One way to reduce waste loss is using dips such as CaAsc to control the fresh-cut apple quality and bioactive compounds level if stored at higher temperatures.

CONCLUSIONS

CaAsc on fresh-cut apples combined with proper storage temperature resulted in a good quality product obtaining a shelf life of 28 d at 0 or 4°C. High temperature of storage lead a rapid bioactive compound reduction and overall quality decay of apple, the application of CaAsc helped to maintain antioxidant capacity and ascorbic acid level.

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