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Effect of slicing and controlled-atmosphere storage on the ascorbate content and quality of strawberries and persimmons

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Abstract

Changes in quality, total ascorbic acid, reduced ascorbic acid and dehydroascorbate in fresh cut 'Selva' strawberries (*Fragaria x ananassa* Duch.) held for 7 days and 'Fuyu' persimmons (*Diospyros kaki* L.) held for 8 days at 5°C in air or controlled atmospheres were evaluated. Various atmospheres had significantly different effects on the color, pH, and titratable acidity of the fruits. The two fruits responded differently to the wounding stress in regards to oxidation of ascorbic acid, but in both cases, the postcutting life based on visual quality ended before significant losses of total ascorbic acid occurred. Controlled atmospheres of 2% O_2, air + 12% CO_2, or 2% O_2 + 12% CO_2 had no significant effect on changes in total ascorbate content for either fruit. Washing of intact or sliced strawberries in 100 ppm sodium hypochlorite was found to induce significant oxidation of reduced ascorbic acid, but resulted in no changes in total ascorbic acid.

Keywords: Strawberry; *Fragaria x ananassa* Duch.; Persimmon; *Diospyros kaki* L.; Controlled atmosphere; Ascorbic acid

1. Introduction

Fresh fruits and vegetables supply more than 90% of the ascorbic acid in the US diet (Goddard and Matthews, 1979). Fresh strawberries are a good source of ascorbic acid; estimates of total ascorbic acid (TAA) content range from 59 mg/100 g (USDA, 1982) to 66–78 mg/100 g for the 'Selva' variety evaluated in this study (Kader, 1991). 'Fuyu' persimmon fruit grown in Georgia contained 97 mg/100 g reduced ascorbic acid (RAA) and 218 mg/100 g TAA (Homnava et al., 1990), making them an excellent source of this nutrient. In addition to its anti-scorbutic properties and its enhancement of the absorption of non-heme iron, ascorbic acid is an antioxidant which reacts directly with superoxide, hydroxyl radicals and singlet oxygen. It may therefore offer some protection against oxidative stress-related disease and degeneration associated with aging, such as coronary heart disease, cataract formation and cancer (Gershoff, 1993; Sauberlich, 1994). RAA is reversibly oxidized to dehydroascorbate (DHA), which is the basis of its physiological activity, both in humans and in plants (Erdman and Klein, 1982); DHA is reduced enzymatically to regenerate the active form (Tolbert and Ward, 1982). DHA is less stable than RAA and may be hydrolyzed to 2,3-diketogulonic acid, which does not have physiological activity (Klein, 1987).

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As the consumption of fresh-cut fruits increases, it has become important to discover what effect the preparation steps involved in this type of processing have on the ascorbate content of these products; it is conjectured that it will be lower than in intact produce (Klein, 1987; McCarthy and Matthews, 1994). Wounding, such as cutting, could lead to the loss of ascorbate in several ways. Ascorbate is susceptible to degradation in the presence of light and oxygen (Klein, 1987), to which the interior of the fruit is exposed by cutting. Oxidation also occurs on exposure to halides, such as hypochlorite (Bielski, 1982); due to concerns about the microbiological safety of fresh-cut produce, many products are washed in a solution of sodium hypochlorite. Ascorbate is oxidized by interaction with enzymes, such as ascorbate oxidase, polyphenol oxidase, cytochrome oxidase and peroxidase (Erdman and Klein, 1982). Cutting damages cells adjacent to the cut, resulting in the mixing of enzymes and substrates that would be compartmentalized in undamaged tissue (Watada et al., 1990). Membrane deterioration that results after wounding may also result in the formation of free radicals, which interact with antioxidants, such as ascorbate (Thompson et al., 1987; Watada et al., 1990)

The effect of controlled atmospheres on the ascorbate content of intact fruit has not been extensively studied; the results vary among fruit species and cultivars, but the tendency is for reduced oxygen and/or elevated carbon dioxide levels to enhance the retention of ascorbate (Kader et al., 1989; Weichmann, 1986). For sliced 'Pajaro' strawberries, Rosen (1987) found no significant differences between air storage and CA treatments; however, 'G-3' strawberries stored in 2% O_2 for 7 days at 2.5°C had a significantly higher level of ascorbate than fruit stored in air. To the best of our knowledge, no other studies on the effect of controlled-atmosphere storage on the ascorbate content of fresh cut fruit have been published. In this study, we investigated the effect of controlled-atmosphere storage on the ascorbate species present in sliced strawberries and persimmons, and evaluated the immediate effect of washing in sodium hypochlorite on ascorbate content of strawberries. We also studied the effect of controlled-atmosphere storage on the quality of the fruit.

2. Materials and methods

2.1. Plant material

'Selva' strawberries were obtained on the day of harvest from the Naturipe Cooperative in Watsonville, CA. The fruit was forced-air cooled to near 1°C and was transported to Davis in an air-conditioned vehicle. The fruit was stored overnight at 0°C before being prepared for experiments the following morning. The berries were sorted to remove damaged and defective fruit. Fruit that were less than 3/4 red or over mature were also eliminated. Three replicates consisting of 8 berries each and weighing approximately 150 g were used per treatment.

'Fuyu' persimmon fruit were obtained from a packinghouse in Winters, California. The persimmons were transported to Davis, where they were sorted to remove damaged and underripe fruit and held at 20°C in ethylene-free air for 2 days before being prepared for experiments. Three replicates consisting of two fruits each and weighing approximately 370 g were used per treatment.

For the washing experiment, 'Selva' strawberries were obtained on the day of harvest from the Naturipe Cooperative. The fruit were cooled and transported to Davis on ice in an insulated container. The strawberries were stored and sorted as described previously. Three replicates consisting of 7 berries each and weighing approximately 135 g were used per treatment.

2.2. Slice preparation for controlled-atmosphere treatments

For strawberry fruit, the calyx was cut off and the berries cut into four lengthwise slices. For persimmon fruit, the calyx was cut off and the fruit was cut into eight wedges. Fruit were sliced on a plastic cutting board with a sharp non-serrated cutting knife. Cut fruit were placed in a metal colander and dipped in ice water containing 100 ppm sodium hypochlorite for 60 s. The slices were then drained and blotted dry with cheesecloth. All preparation steps were performed at 10°C.

CA treatments of 2% O_2 with the balance N_2, 12% CO_2 in air, and 2% O_2 + 12% CO_2 were compared to air. Due to the perishability of straw-

berry fruit, an additional control of intact fruit in air was included. The intact strawberries were sliced immediately before evaluation without washing.

Fruit slices were placed in 1-l glass jars at 5°C under a continuous flow of air or the specified gas mixture humidified by passage through distilled water to maintain a relative humidity of 90–95%. The flow rate for strawberry fruit was 20 ml/min and for persimmon fruit 24 ml/min. Flow rates were selected to prevent the accumulation of more than 0.2% CO_2 in the atmosphere, and to prevent the accumulation of ethylene. Glass capillaries were used to control the flow rate. Atmospheric composition as supplied to the jars was measured using a Carle gas chromatograph model 111 equipped with a thermal conductivity detector for O_2 and CO_2 or a Horiba Infrared CO_2 analyzer.

Strawberry fruit were evaluated on days 0, 1, 3, 5 and 7; persimmon fruit were evaluated on days 0, 1, 3, 5 and 8. Subsamples of fruit were frozen in liquid nitrogen and stored at −80°C for future analysis.

2.3. Quality evaluation

All quality evaluation procedures were performed at ambient temperature (about 20°C). Visual evaluation was made of all slices in each replicate; 32 for strawberries and 16 for persimmons. Ratings were based on a 9-point hedonic scale, where 9 = excellent, freshly cut; 7 = very good; 5 = good, limit of marketability; 3 = fair, limit of usability; and 1 = poor, unusable. Observations regarding the nature of quality loss were also noted.

A Minolta Chroma Meter, model CR-200 (Minolta Corp., Ramsay, NJ), was used to evaluate color. It was calibrated with a white plate before use. The $L^*a^*b^*$ color space was used. The instrument measures color of a 1-cm diameter area. The color of the strawberry slices was measured at the widest part of the shoulder of the cut surface; one shoulder of 16 center slices was evaluated per replicate. Persimmon slices were evaluated at the widest portion of the cut surface; one side each of 16 slices was measured per replicate.

Firmness of the cut slices was measured using a U.C. Fruit Firmness tester. A 3-mm tip was used for strawberries and a 6-mm tip was used for persimmons. Firmness of the fruit was measured in the same location as the color measurements were made. Firmness of 8 slices per replicate was measured.

Juice samples were obtained by squeezing half of the fruit slices from each replicate through four layers of cheesecloth with a hand juicer. Soluble solids content of the juice was measured with an Abbé Refractometer, model 10450 (American Optical, Buffalo, NY).

An automatic titrator (Radiometer, Copenhagen, Denmark) equipped with a PHM85 Precision pH meter, ABU80 Autoburette, PRS12 Alpha printer and a SAC80 sample changer was used to measure pH and titratable acidity. Titration was with 0.1 N NaOH to pH 8.1. Four grams of juice diluted with 20 ml of distilled water was evaluated for each replicate. Titratable acidity was calculated as citric acid for strawberries and as malic acid for persimmons.

2.4. Washing treatments

Three washing treatments were compared to an unwashed control. The treatments were: (1) strawberries were sliced and immediately frozen in liquid nitrogen; (2) strawberries were sliced and then immersed in distilled ice water for 1 min, drained, blotted dry with cheesecloth and then frozen; (3) strawberries were sliced and then immersed in distilled ice water containing 100 ppm sodium hypochlorite for 1 min, drained, dried and frozen; and (4) intact fruit were immersed in distilled ice water containing 100 ppm sodium hypochlorite for 1 min, drained and dried, then sliced and frozen. All slice preparation was carried out at 10°C. Frozen samples were held at −80°C until analyzed for ascorbates.

2.5. HPLC analysis of ascorbates

The method used was based on that of Zapata and Dufour (1992). Subsamples of strawberry and persimmon slices which had been stored at −80°C were evaluated for reduced L-ascorbate and L-dehydroascorbate content. Frozen samples were crushed and then homogenized with an extraction solution of 0.1 M citric acid and 0.05% EDTA in 5% aqueous methanol for 2 min at high speed in an Oster blender. Twenty grams of strawberry fruit was added to 180 ml of extraction solution; 10 g of persimmon fruit was added to 190 ml of extraction solution. An

internal standard of isoascorbic acid was added at 25 mg/100 g of fruit.

The homogenate was filtered through cheesecloth and then centrifuged for 10 min at 11 950 × g and 2°C in a Sorvall RC-5B centrifuge using a SS-34 rotor. After adjusting the pH of the supernatant to 2.35–2.40, the sample was passed through a Sep-Pak C18 cartridge (Waters Assoc.) which had been preconditioned with 10 ml HPLC-grade methanol and 10 ml of ultrapure water. The first 5 ml of eluent was discarded and the next 3 ml retained for analysis. As specified by Zapata and Dufour (1992), 37 min before injection onto the HPLC system 1 ml of 1,2-phenylenediamine (3.33 mg/ml) in methanol/water (5 : 95, v/v) was added. The mixture was immediately passed through a 0.45-mm filter (Acrodisc, Gelman Sciences, Ann Arbor, MI) into an amber sample vial and sealed.

The HPLC system consisted of a Hewlett Packard Series 1050 autosampler, Series 1050 pump, and a Series 1040 M diode array detector, operated by HP ChemStation software. A Waters μBondapak C18 reversed-phase column, 30 cm × 3.9 mm i.d. was used for separation, with a Bio-Rad Bio-sil Micro-Guard ODS-5S 4.6 mm × 3 cm i.d. guard column. The eluent was methanol/water (5 : 95, v/v) containing 5 mM hexadecyltrimethylammonium bromide and 50 mM potassium dihydrogen phosphate, with the pH adjusted to 4.59. The flow rate was 1.6 ml/min. Detection was at 261 nm for reduced L-ascorbate and isoascorbate and at 348 nm for L-dehydroascorbate. Retention times were 4.2, 7.3 and 8.3 min for L-dehydroascorbate, reduced L-ascorbate and isoascorbate, respectively. Standards of L-ascorbate and isoascorbate were supplied by Sigma Chemical Company; dehydroascorbate was from the Aldrich Chemical Co.

2.6. Statistical analysis

Statistical significance was determined by analysis of variance. In the case of a significant F-value, data were then subjected to Fisher's protected least significant difference test. Significance was determined at $P < 0.05$.

3. Results

3.1. Controlled-atmosphere treatments: effect on quality

The visual quality of the strawberries stored at 5°C under various atmospheres decreased over 7 days (Table 1). All sliced treatments had passed the limit of marketability by day 7, with the quality of the fruit stored under 2% O_2 significantly lower than the other treatments. The surface of the sliced fruit appeared dry and the texture appeared mealy. The firmness measured as penetration force increased over the 7-day storage period for all treatments, with no clear difference among treatments (Table 1).

All sliced treatments resulted in lower 'L' color values over the first 3 days, with the intact fruit also tending to show a decrease; however, by day 7 fruit stored under the air + 12% CO_2 and the 2% O_2 + 12% CO_2 treatments had lightened and appeared bleached, while the sliced fruit stored under air or 2% O_2 darkened. The intact fruit stored in air showed a significant increase in a-value over 7 days; storage of sliced fruit in air or 2% O_2 resulted in no significant changes, while storage in air + 12% CO_2 or in 2% O_2 + 12% CO_2 resulted in a decrease in a-value. Intact fruit also showed an increase in b-value, whereas sliced fruit stored in air showed no change, 2% O_2-stored sliced fruit showed a decrease, and sliced fruit stored under air + 12% CO_2 or 2% O_2 + 12% CO_2 showed an additional decrease over 7 days.

There was no difference in soluble solids (range 7.1–8.6%) among treatments or over the 7-day storage period (data not shown). The pH of the strawberries increased over time for all treatments; by day 7, the sliced fruit stored in air or 2% O_2 had higher pH values than the intact fruit, the 2% O_2 + 12% CO_2-stored fruit were higher than these, and storage of fruit under air + 12% CO_2 resulted in a further increase in pH (Table 1). There were also significant differences in titratable acidity; intact fruit showed an increase, sliced fruit stored under 2% O_2 showed no change over 7 days, sliced fruit stored in air showed a decrease, and the 2% O_2 + 12% CO_2 and air + 12% CO_2 treatments resulted in further decreases.

Storage of the persimmons under all of the various atmospheres resulted in the maintenance of good

Table 1
Effect of controlled-atmosphere storage at 5°C on quality of sliced strawberries. Values for each quality aspect in the same row or column having different letters in parentheses are significantly different, $P < 0.05$

Quality aspect	Treatment	Storage time (days)				
		0	1	3	5	7
Visual quality	intact in air	9.00 (a)	8.50 (b)	8.00 (c)	7.50 (d)	6.70 (e)
	sliced in air	9.00 (a)	7.90 (c)	6.60 (e)	6.20 (f)	4.60 (h)
	2% O_2	9.00 (a)	7.90 (c)	7.10 (d)	5.80 (g)	4.00 (i)
	air + 12% CO_2	9.00 (a)	8.00 (c)	7.10 (d)	6.00 (fg)	4.70 (h)
	2% O_2 + 12% CO_2	9.00 (a)	8.10 (c)	7.00 (d)	6.30 (f)	4.80 (h)
L (lightness)	intact in air	60.30 (a)	59.40 (ab)	58.00 (ab)	58.10 (ab)	55.90 (bc)
	sliced in air	60.30 (a)	56.80 (b)	56.20 (b)	55.90 (bc)	54.30 (c)
	2% O_2	60.30 (a)	57.10 (b)	57.20 (b)	55.30 (c)	55.40 (c)
	air + 12% CO_2	60.30 (a)	57.10 (b)	56.50 (b)	59.30 (a)	58.00 (ab)
	2% O_2 + 12% CO_2	60.30 (a)	57.30 (b)	57.10 (b)	55.70 (bc)	57.50 (b)
a (+red, −green)	intact in air	+24.40 (b)	+24.70 (bc)	+26.50 (ab)	+26.50 (ab)	+29.20 (a)
	sliced in air	+24.40 (b)	+23.80 (bc)	+24.20 (b)	+23.90 (bc)	+24.90 (b)
	2% O_2	+24.40 (bc)	+22.90 (c)	+23.80 (bc)	+23.40 (c)	+24.00 (bc)
	air + 12% CO_2	+24.40 (bc)	+25.20 (bc)	+22.30 (c)	+19.50 (d)	+19.40 (d)
	2% O_2 + 12% CO_2	+24.40 (b)	+23.80 (bc)	+22.60 (bc)	+22.50 (cd)	+20.90 (cd)
b (+yellow; −blue)	intact in air	+25.50 (b)	+24.80 (b)	+25.80 (ab)	+25.50 (b)	+27.00 (a)
	sliced in air	+25.50 (b)	+23.00 (c)	+23.10 (c)	+24.10 (c)	+24.70 (bc)
	2% O_2	+25.50 (b)	+23.20 (c)	+23.50 (c)	+23.10 (c)	+24.30 (c)
	air + 12% CO_2	+25.50 (b)	+24.90 (b)	+21.70 (d)	+21.60 (d)	+21.90 (d)
	2% O_2 + 12% CO_2	+25.50 (b)	+23.00 (cd)	+21.90 (d)	+21.80 (d)	+22.30 (d)
Firmness (N)	intact in air	1.10 (a)	1.30 (b)	1.60 (c)	1.90 (e)	1.60 (c)
	sliced in air	1.10 (a)	1.00 (a)	1.50 (bc)	1.90 (e)	1.80 (de)
	2% O_2	1.10 (a)	1.10 (a)	1.40 (b)	1.70 (d)	1.70 (cd)
	air + 12% CO_2	1.10 (a)	1.10 (a)	1.40 (bc)	1.90 (e)	1.50 (c)
	2% O_2 + 12% CO_2	1.10 (a)	1.10 (a)	1.40 (bc)	1.40 (bc)	1.50 (c)
pH	intact in air	3.47 (a)	3.50 (b)	3.54 (c)	3.54 (c)	3.55 (d)
	sliced in air	3.47 (a)	3.48 (a)	3.56 (d)	3.57 (e)	3.58 (e)
	2% O_2	3.47 (a)	3.49 (ab)	3.60 (f)	3.58 (e)	3.57 (e)
	air + 12% CO_2	3.47 (a)	3.51 (b)	3.60 (fg)	3.62 (g)	3.68 (i)
	2% O_2 + 12% CO_2	3.47 (a)	3.51 (b)	3.60 (fg)	3.61 (g)	3.65 (h)
Titratable acidity (%)	intact in air	0.86 (c)	0.89 (bc)	0.91 (b)	0.96 (a)	0.90 (b)
	sliced in air	0.86 (cd)	0.85 (cd)	0.83 (de)	0.84 (cd)	0.80 (ef)
	2% O_2	0.86 (cd)	0.83 (de)	0.81 (e)	0.84 (cd)	0.84 (cd)
	air + 12% CO_2	0.86 (cd)	0.86 (cd)	0.83 (de)	0.82 (e)	0.75 (g)
	2% O_2 + 12% CO_2	0.86 (cd)	0.85 (cd)	0.84 (cd)	0.83 (de)	0.79 (f)

visual quality for up to 8 days (Table 2). Fruit stored under air + 12% CO_2 or 2% O_2 + 12% CO_2 treatments were still marketable at the end of the study; air- and 2% O_2-stored fruit had just begun to develop areas of faint black pigmentation on the cut surfaces and were therefore judged to be at the limit of marketability. The thin cut edge and the blossom end of the slices tended to soften and develop a slight water-soaked appearance. Firmness, measured as penetration force, tended to decrease for all treatments, with no significant difference among treatments.

The *L* color value of all treatments tended to increase over 8 days; storage of fruit in air resulted in a slight increase, while storage in 2% O_2 resulted in a significant increase from day 0, with no difference between the two treatments. Persimmons stored under treatments including 12% CO_2 showed a significant increase in *L*-value over the other treatments.

Table 2
Effect of controlled-atmosphere storage at 5°C on quality of sliced persimmons. Values for each quality aspect in the same row or column having different letters in parentheses are significantly different, $P < 0.05$

Quality aspect	Treatment	Storage time (days)				
		0	1	3	5	8
Visual quality	air	9.00 (a)	8.00 (b)	7.00 (c)	7.00 (c)	5.00 (d)
	2% O_2	9.00 (a)	8.00 (b)	7.00 (c)	7.00 (c)	5.00 (d)
	air + 12% CO_2	9.00 (a)	8.00 (b)	7.00 (c)	7.00 (c)	7.00 (c)
	2% O_2 + 12% CO_2	9.00 (a)	8.00 (b)	7.00 (c)	7.00 (c)	7.00 (c)
L (lightness)	air	64.80 (a)	64.10 (a)	65.30 (ab)	65.70 (ab)	65.50 (ab)
	2% O_2	64.80 (a)	64.70 (a)	65.80 (ab)	65.30 (ab)	66.00 (b)
	air + 12% CO_2	64.80 (a)	65.50 (a)	67.50 (cd)	67.00 (c)	68.10 (d)
	2% O_2 + 12% CO_2	64.80 (a)	66.30 (bc)	66.90 (cd)	67.40 (cd)	67.70 (d)
a (+red, −green)	air	+14.30 (ab)	+14.00 (ab)	+14.50 (ab)	+13.70 (bc)	+13.20 (bc)
	2% O_2	+14.30 (ab)	+14.30 (ab)	+14.90 (a)	+14.30 (ab)	+13.50 (bc)
	air + 12% CO_2	+14.30 (ab)	+14.30 (ab)	+13.30 (bc)	+13.40 (bc)	+12.80 (cd)
	2% O_2 + 12% CO_2	+14.30 (ab)	+13.80 (bc)	+13.70 (bc)	+13.20 (cd)	+12.60 (d)
b (+yellow, −blue)	air	+44.80 (a)	+43.80 (bc)	+41.80 (d)	+40.60 (ef)	+38.30 (g)
	2% O_2	+44.80 (a)	+43.50 (c)	+41.80 (d)	+40.90 (de)	+38.50 (g)
	air + 12% CO_2	+44.80 (a)	+43.90 (ab)	+40.50 (e)	+40.00 (ef)	+39.50 (fg)
	2% O_2 + 12% CO_2	+44.80 (a)	+44.50 (ab)	+40.90 (de)	+39.60 (f)	+39.00 (fg)
Firmness (N)	air	28.50 (a)	27.10 (ab)	25.80 (b)	26.20 (b)	27.60 (ab)
	2% O_2	28.50 (a)	26.80 (ab)	25.10 (b)	27.00 (ab)	25.90 (b)
	air + 12% CO_2	28.50 (a)	25.20 (b)	25.50 (b)	25.20 (bc)	25.10 (b)
	2% O_2 + 12% CO_2	28.50 (a)	26.80 (ab)	24.80 (bc)	23.90 (c)	24.30 (bc)
Soluble solids (%)	air	16.90 (a)	17.20 (ab)	18.20 (c)	17.70 (b)	17.60 (b)
	2% O_2	16.90 (a)	17.90 (bc)	18.10 (c)	17.40 (ab)	17.40 (a)
	air + 12% CO_2	16.90 (a)	17.50 (b)	17.70 (bc)	17.80 (bc)	18.20 (c)
	2% O_2 + 12% CO_2	16.90 (a)	17.10 (ab)	17.70 (bc)	17.50 (b)	18.10 (c)
pH	air	5.60 (b)	5.49 (a)	5.78 (c)	5.86 (cd)	5.99 (e)
	2% O_2	5.60 (b)	5.60 (b)	5.83 (cd)	5.67 (b)	5.80 (c)
	air + 12% CO_2	5.60 (b)	5.65 (bc)	5.94 (e)	5.92 (de)	5.98 (e)
	2% O_2 + 12% CO_2	5.60 (b)	5.73 (c)	5.91 (de)	5.92 (de)	5.95 (e)
Titratable acidity (%)	air	0.073 (a)	0.065 (bc)	0.069 (ab)	0.062 (cd)	0.059 (d)
	2% O_2	0.073 (a)	0.066 (bc)	0.064 (c)	0.057 (e)	0.063 (cd)
	air + 12% CO_2	0.073 (a)	0.060 (d)	0.061 (cd)	0.057 (de)	0.063 (cd)
	2% O_2 + 12% CO_2	0.073 (a)	0.061 (cd)	0.058 (d)	0.060 (cd)	0.063 (cd)

The *a*-value tended to decrease over 8 days for all treatments; the fruit stored in air showed a decrease, while that stored under the treatments including 12% CO_2 showed a greater decrease. The *b*-value declined significantly by day 3 for all treatments, and continued to decrease through day 8; with no differences among treatments.

The percent soluble solids for all treatments increased significantly within 3 days of storage, with no differences among treatments. The pH of the persimmons stored under various atmospheres tended to increase; by day 8, the fruit stored under 2% O_2 had a significantly lower pH than that stored under the other treatments. The titratable acidity decreased over 8 days for all treatments.

3.2. Controlled-atmosphere treatments: effect on ascorbate content

For strawberry fruit, there was no significant difference in TAA content among treatments during storage at 5°C for 7 days (Fig. 1A). However, by

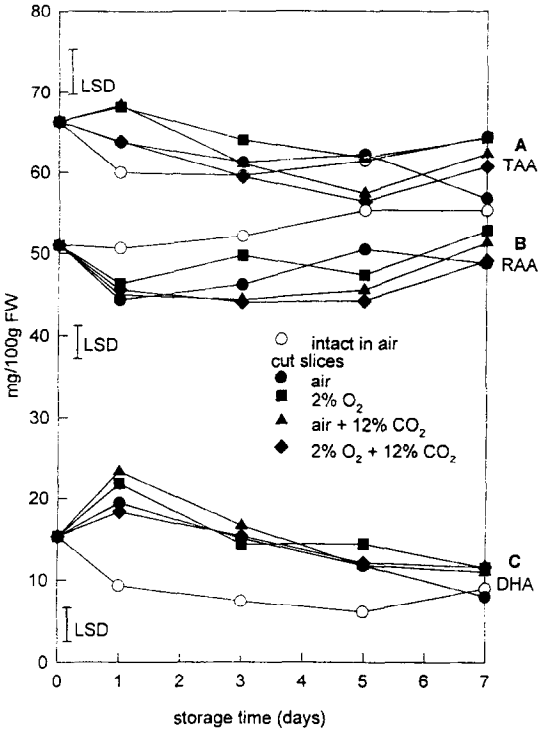

Fig. 1. Effect of controlled-atmosphere storage at 5°C on total ascorbic acid (A), reduced ascorbic acid (B), and dehydroascorbate (C) content of sliced strawberries.

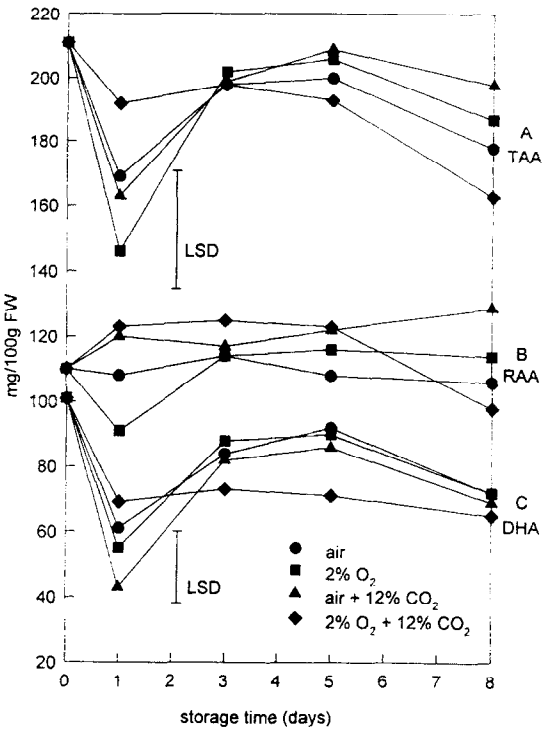

Fig. 2. Effect of controlled-atmosphere storage at 5°C on total ascorbic acid (A), reduced ascorbic acid (B), and dehydroascorbate (C) content of sliced persimmons.

day 7, the air-stored fruit had lower TAA than the day 0 fruit, and less than the intact, 2% O_2-stored or air + 12% CO_2-stored fruit. All treatments tended to have lower TAA by day 7. Intact fruit maintained greater RAA than the sliced fruits kept in other atmospheres (Fig. 1B); there was an initial significant loss of RAA for all sliced fruit treatments during the first day after slicing, with recovery to levels not significantly different from the initial level by day 7. The 2% O_2 treatment slightly reduced the loss of RAA. All sliced fruit treatments showed an increase in DHA during the first day (Fig. 1C), apparently in response to the slicing. All sliced fruit treatments underwent a decline in DHA during the remaining time of the study.

Persimmon fruit tended to lose TAA during storage at 5°C for 8 days, with only the 2% O_2 + 12% CO_2 treatment showing a significant loss over 8 days, but with no difference among treatments (Fig. 2A). Fruit stored under air, 2% O_2 or air + 12% CO_2 showed a loss of TAA in the first day, but then recovered to levels not significantly different from the initial by day 3 before tending to lose TAA by day 8. There was no significant loss of RAA over the 8 days of the study (Fig. 2B), and no significant differences among treatments. All treatments showed a decrease in DHA after 1 day (Fig. 2C); the treatments recovered to levels not significantly different from the initial level by day 3, then showed a gradual loss until day 8.

3.3. Washing treatments

Washing the sliced strawberry fruit in distilled water resulted in an increase in the proportion of total ascorbate that was in the oxidized dehydroascorbate form (Fig. 3). The addition of chlorine to the wash water for sliced fruit resulted in a further increase. Washing the fruit in chlorine before slicing resulted in a level of oxidation intermediate between that of the water and chlorine treatments.

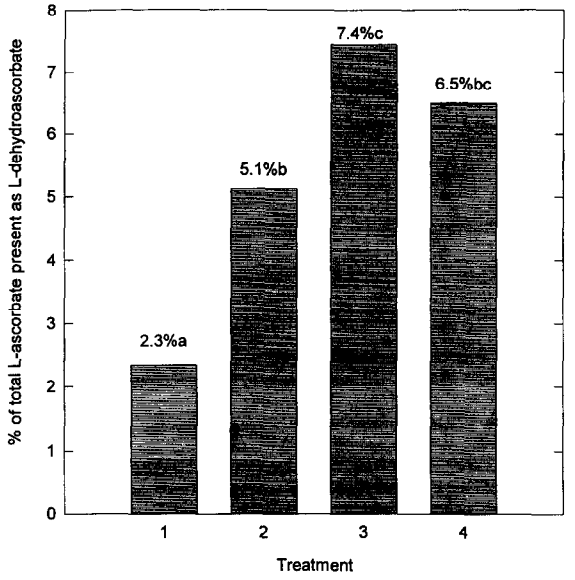

Fig. 3. Effect of different washing treatments on percentage of total ascorbate oxidized to dehydroascorbate in strawberries. Values followed by different letters are significantly different, $P < 0.05$. Treatments: 1, control, sliced without washing; 2, sliced, washed in water; 3, sliced, washed in water with 100 ppm chlorine; 4, washed in water with 100 ppm chlorine, then sliced.

4. Discussion

The purpose of this study was to investigate the effects of slicing and controlled-atmosphere storage on the quality and ascorbate content of fresh-cut fruit, using two fruits considered to be good to excellent sources of that nutrient as models. The two fruits are very different physiologically; strawberry fruits have a high respiration rate, low pH (initially 3.45–3.55) and a short postharvest life, whereas 'Fuyu' persimmon fruits have a low rate of respiration, higher pH (initially 5.5–6.0) and a longer postharvest life. Morphologically, the strawberry is an enlarged receptacle with achenes on the surface, classified as an aggregate accessory fruit; the persimmon is a berry, and the 'Fuyu' variety is seedless.

There was no difference in visual quality among the various atmospheric treatments for the strawberries, whereas the treatments containing 12% CO_2 increased the shelf-life of the persimmons by delaying the appearance of black areas on the cut surface. The origin of this pigmentation is uncertain, but it did not appear to be due to fungal growth. Both fruits responded to the treatments containing 12% CO_2 by an increase in the L color value; this was visible in strawberries as a bleached appearance, but was not observed by Rosen (1987) in either 'Pajaro' or 'G-3' strawberries stored for 7 days at 2.5°C under similar atmospheres. Bleeding of red pigments in sliced strawberries was noted by Rosen, but was not seen here.

The firmness of the all of the strawberries increased over the storage period; this was an unexpected result, as fruit in a preliminary study had softened over a 3-day storage period (data not shown), and studies of cut kiwifruit, papaya and pineapple fruit stored at 4°C showed softening to be a limiting factor in shelf-life (O'Connor-Shaw et al., 1994). The strawberries in this study had been stored at 0°C overnight, prepared at 10°C and cooled rapidly by immersion in ice water, while the other fruits were prepared at approximately 20°C. All firmness measurements were made at room temperature, and there was no significant weight loss over 7 days (data not shown). The texture of the portion of the fruit where the measurements were made appeared to become mealy, while the edges softened and became translucent. The persimmons tended to soften over 8 days. There was no significant effect of the various atmospheres for either fruit.

The percentage of soluble solids of the strawberries did not change significantly during 7 days of storage. The persimmons, which continue to ripen after harvest, tended to show an increase in soluble solids over 8 days. The pH of both fruits increased during storage. Strawberries showed a significant effect of storage under atmospheres containing 12% CO_2. Persimmons stored in air or atmospheres containing 12% CO_2 had similar pH, whereas those stored under 2% O_2 had significantly lower pH. The titratable acidity of slices of both fruits decreased during storage, except for the strawberries stored under 2% O_2.

Strawberry fruits showed an initial increase in the oxidation of RAA to DHA during the first 24 h, followed by the apparent reduction of the DHA to RAA and some loss of DHA, resulting in a decrease in TAA. Persimmons showed an initial increase in RAA accompanied by a decrease in DHA, followed by a decrease in RAA and TAA, but not DHA, over the course of the study. Controlled atmospheres of

2% O_2, air + 12% CO_2 or 2% O_2 + 12% CO_2 had no significant effect on these changes for either fruit.

Several mechanisms which could produce these results have been seen in other plants. In tomato, ascorbate free radical reductase mRNA levels were induced by wounding (Grantz et al., 1995); this enzyme regenerates partially oxidized ascorbate to RAA, and could be a defense against the depletion of RAA during the oxidative damage that occurs in wounding. Activity of the enzyme L-galactono-γ-lactone dehydrogenase, which is required for the synthesis of ascorbic acid, was induced in wounded white potato tuber tissue accompanied by a slight initial decrease in TAA during the first 12 h followed by an increase over the subsequent 36 h; during the same time period, RAA first decreased slightly, then increased and then gradually decreased (Ôba et al., 1994). Ascorbate oxidase from green zucchini fruit, which catalyses the oxidation of RAA to DHA, has been found to be unstable and to lose activity below pH 4 (Maccarrone et al., 1993). This could partially explain the lower DHA content of the strawberries (pH 3.4–3.7) and the higher DHA content of the persimmons (pH 5.4–6.0) as well as the tendency for some non-fruit vegetables with near-neutral pH to lose TAA during storage. However, other storage factors, such as relative humidity and temperature, also affect TAA (Watada, 1987). In a study comparing cut broccoli florets to intact heads of broccoli in which the vegetable was stored at 4°C in air with approximately 100% relative humidity for 21 days, TAA content was stable and there was no difference between the cut and the intact vegetable (Paradis et al., 1995).

Washing of either sliced or intact strawberries in 100 ppm sodium hypochlorite resulted in significant oxidation of RAA over unwashed fruit. There were no differences in TAA, and the results of the time-course study indicate that the fruit tissue is capable of reducing the ascorbate to the active form before losses occur.

From these results, it appears possible that products with a long shelf-life may lose a significant amount of TAA after cutting and before consumption, whereas products such as fresh cut strawberries with a shorter shelf-life are likely to be unacceptable for consumption before the loss of a significant amount of TAA.

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