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Effect of controlled-atmosphere storage on the quality and carotenoid content of sliced persimmons and peaches

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Abstract

Changes in quality, retinol equivalents (RE) and individual provitamin A carotenoids in fresh cut 'Fay Elberta' peaches (*Prunus persica* (L.) Batsch) held for 7 days and 'Fuyu' persimmons (*Diospyros kaki* L.) held for 8 days at 5°C in air or controlled atmospheres were evaluated. Controlled atmospheres of 2% O₂, 12% CO₂ in air, and 2% O₂ + 12% CO₂ had no effect on quality attributes of sliced peaches over 7 days of storage. Visual quality of persimmon slices was slightly enhanced by the treatments containing 12% CO₂, which also resulted in significant differences in color. Peach slices stored in air + 12% CO₂ had a lower content of β -carotene and β -cryptoxanthin, resulting in lower RE than the other treatments. The various carotenoids found in persimmon slices responded differently to the tested atmospheres; storage in 2% O₂ or air + 12% CO₂ tended to result in lower RE after 8 days, but the loss was not significant for fruit stored under 2% O₂ + 12% CO₂. For sliced peaches and persimmons, the limit of shelf life was reached before major losses of carotenoids occurred.

Keywords: Peach; *Prunus persica* (L.) Batsch; Persimmon; *Diospyros kaki* L.; Controlled atmosphere; carotenoids

1. Introduction

Fresh fruits and vegetables are an important dietary source of vitamin A (retinol), estimated to supply 50% of that nutrient in the United States (Goddard and Matthews, 1979). Vitamin A is essential for normal growth, reproduction and resistance to infection; severe deficiency may lead to irreversible blindness (Tee, 1992). Plant materials do not contain vitamin A, but provide carotenoids that are converted to vitamin A after ingestion. Provitamin A carotenoids found in significant quantities in fruits include β -carotene, β -cryptoxanthin, and

α -carotene (Gross, 1987). Recent research has indicated that these and other carotenoids, such as lycopene, present in some fruits may have a role in cancer prevention by acting as free radical scavengers or antioxidants (Tee, 1992). Carotenoids have also been used to treat chronic diseases, such as photosensitivity diseases (Matthews-Roth, 1993), and may have a role in preventing cardiovascular disease (Gaziano and Hennekens, 1993). These health effects appear to be due to the antioxidant effect of the carotenoids. Lycopene, although it has no provitamin A activity, has been identified as a particularly effective quencher of singlet oxygen in vitro (Di Mascio et al., 1989).

The fruits studied here are both good sources

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of provitamin A carotenoids. Yellow-flesh peaches, such as 'Fay Elberta', contain 54 RE/100 g of provitamin A carotenoids (USDA, 1982), predominantly as β -carotene and β -cryptoxanthin (Gross, 1987). 'Fuyu' persimmon fruit grown in Georgia contained 158 mg/100 g β -carotene, 60 mg/100 g β -cryptoxanthin and 60 mg/100 g α -carotene, for a total of 36 RE/100 g (Homnava et al., 1990). Persimmons also contain relatively large amounts of lycopene.

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 carotenoid 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 degradation of carotenoids in several ways. Carotenoids are unstable when exposed to acidic pH, oxygen or light (Klein, 1987), all of which may occur when the cells are disrupted by cutting. Wounding, such as cutting, also promotes the production of wound ethylene (Watada et al., 1990), which hastens senescence, including the oxidation of fatty acids by lipoxygenase, during which carotenoids may be degraded by co-oxidation (Thompson et al., 1987).

The effect of controlled and modified atmospheres on the carotenoid content of intact fruits has not been well studied. Modified atmospheres including either reduced O₂ or elevated CO₂ are generally considered to reduce the loss of provitamin A, but also to inhibit the biosynthesis of carotenoids (Kader et al., 1989). Reducing O₂ to lower and lower concentrations enhanced the retention of carotene in carrots (Weichmann, 1986). Five percent CO₂ caused a loss of carotene, while 7.5% CO₂ or higher appeared to cause *de novo* synthesis of carotene. The carotene content of leeks was found to be higher after storage in 1% O₂ + 10% CO₂ than after storage in air (Weichmann, 1986). To the best of our knowledge, no other studies on the effect of controlled-atmosphere storage on the provitamin A carotenoid content of fresh cut fruit have been published.

In this study, we investigated the effect of controlled-atmosphere storage on the concentration of β -carotene and β -cryptoxanthin present in sliced peaches, and the concentration of β -carotene, α -carotene, β -cryptoxanthin and lycopene in sliced

persimmons. High-performance liquid chromatography with diode-array detection has been shown to be a good method for the separation, identification and quantification of carotenoids (Bramley, 1992); therefore this method was chosen for analysis. We also studied the effect of controlled-atmosphere storage on the quality of the sliced fruit.

2. Materials and methods

2.1. Plant material

'Fay Elberta' peach fruit were obtained from a packing house in Kingsburg, CA, on the day of harvest and transported to Davis in an air-conditioned vehicle. The peaches were sorted to remove defective fruit, and were further sorted by ground color. Ripening was initiated by exposure to 100 ppm ethylene for 24 h at 20°C, and the peaches were then held in air at 20°C until they had reached acceptable eating quality, from 1 to 3 days, depending on initial maturity. After ripening, the fruit was stored at 0°C for 1–3 days before being prepared for experiments. Three replicates of 16 slices each, equivalent to two fruits and weighing approximately 250–300 g were used per treatment.

'Fuyu' persimmon fruit were obtained from a packing house in Winters, CA. The persimmons were transported to Davis, where they were sorted to remove damaged and under-ripe fruit and held at 20°C in ethylene-free air for 2 days before being prepared for experiments. Three replicates of 16 slices each, equivalent to two fruits and weighing approximately 370 g were used per treatment.

2.2. Slice preparation

For peach fruit, 8 lengthwise slices were cut around the stone and carefully separated from the stone. For persimmon fruit, the calyx was cut off and each fruit was cut into 8 wedges. A sharp non-serrated cutting knife and a plastic cutting board were used for slicing. Cut fruit was placed in a metal colander and dipped in ice water containing 100 ppm chlorine for 60 s. The slices were then drained and blotted dry with cheesecloth. All preparation steps were performed at 10°C. Exposure to light was not controlled.

2.3. Controlled-atmosphere (CA) storage treatments

CA treatments of 2% O₂ with the balance N₂, 12% CO₂ in air, and 2% O₂ + 12% CO₂ were compared to air. 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 was 40 ml/min for peaches and 24 ml/min for persimmons. Flow rates were selected to prevent the accumulation of more than 0.2% CO₂ 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 O₂ and CO₂ or a Horiba Infrared CO₂ analyzer. Light exposure was not controlled during storage.

Peach slices were evaluated on days 0, 1, 3, 5 and 7; persimmon slices were evaluated on days 0, 1, 3, 5 and 8. Subsamples were frozen in liquid nitrogen and held at –80°C until analyzed for carotenoid content.

2.4. Quality evaluation

All quality evaluation procedures were performed at ambient temperature (about 20°C). Visual evaluation was made of all slices in each replicate. 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 reasons for 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 sliced fruit was 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 equipped with a 6-mm tip. 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; 4 g of juice diluted with 20 ml of distilled water was evaluated for each replicate. Titratable acidity was calculated as percent malic acid.

2.5. Extraction, saponification and HPLC analysis of provitamin A carotenoids

All extraction and saponification steps were carried out under yellow or dimmed lights. The extraction method was based on that of Marsili and Callahan (1993). The frozen fruit sample was ground in an Oster blender until just pulverized. Five g of sample was added to a 50 ml round-bottomed Nalgene centrifuge tube. Ten ml of cold ethanol was added and the sample was homogenized with a Polytron homogenizer at medium speed for 3 min. Eight ml of hexane was added and the sample was homogenized for an additional 2 min. The mixture was then centrifuged for 4 min at 7000 × *g*. The carotenoid-bearing hexane layer was transferred with a Pasteur pipet to a 125-ml screw-cap Erlenmeyer flask. Five ml of saturated sodium chloride solution was added to the contents of the centrifuge tube, and the contents stirred gently to homogenize. An additional 8 ml of hexane was added, and the mixture was homogenized at low speed with the Polytron for 1 min. The mixture was centrifuged as before, and the hexane layer transferred to the Erlenmeyer flask with the first extract.

Saponification was carried out as described by Kimura et al. (1990). Fifteen ml of 10% methanolic potassium hydroxide was added to the contents of the Erlenmeyer flask; the flask was flushed with nitrogen, sealed, and wrapped in aluminum foil to exclude light. The flask was left at room temperature for 16 h, with gentle shaking. The mixture was then transferred to a separatory funnel and washed to re-

move the KOH, first with 50 ml of 10% NaCl and then with deionized water until the rinse had a neutral pH. The KOH was extracted with an additional 10 ml hexane. The combined hexane extracts were evaporated under nitrogen just to dryness, then redissolved in methylene chloride and brought to volume with mobile phase. The final volume was 2.5 ml for peaches and 5 ml for persimmons. The sample was immediately filtered through a 0.45 mm filter into an amber sample vial and sealed.

HPLC analysis was based on the method of Hart and Scott (1995). The HPLC system consisted of a Hewlett Packard Series 1050 autosampler, Series 1050 pump, and a Series 1040M diode array detector, operated by HP ChemStation software. A 250 × 4.6 mm, 5 mm Vydac 201TP54 reversed-phase C18 column fitted with biocompatible titanium frits was used for separation, together with a Vydac High Performance guard column, 4.6 × 25 mm, filled with the same packing material. The mobile phase consisted of acetonitrile, methanol and methylene chloride 75:20:5 v/v/v, containing 0.1% butylated hydroxytoluene and 0.05% triethylamine. The methanol contained 0.05 M ammonium acetate. All reagents were HPLC grade. The flow rate was 1.5 ml/min. Detection was at 450 nm. Identification and purity of peaks was confirmed by comparing spectra using the computer software.

Standards for β -carotene, α -carotene and lycopene were purchased from the Sigma Chemical Company; β -cryptoxanthin was a gift of Hoffman-La Roche, Nutley, NJ. Concentration of stock solutions was determined spectrophotometrically as described by Hart and Scott (1995).

Retinol equivalent (RE) was calculated on the basis of 1 RE = 6 μ g of β -carotene or 12 μ g of other provitamin A carotenoids.

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. Effect of controlled atmospheres on quality

Peach slices browned rapidly after slicing. Fruit was judged to be just marketable after 1-day storage, and unmarketable by day 3, although still usable through 7 days of storage (Table 1). There were no significant differences among the various atmospheric treatments. The rapid browning resulted in a decrease in *L*-value after 1 day, with only slightly more decrease over 7 days storage; there were no differences among treatments. The *a*-value increased by day 1, also indicative of browning. There was a slight increase in *b*-value over 3 days for all treatments, with the slices stored under 2% O₂ and 2% O₂ + 12% CO₂ increasing more than those stored under air or air + 12% CO₂. The *b*-values decreased to initial levels for all treatments by day 7 of storage. The firmness of the stored slices showed no clear trends; the texture appeared to become mealy.

There were no significant differences in soluble solids (range 10.4–13.5%) of the peach slices either over time of storage or among treatments (data not shown). The pH of all treatments was lower after 5 days of storage, but returned to initial levels after 7 days. The titratable acidity of all treatments decreased after 1 day of storage, with all treatments continuing to decrease up to 5 days of storage. There were no significant differences among treatments.

Persimmon slices maintained good visual quality up to day 8 of storage under the various atmospheres (Wright and Kader, 1997). Fruit stored under air + 12% CO₂ or 2% O₂ + 12% CO₂ treatments were still marketable at the end of the study; air- and 2% O₂-stored fruit had 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 with time for all treatments.

3.2. Effect of controlled atmospheres on carotenoid content

There were no significant changes in the β -carotene content of the sliced peach fruit over the

Table 1

Effect of controlled-atmosphere storage at 5°C on quality of sliced peaches. 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	air	9.00 (a)	5.80 (b)	3.90 (e)	4.00 (de)	3.60 (ef)
	2% O ₂	9.00 (a)	5.80 (b)	4.00 (de)	4.60 (c)	3.20 (f)
	air + 12% CO ₂	9.00 (a)	5.90 (b)	4.80 (c)	4.40 (cd)	3.80 (e)
	2% O ₂ + 12% CO ₂	9.00 (a)	6.30 (b)	4.70 (c)	4.30 (cd)	3.20 (f)
<i>L</i> (lightness)	air	72.70 (a)	67.50 (b)	66.00 (c)	67.90 (b)	67.40 (b)
	2% O ₂	72.70 (a)	67.00 (b)	65.10 (cd)	67.60 (b)	65.90 (c)
	air + 12% CO ₂	72.70 (a)	66.80 (bc)	65.60 (cd)	65.70 (c)	66.80 (bc)
	2% O ₂ + 12% CO ₂	72.70 (a)	67.50 (b)	64.90 (d)	65.60 (cd)	66.80 (bc)
<i>a</i> (+red, –green)	air	+3.00 (a)	+6.70 (b)	+7.40 (bc)	+7.00 (bc)	+7.30 (bcd)
	2% O ₂	+3.00 (a)	+7.10 (bc)	+8.20 (d)	+7.40 (cd)	+8.00 (d)
	air + 12% CO ₂	+3.00 (a)	+7.10 (b)	+7.50 (cd)	+8.00 (d)	+7.10 (bc)
	2% O ₂ + 12% CO ₂	+3.00 (a)	+6.40 (b)	+7.80 (cd)	+7.80 (cd)	+6.90 (bc)
<i>b</i> (+yellow, –blue)	air	+44.70 (ab)	+45.40 (bc)	+46.10 (c)	+45.60 (c)	+44.50 (a)
	2% O ₂	+44.70 (b)	+45.50 (bc)	+46.20 (d)	+46.60 (d)	+45.20 (ab)
	air + 12% CO ₂	+44.70 (ab)	+45.50 (b)	+45.70 (bc)	+45.40 (bc)	+44.50 (a)
	2% O ₂ + 12% CO ₂	+44.70 (ab)	+45.40 (bd)	+46.40 (d)	+45.70 (cd)	+44.70 (ab)
Firmness (N)	air	34.60 (c)	33.20 (bc)	31.10 (bc)	29.50 (ab)	39.90 (d)
	2% O ₂	34.60 (c)	37.40 (cd)	33.50 (bc)	31.10 (bc)	35.10 (cd)
	air + 12% CO ₂	34.60 (c)	37.80 (cd)	28.90 (ab)	25.80 (a)	35.30 (cd)
	2% O ₂ + 12% CO ₂	34.60 (c)	41.50 (d)	34.00 (c)	35.90 (c)	36.50 (cd)
pH	air	3.53 (ab)	3.49 (b)	3.52 (ab)	3.43 (c)	3.51 (b)
	2% O ₂	3.53 (ab)	3.51 (b)	3.55 (ab)	3.44 (c)	3.55 (ab)
	air + 12% CO ₂	3.53 (a)	3.56 (a)	3.55 (a)	3.46 (c)	3.57 (a)
	2% O ₂ + 12% CO ₂	3.53 (ab)	3.53 (ab)	3.51 (b)	3.43 (c)	3.57 (a)
Titratable acidity (%)	air	0.66 (a)	0.61 (b)	0.62 (ab)	0.55 (c)	0.56 (c)
	2% O ₂	0.66 (a)	0.59 (b)	0.56 (bc)	0.53 (c)	0.53 (c)
	air + 12% CO ₂	0.66 (a)	0.58 (b)	0.53 (c)	0.52 (c)	0.53 (c)
	2% O ₂ + 12% CO ₂	0.66 (a)	0.61 (bc)	0.63 (ab)	0.56 (c)	0.57 (c)

time of storage, with the exception of the fruit stored under air + 12% CO₂; this treatment resulted in a lower concentration of β -carotene (Fig. 1A). The β -cryptoxanthin content of the fruit tended to increase in the fruit stored under 2% O₂ or 2% O₂ + 12% CO₂, while the air + 12% CO₂ treatment resulted in lower levels (Fig. 1B). When the carotenoid content was calculated as RE, the slices kept in air + 12% CO₂ had a lower nutritional value (Fig. 2).

Persimmon fruit slices stored under air showed a decrease in β -carotene over the course of the study; however, overall, there was no significant difference among treatments (Fig. 3A). The air + 12% CO₂ treatment resulted in a loss of β -cryptoxanthin

over the first 3 days, followed by a slight recovery (Fig. 3B). The remaining treatments tended to show a steady decline over the time of the study. Levels of α -carotene were highly variable (Fig. 4A); for fruit stored under air, there was a significant increase before a slight decrease by day 8; fruit stored under 2% O₂ showed an increase and then decreased to the original level, whereas the fruit stored under air + 12% CO₂ showed a decrease before returning to above the original level. Fruit stored under 2% O₂ + 12% CO₂ tended to maintain a concentration higher than the original. Concentrations of lycopene were so variable that no significant differences were seen (Fig. 4B). Based on RE, fruit slices kept under air,

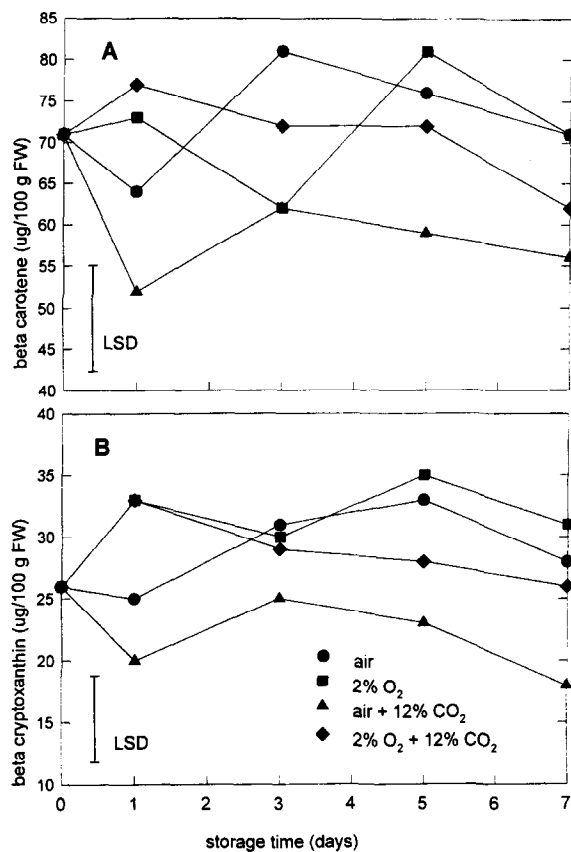


Fig. 1. Effect of controlled-atmosphere storage at 5°C on β -carotene (A) and β -cryptoxanthin (B) content of sliced peaches.

2% O₂ or air + 12% CO₂ decreased in nutritional value after 8 days (Fig. 5).

4. Discussion

The purpose of this study was to investigate the effects of slicing and controlled-atmosphere storage on the quality and provitamin A carotenoid content of fresh-cut fruit, using two fruits considered to be good sources of that nutrient as models. The various atmospheres studied here appear to have no effect on the quality attributes of sliced peaches, although changes in the flesh color which occur in other fruits may have been masked by the rapid browning of the sliced fruit. One area of research that needs to be addressed is the selection of cultivars for the light processing market (Romig, 1995). It can be concluded from the results that the 'Fay Elberta' peach

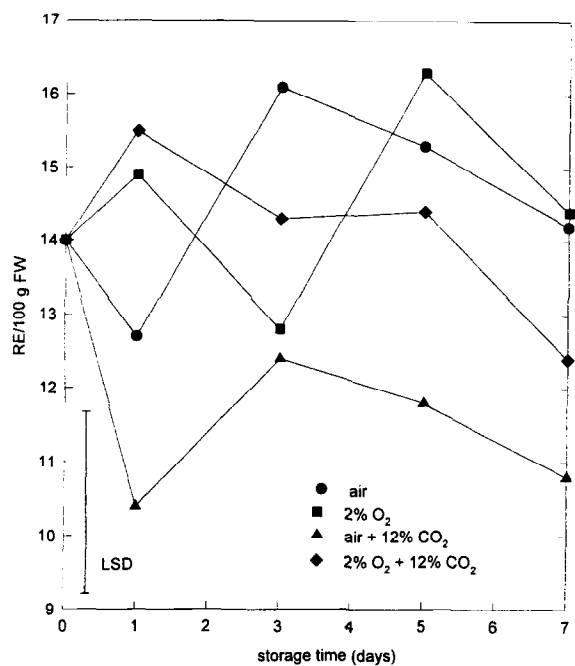


Fig. 2. Effect of controlled-atmosphere storage at 5°C on retinol equivalents (RE) content of sliced peaches.

would be a poor choice, due to its rapid browning when cut. Various dips, such as calcium chloride and citric and ascorbic acids, have been used to reduce browning of cut peaches (Bolin and Huxsoll, 1989); but we did not use dips in this study to focus on the O₂ and CO₂ effects. The persimmon slices exhibited only a slight response to the atmospheres studied; 12% CO₂-enriched air appeared to have a bleaching effect, and may have an effect on the biochemical processes that affect soluble solids content. The 2% O₂ atmosphere resulted in persimmon slices with a significantly lower pH than the other treatments, which could affect flavor.

'Fay Elberta' peaches used in this study contained only trace quantities of α -carotene, and the total content of provitamin A carotenoids present averaged 13.7 RE/100 g, well below the USDA Handbook 8 mean value of 54/100 g. The peaches did not appear well-colored, and weather conditions in the growing region were unusually cool and wet just before harvest. The values for the persimmons corresponded closely to the data published for that variety by Homnava et al. (1990).

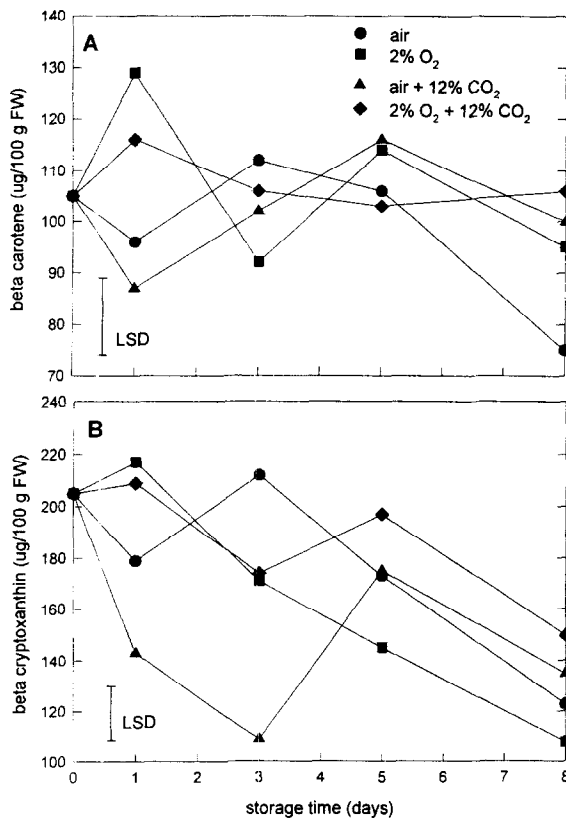


Fig. 3. Effect of controlled-atmosphere storage at 5°C on β -carotene (A) and β -cryptoxanthin (B) content of sliced persimmons.

Peach slices stored in air + 12% CO₂ had a lower content of provitamin A carotenoids within 1 day of cutting, which continued through the 7 days of storage. This effect could be caused by enhanced loss of β -carotene and β -cryptoxanthin, by inhibition of the biosynthetic pathways leading to the synthesis of these compounds, or by a combination of these two effects. β -Carotene is an immediate precursor of β -cryptoxanthin (Sandmann, 1994), but little is known about the mechanisms of the enzyme(s) involved in carotenoid biosynthesis in plants (Bartley and Scolnik, 1995). The biosynthetic enzymes are encoded by nuclear genes, and precursor proteins are post-translationally imported into plastids where carotenoid biosynthesis occurs. Disruption of the tissue by wounding, followed by exposure to various atmospheres, could promote or inhibit the transcription of the genes or the transport of the mRNA. The

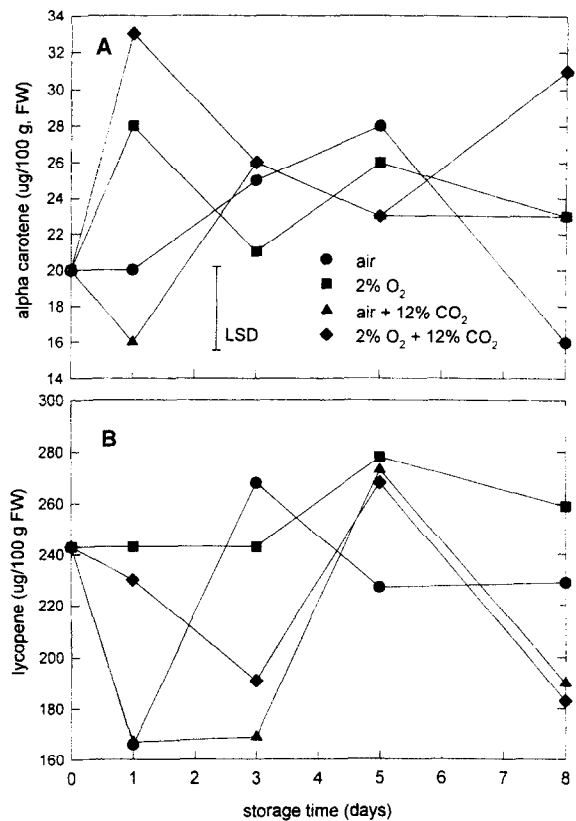


Fig. 4. Effect of controlled-atmosphere storage at 5°C on α -carotene (A) and lycopene (B) content of sliced persimmons.

mRNA levels for genes encoding enzymes for earlier steps in carotenoid biosynthesis in tomatoes are controlled by both developmental and environmental signals (Bartley and Scolnik, 1995). No significant loss of β -carotene occurred in air or the other atmospheres; this is consistent with the findings of Paradis et al. (1995), who found no significant loss of β -carotene in broccoli florets stored in air for 21 days at 4°C. The degree of cutting may have an effect, as grated carrots stored in 40 μ m oriented polypropylene bags in normal air at 5°C for 8 days lost from 20 to 40% of their initial β -carotene; approximately 10% of the initial content was lost during the washing stage of preparation (Hägg et al., 1994).

Persimmon slices tended to lose total RE over 8 days storage under the various atmospheres, although the loss for the 2% O₂ + 12% CO₂ treatment was not significant. There were no clear trends

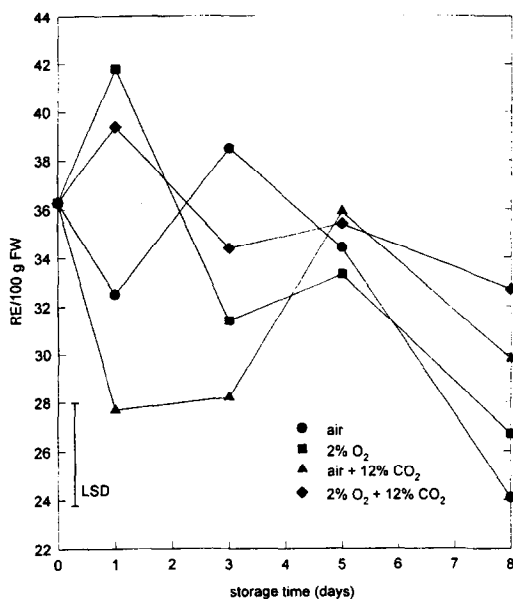


Fig. 5. Effect of controlled-atmosphere storage at 5°C on retinoid equivalents (RE content) of sliced persimmons.

for any treatment except the 2% O₂, in which the lycopene content tended to increase while the β -cryptoxanthin content decreased; lycopene is a biosynthetic precursor of β -carotene, and therefore of β -cryptoxanthin. The lycopene content was highly variable, which could be related to sun exposure depending on position of the fruit on the tree, or other intrinsic or environmental factors. The slices stored under air or 2% O₂ tended to lose more RE content over 8 days than those stored under the remaining atmospheres. Persimmon slices stored under 2% O₂ + 12% CO₂ lost no RE over 8 days, and maintained the most consistent levels during the course of storage.

From the results of this study, it appears that an atmosphere of air + 12% CO₂ does some damage to the sliced fruits; however, it is unlikely that packaged fruits would be exposed to this atmosphere unless CO₂ was injected into the package. Significant loss of provitamin A carotenoids does not occur before the slices reach their limit of marketability due to loss of quality.

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References

- Bartley, G.E. and Scolnik, P.A., 1995. Plant carotenoids: pigments for photoprotection, visual attraction, and human health. *Plant Cell*, 7: 1027–1038.
- Bolin, H.R. and Huxsoll, C.C., 1989. Storage stability of minimally processed fruit. *J. Food Process. Preserv.*, 13: 281–292.
- Bramley, P.M., 1992. Analysis of carotenoids by high performance liquid chromatography and diode-array detection. *Phytochem. Anal.*, 3: 97–104.
- Di Mascio, P., Kaiser, S. and Sies, H., 1989. Lycopene as the most efficient biological carotenoid singlet oxygen quencher. *Arch. Biochem. Biophys.*, 274: 532–538.
- Gaziano, J.M. and Hennekens, C.H., 1993. The role of beta-carotene in the prevention of cardiovascular disease. In: L.M. Canfield, N.I. Krinsky, and J.A. Olson (Editors). *Carotenoids in Human Health*. New York Academy of Sciences, New York, pp. 148–155.
- Goddard, M.S. and Matthews, R.H., 1979. Contribution of fruits and vegetables to human nutrition. *HortScience*, 14: 245–247.
- Gross, J., 1987. *Pigments in Fruits*. Academic Press, London.
- Hägg, M., Häkkinen, U., Kumpulainen, J., Hurme, E. and Ahvenainen, R., 1994. Effects of preparation procedures on nutrient contents in grated carrots. In: R. Ahvenainen, T. Mattila-Sandholm and T. Ohlsson (Editors), *Minimal Processing of Foods*. Technical Research Centre of Finland, Espoo, pp. 237–238.
- Hart, D.J. and Scott, K.J., 1995. Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. *Food Chem.*, 54: 101–111.
- Hornava, A., Payne, J., Koehler, P. and Eitenmiller, R., 1990. Provitamin A (alpha-carotene, beta-carotene and beta-cryptoxanthin) and ascorbic acid content of Japanese and American persimmons. *J. Food Qual.*, 13: 85–95.
- Kader, A.A., Zagory, D. and Kerbel, E.L., 1989. Modified atmosphere packaging of fruits and vegetables. *Crit. Rev. Food Sci. Nutr.*, 28: 1–30.
- Kimura, M., Rodriguez-Amaya, D.B. and Godoy, H.T., 1990. Assessment of the saponification step in the quantitative determination of carotenoids and provitamin A. *Food Chem.*, 35: 187–195.
- Klein, B.P., 1987. Nutritional consequences of minimal processing of fruits and vegetables. *J. Food Qual.*, 10: 179–193.
- Marsili, R. and Callahan, D., 1993. Comparison of a liquid solvent extraction technique and supercritical fluid extraction for the determination of α - and β -carotene in vegetables. *J. Chromatogr. Sci.*, 31: 422–428.
- Matthews-Roth, M.M., 1993. Carotenoids in erythropoietic protoporphyria and other photosensitivity diseases. In: L.M. Can-

- field, N.I. Krinsky and J.A. Olson (Editors), *Carotenoids in Human Health*. New York Academy of Sciences, New York. pp. 127–138.
- McCarthy, M.A. and Matthews, R.H., 1994. Nutritional quality of fruits and vegetables subject to minimal processes. In: R.C. Wiley (Editor), *Minimally Processed Refrigerated Fruits and Vegetables*. Chapman and Hall, New York. pp. 313–326.
- Paradis, C., Castaigne, F., Desrosiers, T. and Willemot, C., 1995. Evolution des teneurs en vitamine C, β -carotène et chlorophylle du brocoli découpé et entier au cours d'un entreposage à l'air. *Sci. Alim.*, 15: 113–123.
- Romig, W.R., 1995. Selection of cultivars for lightly processed fruits and vegetables. *HortScience*, 30: 38–40.
- Sandmann, G., 1994. Carotenoid biosynthesis in microorganisms and plants. *Eur. J. Biochem.*, 223: 7–24.
- Tee, E.-S., 1992. Carotenoids and retinoids in human nutrition. *Crit. Rev. Food Sci. Nutr.*, 31: 103–163.
- Thompson, J.E., Legge, R.L. and Barber, R.F., 1987. The role of free radicals in senescence and wounding. *New Phytol.*, 105: 317–344.
- USDA, 1982. *Composition of foods: fruits and fruit products – raw, processed, prepared*. U.S. Dept. Agr., Agr. Handbook 8–9, 283 pp.
- Watada, A.E., Abe, K. and Yamauchi, N., 1990. Physiological activities of partially processed fruits and vegetables. *Food Technol.*, 44(5): 116, 118, 120–122.
- Weichmann, J., 1986. The effect of controlled-atmosphere storage on the sensory and nutritional quality of fruits and vegetables. *Hort. Rev.*, 8: 101–127.
- Wright, K.P. and Kader, A.A., 1997. Effect of slicing and controlled-atmosphere storage on the ascorbate content and quality of strawberries and persimmons. *Postharvest Biol. Technol.*, 10: 39–48.