Browning Inhibition in Fresh-Cut Pears

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ABSTRACT

Treatments to control browning and maintain quality of fresh-cut pears were evaluated. Pear wedges were dipped in solutions containing sodium erythorbate, $CaCl_2$ and 4-hexylresorcinol; packed in air or with a modified atmosphere (MAP); and stored at 4°C. Samples were evaluated for browning, microbial spoilage, and presence of off-flavors or loss of firmness. For treatments to be successful, pears had to be above a minimum firmness of 4 kg (d'Anjou) or 5 kg (Bartlett) when treated. Inhibitor treatments, in conjunction with MAP, controlled browning and maintained quality of fresh-cut Bartlett and d'Anjou (but not Bosc pears) for 12-14 days.

Key Words: pears, browning inhibitors, modified atmosphere, firmness, sodium erythorbate

INTRODUCTION

FRESH-CUT VEGETABLES REPRESENT A large and rapidly growing segment of the food industry (Garrett, 1995; Schlimme, 1995). Many pre-cut vegetables or salad mixes are available, but development of comparable fruit products has not been as prevalent. This is largely due to the susceptibility of cut fruits to enzymatic browning and textural defects which limit product quality and shelf-life (Rolle and Chism, 1987; King and Bolin, 1989; Brecht, 1995). Addition of sulfites to control browning of fresh-cut fruits is not permitted (Anon., 1986).

Alternatives to sulfites have been proposed, most employing ascorbic (AA) or erythorbic acid (EA) in combination with adjuncts such as citric acid (CA), calcium salts, phosphates, cysteine, and other complexing agents and/or polyphenol oxidase (PPO) inhibitors (McEvily et al., 1992; Sapers, 1993). Most experimental and commercial browning inhibitor formulations are highly acidic (McEvily et al., 1992). However, Ponting et al. (1972) demonstrated the increased effectiveness of neutral browning inhibitor formulations for refrigerated apple slices. We found that sodium erythorbate (NaE) and ascorbate (NaA) were more effective than their corresponding acids for Red Delicious and Golden Delicious wedges (Sapers, 1988).

Fresh-cut pears might be a suitable component for salad bars or other food service or consumer products but are subject to rapid enzymatic browning and tissue breakdown. Considerable data are available on pear PPO (Rivas and Whitaker, 1973; Halim and Montgomery, 1978; Siddiq et al., 1994) and its substrates (Blankenship and Richardson, 1985; Risch and Herrmann, 1988; Amiot et al., 1995); however, information on controlling browning of pears is limited. Browning of pear slices has been prevented by placing them in 0.2% solutions of AA, sodium chloride or potassium chloride or in 0.02% cysteine-HCl (cyst) solution; acetic acid and CA were ineffective (Herrman et al., 1969). El-Ashwah et al. (1975) controlled browning of frozen, sliced pears by peeling, slicing and coring them while they were submerged in 0.2% $KHSO_3$ or 1% NaCl, and then storing slices in 35% sucrose syrup at −12°C. Bolin and Huxsoll (1989) found browning was not retarded in pear halves after dipping first in 2% AA and 2% CA and then in 2% calcium chloride/1% zinc chloride, followed by modified atmosphere packaging (MAP). Rosen and Kader (1989) reported that a 1.0% $CaCl_2$ dip reduced browning of Bartlett pear slices; however, dips in 1% AA, 1% CA or 1% AA + 1% CA were ineffective. Halim and Montgomery (1978) and Siddiq et al. (1994) demonstrated effectiveness of AA, L-cysteine, sodium metabisulfite, and other chemicals as inhibitors of pear PPO *in vitro,* but did not report browning inhibitor treatments for cut pears. The effectiveness of 4-hexylresorcinol (4-HR) as a browning inhibitor for apple slices suggests that it might be effective with fresh-cut pears (Monsalve-Gonzalez et al., 1995). It has been used commercially to control browning of shrimp, but its regulatory status for other applications is uncertain.

Our objective was to develop effective browning inhibitor dips and MAP conditions for fresh-cut pears.

MATERIALS & METHODS

SLIGHTLY UNDERRIPE D'ANJOU, BOSC, Argentine Bartlett (winter), and California Bartlett (summer) pears were obtained from local food stores during their respective seasons. The pears were stored briefly at 4°C or held at 20°C for 1-2 days to provide a range of ripeness.

In a preliminary experiment, pears were cut in half along the stem axis, and 3 plugs were cut from each half with an electric cork borer and a 22 mm dia stainless steel cutting tube (Sapers and Douglas, 1987). Each plug was cut transversely at its midpoint, producing a freshly cut cross-sectional surface for color measurement. Four replicate plugs (representing 2 pears) were treated by immersion for 90 sec either in water (control) or in a solution containing 1% AA + 0.2% $CaCl_2$ (pH 3.3) or 1.13% NaA + 0.2% $CaCl_2$ (pH 7.7). Treated plugs were drained and placed in crystallizing dishes, covered with Petri dish lids, for storage at 4°C. Samples were evaluated for browning by visual examination and by measurement of tristimulus color coordinates in the CIELAB scale with a spectrocolorimeter (The Color Machine; Byk-Gardner, Inc., Silver Spring, MD) (Sapers and Douglas, 1987).

In subsequent experiments carried out with fresh-cut pears, raw material firmness was determined with a McCormick Fruit Tester (Model FT 327; McCormick Fruit Technology, Yakima, WA) with the 7.94 mm plunger, and the pears were sorted into several ranges of firmness prior to treatment. In some trials, the pears were sanitized by immersion for 1 min in 200 ppm Cl_2 (sodium hypochlorite solution, adjusted to pH 6.5 with citric acid). The pears were cut into 10 wedges with a stainless steel apple and pear slicer (Westmark Divisorex, Herscheid, Germany), and wedges damaged by pressure testing were discarded. Wedges were hand-trimmed to exclude tissue compressed by the wedge cutter, seed pockets, and most of the adjacent core tissue which are highly susceptible to browning during storage. Wedges from 5 or more pears were composited and held briefly in a solution containing 0.25% NaCl to prevent browning prior to application of the inhibitor dip. Sufficient wedges for each treatment were removed from the holding solution, drained in a colander, and immersed for 1 min in water (control) or solutions containing 4% NaE, 4% NaE + 0.2% $CaCl_2$, 4% NaE + 50-400 ppm 4-HR, 4% NaE + 0.2% cyst, or 4% NaE + 0.2% $CaCl_2$ + 50-100 ppm 4-HR. Treated wedges were drained in a colander and then distributed, 5 per container, in 10 × 12 × 5 cm plastic boxes. The containers either were over-wrapped with 0.6 mil plasticized polyvinyl chloride film, with 6 perforations (3.18 mm diameter) per box (Goodyear Films Division, Goodyear Tire & Rubber Co., Akron, OH) or were heat-sealed within MAP bags having specified OTR values of 1395 (laminated polyethylene film; Cypress Packaging, Rochester, NY) or 4650 cc/m^2/day (coextruded polyethylene film; CVP Systems, Inc., Downers Grove, IL). Under the conditions of these experiments, the cypress packages contained ca. 14% O_2 and 3% CO_2 after 14 days at 4°C.

Samples (duplicate containers per treatment

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and storage time) were stored at 4°C and examined at frequent intervals over 2 wk for visual indications of quality loss. Samples were rated for degree (slight, moderate, severe) of browning of cut surfaces, the cut edge of the skin, and residual core tissue, and for evidence of microbial spoilage (mold, colonies, soft rot, etc.). Where wedge-to-wedge variation in degree of discoloration was observed, a range was reported. Reflectance measurements were made at the cut surface on both sides of each wedge (20 measurements/sample) with the Byk-Gardner Color Machine. We also informally tasted each individual wedge within containers of samples where treatments appeared to be effective, immediately after preparation and after storage for 1 or 2 wk, to determine whether treatments or storage produced off-flavors or textural defects.

Means and standard deviations were calculated for a*-values, measured at cut surfaces of 10 wedges (both sides) for each treatment and storage time. Further statistical analyses were not performed because of large sample variability.

RESULTS & DISCUSSION

Effect of browning inhibitor pH

Previous observations had indicated that neutral solutions of ascorbate or erythorbate were more effective than their respective acids in controlling browning of fresh-cut apple pieces (Sapers, 1988). We compared acidic (pH 3.3) and neutral (pH 7.7) ascorbate-based browning inhibitor formulations for cut pear plugs (Fig. 1). Treatment of d'Anjou plugs with the neutral formulation was more effective in inhibiting browning during storage at 4°C than treatment with the acidic formulation. This was based on the decrease in L* and increase in a*, changes in the tristimulus parameters indicative of browning (Sapers and Douglas, 1987), and visual observation. After 7 days, the AA/$CaCl_2$ treated samples showed moderate to severe browning and were no lighter than water-dipped controls while samples treated with NaA/$CaCl_2$ showed only slight browning. Similar results were obtained with Bartlett and Bosc pears (data not shown). We suggest that the lack of control of browning in pears, reported by Bolin and Huxsoll (1989), was due to the acidic treatment.

Factors affecting response to browning inhibitors

In subsequent experiments with pear wedges, various modifications of the neutral browning inhibitor treatment and MAP were evaluated with d'Anjou, Bartlett, and Bosc pears to identify quality problems limiting shelf-life and potential approaches for shelf-life extension (Table 1). The standard dip contained NaE, which was equivalent in effectiveness to NaA (Sapers and Ziolkowski, 1987), at a higher concentration than used previously with NaA, so that suppression of browning might be more effective. In a comparison of packaging methods (Expt. A), air-packed Anjou wedges showed moderate browning of cut surfaces and residual core tissue, Bartlett wedges showed more severe darkening of cut skin edges and core tissue, while Bosc wedges showed more severe browning of cut surfaces after 15 days at 4°C. Mold growth was visible on some samples after about 2 wk of storage. MAP with 1395 OTR film reduced discoloration of d'Anjou and Bartlett but not Bosc samples and did not completely suppress mold growth; MAP with 4650 OTR film was not effective in reducing browning.

In a comparison of slightly underripe and overripe (held 2 days at 20°C prior to treatment) pears, given the standard treatment and packaged with 4650 OTR film (Expt. B), wedges from the slightly overripe pears generally showed more discoloration during storage than those from the slightly underripe sample after 10-11 days at 4°C. Each of the cultivars showed this effect although the location and severity of browning varied.

In a comparison of Bartlett wedges given different browning inhibitor treatments and stored in air (Expt. C and D), addition of 0.2% cyst to the standard browning inhibitor dip did not control browning. It also induced a red or pink discoloration under the cut skin edge and in core tissue within 4 days. Omission of $CaCl_2$ from the standard dip resulted in greater discoloration of the cut skin edge and core tissue. Addition of 100 ppm 4-HR to the standard dip suppressed core browning in Bartlett wedges; however, higher concentrations induced darkening of the cut skin edge. We had reported that treatment with 4-HR induced browning of fresh mushrooms (Sapers et al., 1994).

These results showed the importance of cultivar, ripeness, tissue differences, and pack-

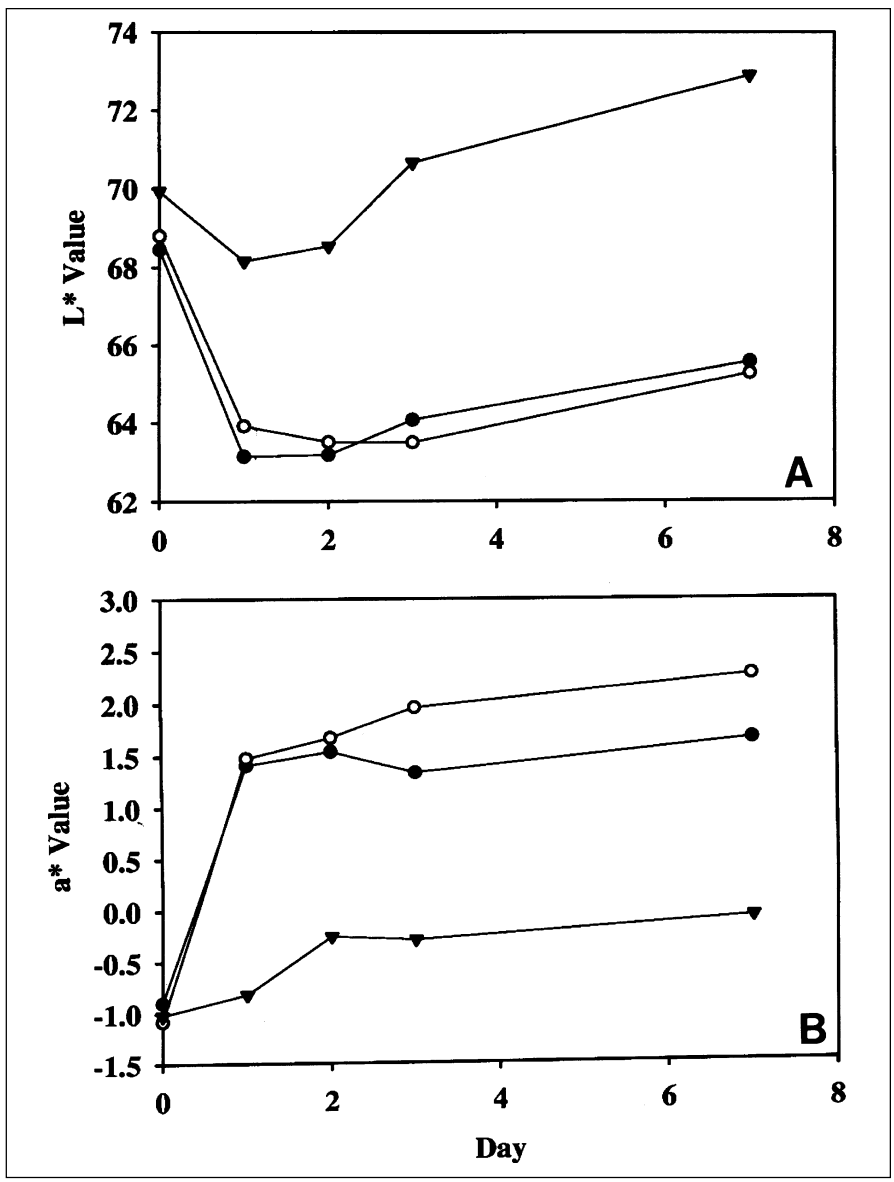

Fig. 1— Browning of d'Anjou pear plugs during storage at 4°C: control (●—●), dipped in 1.0% AA + 0.2% $CaCl_2$ for 90 sec (○—○), or dipped in 1.13% NaA + 0.2% $CaCl_2$ for 90 sec (▼—▼). A. L*-value; B. a*-value.

Table 1—Response of fresh-cut pears to browning inhibitor adjuncts and modified atmosphere storage

Expt.	Cultivar	Treatment[a]	Atmosphere[b]	Days at 4°C	Browning[c] Cut surface	Edge of skin	Core
A	d'Anjou	Std	Air	15	Mod	Mod	Mod
			MAP4650	15	Mod	Mod	Sev
			MAP1395	15	Sl	Sl	Sl
	Bartlett	Std	Air	15[e]	Mod	Mod	Sev
			MAP4650	15[e]	Mod	Mod	Sev
			MAP1395	15	Sl	Sl	Sl/Sev
	Bosc	Std	Air	15	Sev	Sl	0
			MAP4650	15	Sev	Sl	0
			MAP1395	15[e]	Sev	Sl	Sl
B	d'Anjou	Std, underripe	MAP4650	10	Sl	Sl	Mod
		Std, overripe	MAP4650	11	Sl/Mod	Sl	Mod
	Bartlett	Std, underripe	MAP4650	10	Sl	Sev	Sev
		Std, overripe	MAP4650	11	V Sev	Sev	Sev
	Bosc	Std, underripe	MAP4650	10	Sl/Sev	Sl	0
		Std, overripe	MAP4650	11	Sl/Sev	Sl/Sev	—
C	Bartlett	Std	Air	4	0	Sev	Sl
		Std + 0.2% cyst	Air	4	Sl/Sev	Sev[d]	Sl[d]
D	Bartlett	Std	Air	14	Sl	0/Mod	Mod
		NaE only	Air	14[e]	Sl	Sl/Sev	Mod/Sev
		Std + 100 ppm 4-HR	Air	14	Sl	Sl	0
		NaE + 100 ppm 4-HR	Air	14	Sl	Sl/Sev	Sev
		Std + 200 ppm 4-HR	Air	14	Sl	Sl/Sev	Sl
		Std + 400 ppm 4-HR	Air	14	Sl	Mod/Sev	0

[a]Std = 4% sodium erythorbate (NaE) + 0.1% $CaCl_2$ for Expts. A-C and 4% NaE + 0.2% $CaCl_2$ for Expt. D; cyst = cysteine.HCl; 4-HR = 4-hexylresorcinol.
[b]MAP1395 = film with OTR of 1395; MAP4650 = film with OTR of 4650.
[c]Observed on last day of storage; V Sev = very severe; Sev = severe; Mod = moderate; Sl = slight; 0 = none.
[d]Red or pink discoloration.
[e]Mold growth visible.

age atmosphere in determining the response of cut pears to browning inhibitor treatments. d'Anjou and Bartlett pears responded better than Bosc to the standard dip and MAP with 1395 OTR film. The shelf-life of wedges of d'Anjou and Bartlett appeared to be limited by discoloration of the cut skin edge and core tissue rather than browning of the cut surface or microbial spoilage. Further efforts were focused on controlling discoloration of those tissues by modification of inhibitor formulations. However, because mold growth appeared to limit shelf-life of some samples, pears were sanitized with 200 ppm Cl_2 in subsequent trials.

Preservation system for fresh-cut d'Anjou pears

Effectiveness of NaE and various adjuncts in inhibiting browning of air-packed d'Anjou pear wedges was evaluated by tristimulus colorimetry of cut surfaces and by visual observation of cut skin edges and residual core tissue which were too small and irregular for accurate colorimetry. Measurements of a* clearly showed the suppression of browning at cut surfaces resulting from NaE treatment and suggested some enhancement of browning inhibition by addition of $CaCl_2$ and/or 4-HR to NaE (Fig. 2). $CaCl_2$ or 4-HR alone did not inhibit browning of cut surfaces (reflectance data not shown). These results were confirmed by visual observation of cut surfaces (Table 2). Use of 4-HR alone suppressed core browning but not darkening of the cut skin edge. The two-way combinations of NaE with $CaCl_2$ or 4-HR resulted in less browning of cut surface, skin edge, and core than was found with NaE treatment alone, while the 3-way combination resulted in no core browning.

The ripeness effect on browning tendency, observed visually in preliminary experiments, was confirmed with pears that were sorted by firmness (penetrometer reading) after storage at 20°C to accelerate ripening. Browning of cut surfaces during storage, as indicated by visual observation (Table 3), was greater in less firm fruit (penetrometer reading = 2.9±0.21 kg) than in more firm fruit (penetrometer = 4.0±0.36 kg) with both erythorbate and 3-way inhibitor treatments. Increases in a* at wedge cut surfaces over 14 days' storage (Δa*) were consistent with this trend, although a* values were too variable to permit statistical analysis. The less firm fruit also showed more browning of skin edge and core. Mellethin and Wang (1974) reported an increase in phenolic concentration in d'Anjou pears during postharvest storage at −1°C which they correlated with susceptibility to friction discoloration. However, Siddiq et al. (1994) reported that PPO activity, total phenolics, and chlorogenic acid concentration declined during storage of Bosc and Red pears at 25°C for 4 days. Amiot et al. (1995) also reported a decrease in phenolic content of 9 pear cultivars after 4 days at room temperature; browning of some cultivars increased during storage while others decreased. The crucial factor in determining storage effects on browning tendency may be cell wall integrity, as indicated by firmness. The less firm fruits may be more susceptible to mechanical injury during handling or cutting, resulting in more browning during subsequent storage.

Use of MAP with 1395 OTR film enhanced browning inhibition by the combination of NaE with $CaCl_2$, 4-HR, or $CaCl_2$ + 4-HR (Table 4). MAP also suppressed darkening of the cut skin with all inhibitor formulations. Browning of core tissue was suppressed by addition of 4-HR to the inhibitor dip, irrespective of use of MAP (Expt. B).

Because textural or flavor changes might occur during storage of fresh-cut pears, samples prepared from slightly underripe (penetrometer = 4.6±0.19 kg) or ripe (penetrometer = 3.6±0.15 kg) fruit and treated with NaE/$CaCl_2$/4-HR combinations were tasted infor-

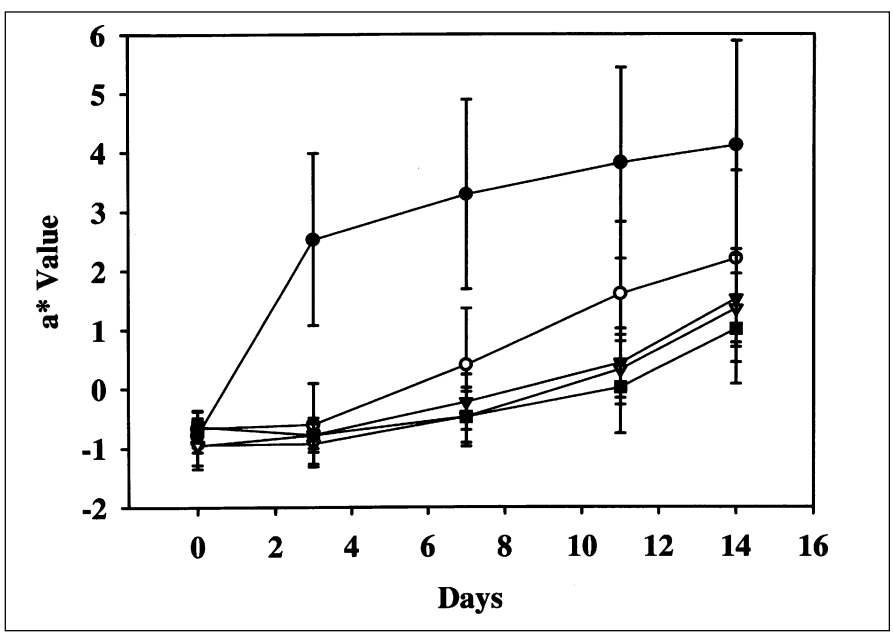

Fig. 2—Effect of browning inhibitors on a*-value at cut surfaces of air-packed d'Anjou pear wedges during storage at 4°C. Treatments: control (●—●), 4% NaE (○—○), 4% NaE + 0.2% $CaCl_2$ (▼—▼), 4% NaE + 100 ppm 4-HR (▽—▽), 4% NaE + 0.2% $CaCl_2$ + 100 ppm 4-HR (■—■).

mally after 8 and 14 days at 4°C. Other than expected differences in firmness (which were slight), the samples were similar in texture and flavor, and no defects were detected.

Based on these results, we recommend that fresh-cut d'Anjou pears be prepared from slightly underripe fruit (i.e., firmness ca. 4 kg); that wedges be treated with a browning inhibitor formulation containing 4% NaE, 0.2% $CaCl_2$, and, if permitted by the FDA, 100 ppm 4-HR; and that the product be packaged with a suitable modified atmosphere, i.e., with a film having OTR value ca. 1395 cc/m^2/day.

Preservation system for fresh-cut Bartlett pears

Browning inhibitor treatments shown to be effective with d'Anjou pears were applied to fresh-cut Argentine (winter) Bartlett pears of varying firmness (Table 5). With pears having penetrometer readings of 3 kg or less, fresh-cut products showed moderate to severe browning within 3–7 days at 4°C, irrespective of inhibitor formulation. Some wedges in samples treated with dips containing 4-HR showed tissue breakdown (development of translucency), even when the 4-HR concentration was reduced from 100 to 50 ppm. In contrast, fresh-cut samples prepared from slightly underripe pears (mean penetrometer reading of 5.7 kg; firm, still sweet, normal pear flavor) showed no breakdown and only slight to moderate browning, even after 13 days at 4°C. By Day 17, severe browning and indications of microbial spoilage were evident. When packaged in the 1395 OTR film, browning was slight, even after 17 days, but some samples showed indications of spoilage (mold spots) on Day 17. All browning inhibitor treatments were similar in effectiveness with fresh-cut samples prepared from the firmer pears (5.7 kg) and packaged with 1395 OTR film (Fig. 3). While all treated samples showed much less browning than untreated controls, which showed severe browning within 3 days, the addition of $CaCl_2$ and/or 4-HR to NaE did not appear to improve product color through Day 6. On Days 10–13, the samples treated with NaE + 4-HR and the 3-way combination had slightly lower a*-values than those treated with NaE alone. By Day 17, all treated samples showed a slight elevation in a* and slight browning. Thus, a shelf-life of at least 2 wk could be obtained with fresh-cut Argentine Bartlett pears treated with NaE, alone or in combination with $CaCl_2$ and/or 4-HR, and packaged using MAP.

Similar results were obtained with California Bartlett pears (Table 6). Treatment of slightly underripe (penetrometer reading ca 5 kg) fruit with a NaE-based browning inhibitor dip, followed by packaging with a 1395 OTR film, gave a shelf-life of 14 days. The cut surface of MAP-packaged wedges showed little or no browning with all dip formulations. However, prevention of browning of the skin cut edge and core tissue re-

Table 2—Effect of browning inhibitor treatments on discoloration in d'Anjou pear wedges during storage in air at 4°C

	Browning[b]					
	Cut surface		Edge of skin		Core tissue	
Treatment[a]	7 d	14 d	7 d	14 d	7 d	14 d
Control	Sev	Sev	Sev	Sev	Mod	Sev
NaE	Sl/Mod	Mod	Sl/Mod	Mod/Sev	Mod	Mod/Sev
Ca	Sev	Sev	Sev	Sev	Sev	Sev
4-HR	Sev	Sev	Sev	Sev	Sl	Sl
NaE + Ca	0/Sl	Sl/Mod	0/Sl	Sl	0	Sl
NaE + 4-HR	0/Sl	Sl/Mod	0	Sl	0	Sl/Mod
NaE + Ca + 4-HR	0	Sl/Mod	0	Sl/Mod	0	0

[a]NaE = 4% sodium erythorbate; Ca = 0.2% calcium chloride; 4-HR = 100 ppm 4-hexylresorcinol.
[b]Sev = severe; Mod = moderate; Sl = slight; 0 = none.

Table 3—Effect of ripeness on response of d'Anjou pear wedges to browning inhibitor treatment during storage for 14 days at 4°C

			Browning[c]		
Treatment[a]	Firmness[b]	Δa*	Cut surface	Edge of skin	Core tissue
Control	2.9	7.26 ± 2.29	Sev	Sev	Sl/Sev
	4.0	5.55 ± 2.75	Sev	Sev	Mod
NaE	2.9	3.30 ± 1.66	Mod/Sev	Sl/Sev	Sl/Sev
	4.0	2.03 ± 1.05	Sl/Mod	Sl/Sev	Mod
NaE + Ca	2.9	2.13 ± 1.55	Mod/Sev	Sl/Mod	0/Sev
+ 4-HR	4.0	1.96 ± 1.05	Sl/Mod	Sl	Sl/Mod

[a]NaE = 4% sodium erythorbate; Ca = 0.2% calcium chloride; 4-HR = 100 ppm 4-hexylresorcinol.
[b]Mean penetrometer reading, kg.
[c] $a^* = a^*_{Day\ 14} - a^*_{Day\ 0}$ ± std. dev.
[d]Sev = severe; Mod = moderate; Sl = slight, 0 = none.

Table 4—Effect of browning inhibitor treatments and modified atmosphere packaging (MAP) on browning of d'Anjou pear wedges during storage for 15 days at 4°C

				Browning		
Expt[a]	Treatment[b]	Atm.	Δa*	Cut surface	Edge of skin	Core tissue
A	Control	Air	4.10 ± 1.18	Sev	Sev	Sev
		MAP	4.14 ± 1.64	Sev	Mod/Sev	Sl
	NaE	Air	1.19 ± 0.76	Sl/Mod	Sl/Sev	0/Sl
		MAP	1.25 ± 0.54	Sl/Mod	Sl/Mod	0
	NaE + Ca	Air	2.77 ± 0.92	Sl/Sev	Sl/Sev	0
		MAP	1.26 ± 0.88	Sl	Sl	Sl
B	Control	Air	3.42 ± 1.02	Sev	Sev	Sev
		MAP	2.97 ± 1.04	Sev	Sev	Sev
	NaE	Air	1.50 ± 0.59	Sl	Sl/Sev	Sl/Sev
		MAP	0.69 ± 0.45	0/Sl	0/Sl	Sl/Mod
	NaE + 4-HR	Air	2.24 ± 0.80	Mod	Mod/Sev	0
		MAP	1.23 ± 0.58	Sl/Mod	0/Sl	0
	NaE + 4-HR + Ca	Air	2.73 ± 0.95	Mod	Mod/Sev	0
		MAP	1.61 ± 0.65	Sl	0/Sl	Sl

[a]Firmness of pears (penetometer reading): Expt. A = 3.0 kg; Expt. B = 3.7 kg.
[b]NaE = 4% sodium erythorbate; Ca = 0.2% calcium chloride; 4-HR = 100 ppm 4-hexylresorcinol.
[c]MAP = modified atmosphere film with OTR of 1395.
[d]Sev = severe; Mod = moderate; Sl = slight; 0 = none.

Table 5—Effect of ripeness on response of Argentine Bartlett pear wedges to browning inhibitor treatment during storage at 4°C[a]

				Browning[d]			
Expt.	Firmness[b]	Atmosphere	Day	Cut surface	Edge of skin	Core tissue	Shelf-life[e] (days)
A	1.1±0.18	Air	7	0/Sev, BD	Sl/Sev	–	<3
	1.8±0.36	Air	7	0/Mod	Sl/Sev	Mod/Sev	3-7
B	2.4±0.13	Air	6	Mod	Sl/Sev	Sev	2-6
	3.0±0.26	Air	6	Sl/Mod	Sl/Mod	Mod	6
C	5.7±0.28	Air	6	0	0/Mod	0/Sl	–
			13	Sl/Mod	Mod	Mod	10-13
			17	Mod+Sp	Sev	Mod	–
		MAP[c]	6	0	0/Sl	0	–
			13	0/Sl	Sl	0	–
			17	Sl + Sp	Sl	Sl	13-17

[a]Pears immersed in 4% NaE + 0.2% $CaCl_2$ for 1 min.
[b]Mean penetrometer reading ± standard deviation, kg.
[c]MAP = modified atmosphere film with OTR of 1395.
[d]Sev = severe; Mod = moderate; Sl = slight; 0 = none; BD = tissue breakdown; Sp = microbial spoilage.
[e]Day(s) at 4°C prior to development of severe browning, tissue breakdown, and/or microbial spoilage.

Table 6—Effect of ripeness on response of California Bartlett pear wedges to browning inhibitor treatment during storage at 4°C[a]

Expt.	Firmness[b]	Atmosphere	Day	Browning[d] Cut surface	Browning[d] Edge of skin	Browning[d] Core tissue	Shelf-life[e] (days)
A	2.1±0.24	Air	6	Sl, BD	Sl/Sev	Sl/Sev	<3
	3.4±0.28	Air	6	Sl	Sl/Sev	Sev	<3
B	3.6±0.36	Air	11	0	Sl/Mod	0	11-14
			14	Sl+Sp	Sl/Mod	—	—
	5.1±0.24	Air	11	0	Sl/Mod	0/Mod	11-14
			14	Sl+Sp	Mod	Sl/Mod	—
C	5.6±0.38	Air	7	0	Sl/Sev	Sl/Mod	3-7
			13	0/Sl	Sl/Sev	Sl/Sev	—
			17	Sl/Sev+Sp	Sev	Sev	—
		MAP[c]	13	0+Sp	Sl	Sl/Mod	—
			17	0+Sp	Sl	—	13-17

[a]Pears immersed in 4% NaE + 0.2% $CaCl_2$ for 1 min.
[b]Mean penetrometer reading ± standard deviation, kg.
[c]MAP = modified atmosphere film with OTR of 1395.
[d]Sev = severe; Mod = moderate; Sl = slight; 0 = none; BD = tissue breakdown; Sp = microbial spoilage.
[e]Day(s) at 4°C prior to development of severe browning, tissue breakdown, and/or microbial spoilage.

quired addition of $CaCl_2$ and 4-HR (data not shown). The occasional presence of mold growth in some samples stored for 2 wk or more at 4°C warrants further study to determine the possible need for a preservative such as potassium sorbate. Without such controls, microbial growth could limit shelf-life and present a safety problem.

Slightly underripe pear wedges (5.0 ± 0.42 kg) treated with browning inhibitor dips containing $CaCl_2$ had a firm texture and showed no evidence of textural or flavor defects initially or after 7 or 14 days at 4°C. Some wedges in samples prepared without $CaCl_2$ were firm initially but became soft and sometimes mealy after storage. Wedges prepared from less ripe pears (6.1 ± 0.24 kg), treated with dips containing $CaCl_2$, were excessively firm and lower in flavor than those prepared from less firm fruit. Without $CaCl_2$ addition, some wedges became soft and mealy, even with the more firm raw material.

CONCLUSIONS

TREATMENT OF FRESH-CUT, SLIGHTLY UNDerripe d'Anjou and Bartlett pears with a dip containing sodium erythorbate, $CaCl_2$ and 4-HR, followed by appropriate MAP conditions, retarded browning of cut surfaces, cut edges of the skin, and residual core tissue, with no apparent deterioration of flavor or texture, for at least 14 days at 4°C. Fully ripe pears did not respond as well to treatment as slightly underripe fruit. A neutral dip was more effective than an acidic dip. Addition of $CaCl_2$ enhanced browning inhibitor performance and also prevented textural deficiencies such as mealiness and loss of firmness. The presence of 4-HR in browning inhibitor dips specifically eliminated core tissue browning which could produce an unsightly product even when cut surface browning was controlled. Fresh-cut Bosc pears underwent severe browning irrespective of inhibitor treatment, ripeness or packaging.

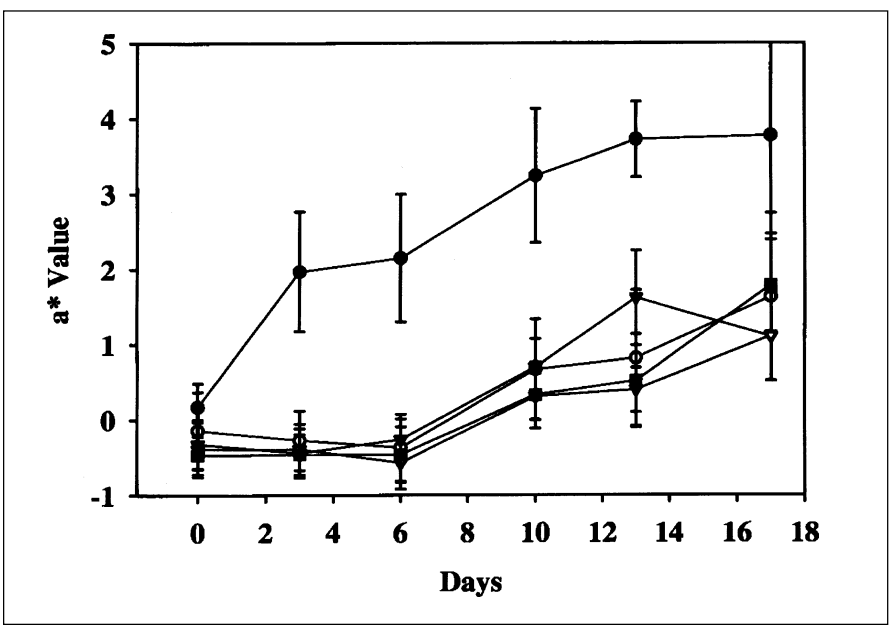

Fig. 3—Effect of browning inhibitor treatments on a*-value at cut surfaces of modified atmosphere packaged Argentine Bartlett pear wedges during storage at 4°C. Treatments: control (●—●), 4% NaE (○—○), 4% NaE + 0.2% $CaCl_2$ (▼—▼), 4% NaE + 50 ppm 4-HR (▽—▽); 4% NaE + 0.2% $CaCl_2$ + 50 ppm 4-HR (■—■).

REFERENCES

Amiot, M.J., Tacchini, M., Aubert, S.Y., and Oleszek, W. 1995. Influence of cultivar, maturity stage, and storage conditions on phenolic composition and enzymatic browning of pear fruits. J. Agr. Food Chem. 43: 1132-1137.

Anonymous. 1986. Sulfiting agents; revocation of GRAS status for use on fruits and vegetables intended to be served or sold raw to consumers. Food and Drug Administration. Fed. Reg. 51: 25021-25026.

Blankenship, S.M. and Richardson, D.G. 1985. Changes in phenolic acids and internal ethylene during long-term cold storage of pears. J. Amer. Soc. Hort. Sci. 110: 336-339.

Bolin, H.R. and Huxsoll, C.C. 1989. Storage stability of minimally processed fruit. J. Food Processing and Preservation 13: 281-292.

Brecht, J.K. 1995. Physiology of lightly processed fruits and vegetables. HortScience 30: 18-22.

El-Ashwah, F.A., Ibrahim, S.S., El-Manatawy, H.K., and Sarhan, M.A. 1975. Prevention of discoloration of pears during processing and storage. Agricultural Research Review 53(3): 35-40.

Garrett, E. 1995. Fresh-cut produce: how have we grown? Presented at Workshop on Fresh-Cut Products: Maintaining Quality and Safety, Univ. of California, Davis, March 27-29.

Halim, D.H. and Montgomery, M.W. 1978. Polyphenol oxidase of d'Anjou pears (*Pyrus communis* L.). J. Food Sci. 43: 603-605, 608.

Herrmann, J., Neubert, K.P, and Bastian, G. 1969. Examinations of the browning of apples and pears during processing. Elelmezesi Ipar 23(9): 257-64. In *Food Sci. Technol. Abstr.* 70-03-J0251.

King, A.D. and Bolin, H.R. 1989. Physiological and microbiological storage stability of minimally processed fruits and vegetables. Food Technology 43(2): 132-135, 139.

McEvily, A J., Iyengar, R., and Otwell, W.S. 1992. Inhibition of enzymatic browning in foods and beverages. Crit. Rev. Food Sci. & Nutr. 32: 253-273.

Mellethin, M.W. and Wang, C.Y. 1974. Friction discoloration of Anjou pears in relation to fruit size, maturity, storage and polyphenoloxidase activities. HortScience 9: 592-593.

Monsalve-Gonzalez, A., Barbosa-Canovas, G.V., McEvily, A.J., and Iyengar, R. 1995. Inhibition of enzymatic browning in apple products by 4-hexylresorcinol. Food Technology 49(4): 110-118.

Ponting, J.D., Jackson, R., and Watters, G. 1972. Refrigerated apple slices: preservative effects of ascorbic acid, calcium and sulfites. J. Food Science 37: 434-436.

Risch, B. and Herrmann, K. 1988. Die gehalte an hydroxyzimtsäure-verbindungen und catechinen in kern- und steinobst. Z. Lebensm. Unters, Forsch. 186: 225-230.

Rivas, N.J. and Whitaker, J.R. 1973. Purification and some properties of two polyphenol oxidases from Bartlett pears. Plant Physiol. 52: 501-507.

Rolle, R.S. and Chism, G.W., III. 1987. Physiological consequences of minimally processed fruits and vegetables. J. Food Quality 10: 157-177.

Rosen, J.C. and Kader, A.A. 1989. Postharvest physiology and quality maintenance of sliced pear and strawberry fruits. J. Food Sci. 54: 656-659.

Sapers, G.M. 1988. Unpublished data. Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Philadelphia, PA.

Sapers, G.M. 1993. Browning of foods: control by sulfites, antioxidants, and other means. Scientific Status Summary. Food Technology 47(10): 75-84.

Sapers, G.M. and Douglas, F. W., Jr. 1987. Measurement of enzymatic browning at cut surfaces and in juice of raw apple and pear fruits. J. Food Sci. 52: 1258-1262, 1285.

Sapers, G.M., Miller, R. L., Miller, F. C., Cooke, P. H., and Choi, S.-W. 1994. Enzymatic browning control in minimally processed mushrooms. J. Food Sci. 59: 1042-1047.

Sapers, G.M. and Ziolkowski, M.A. 1987. Comparison of erythorbic and ascorbic acids as inhibitors of enzymatic browning in apple. J. Food Sci. 52: 1732-1733, 1747.

Schlimme, D.V. 1995. Marketing lightly processed fruits and vegetables. HortScience 30: 15-17.

Siddiq, M., Cash, J.N., Sinha, N.K., and Akhter, P. 1994. Characterization and inhibition of polyphenol oxidase from pears (*Pyrus communis* L. cv Bosc and Red). J. Food Biochem. 17: 327-337.

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