Extending Shelf Life of Fresh-cut Pears

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ABSTRACT: The effects of various treatments were evaluated for extending shelf-life of fresh-sliced pears. Sliced Anjou pears had browning-free color for 30 d by dipping with 1.0% ascorbic acid and 1.0% calcium lactate, but texture was soft with juice leakage. The combination treatment of 0.01% 4-hexylresorcinol (4-HR), 0.5% ascorbic acid and 1.0% calcium lactate can provide 15 to 30 d shelf-life for Anjou, Bartlett, and Bosc pears when the pears are sliced at an average ripeness of 43, 49, and 38 Newton respectively, with 2 min dipping, partial vacuum packaging, and 2 to 5 °C storage. 4-HR residual content ranged from 1 to 7 ppm after 14 d storage. Panelists could detect a flavor difference between 0.01% 4-HR treated pears and controls.

Key Words: fresh-sliced pears, extending shelf-life, 4-HR residue, sensory properties

Introduction

FRESH-CUT OR MINIMALLY PROCESSED FRUITS AND VEGETABLES are a rapid-growing segment of the U.S. fresh produce industry (Gorny and others 1998). These products have the attributes of convenience and fresh-like quality. Two basic problems confront the extension of shelf-life of fresh-cut fruit and vegetable products. First, the processing procedures of peeling and cutting cause intermixing of polyphenol oxidase with phenolics which undergo enzymatic browning to produce an undesirable brown color (Macheix and others 1990; Walker 1995). Second, tissue wounding induces a high respiration rate, which triggers faster texture deterioration compared to intact tissues (Rosen and Kader 1989). A combination of controlled atmosphere packaging and/or firming agents like calcium salts has been reported to successfully retard texture softening (Ponting and others 1972; Poovaiah 1986; Rosen and Kader 1989; Gorny and others 1998). Sulfites have been used to inhibit both enzymatic and nonenzymatic browning in foods. However, their applications have been limited to certain categories of food products due to severe reactions in some asthmatics (Sapers 1993). A long-standing goal of food technology has been to find effective substitutes to prevent cut surface browning in order to extend the shelf-life of fresh produce. Numerous potential browning inhibitors have been tested on fresh-cut fruits and vegetables. Ascorbic acid (AA) and its isomer, erythorbic acid (Ponting and others 1972; Santerre and others 1988; Sapers and Ziolowski 1987; Sapers and others 1989), L-cysteine (Molnar-Perl and Friedman 1990), 4-hexylresorcinol (4-HR) (Luo and Barbosa-Canovas 1995; Monsalve-Gonzalez and others 1993, 1995), and pineapple juice (Lozano-de-Gonzalez and others 1993) have been reported to be effective browning inhibitors for fresh-cut apples.

Sucrose ester (Semperfresh™) is a commercially available browning inhibitor. It is an edible coating film that is proposed to inhibit browning by functioning as an oxygen barrier when it is coated on the surface of fresh-cut fruits.

Pear growers and marketers have shown a high interest in developing fresh-cut pear products to stimulate the consumption of pears. However, fresh-cut pears offer a unique challenge because of their propensity for enzymatic browning and texture softening during storage. Efforts have been made to inhibit or reduce browning of fresh-cut pears during storage by controlled atmosphere storage in combination with/without ascorbic acid and/or calcium salt dipping (Rosen and Kader 1989; Gorny and others 1998). Sapers and Miller (1998) reported that a shelf-life of 12 to 14 d for fresh-cut Anjou and Bartlett (but not Bosc) pears was obtained with a combination of sodium erythorbate/calcium/4-HR and modified atmosphere packaging.

Our objective was to develop effective methods to extend the shelf-life of fresh-cut pears with retention of visually appealing color and acceptable texture.

Results & Discussion

Effect of calcium lactate on color and texture

Calcium has been reported to maintain the cell wall structure in fruits by interacting with pectic acid in the cell wall to form calcium pectate which firms molecular bonding between constituents of cell wall (Fennema 1985). Thus, fruits treated with calcium are generally firmer than controls (Poovaiah 1986). Ponting and others (1972) evaluated both calcium lactate and calcium chloride as firming agents for canned apples and noted that calcium lactate gave a somewhat better flavor than calcium chloride. Calcium lactate as a firming agent helped Bosc pear slices maintain firmness, with increasing benefit from increased concentration (Fig. 1). Bosc pear slices treated with 1.0% calcium lactate had a significantly firmer texture than the control. However, no significant firming effect was obtained for Bartlett slices with calcium dipping treatments (data not shown). Visual observations revealed that the surfaces of both Bartlett and Bosc pear slices dipped with 1.0% calcium lactate were smooth, while treatments not containing calcium lactate had varying degrees of stickiness and mushiness on the surfaces.

With respect to color, calcium lactate did not inhibit browning. Color values of CIE L* (lightness) and hue angle (color itself) for calcium lactate-treated Bosc pear slices decreased similarly for all treatments, indicating that no significant browning inhibition occurred for all calcium lactate concentrations tested. Results were similar for calcium lactate treated Bartlett pear slices (data not shown). These findings are in an agreement with those of Ponting and others (1972) who reported that calcium treatment alone resulted in poor color on apple slices.

Effect of calcium lactate and ascorbic acid

Gorny and others (1998) reported that 1.0% calcium chloride with 2.0% ascorbic acid applied as a dip for 1 min was effective in reducing pear slice surface browning. Ponting et al. (1972) also found that the combination of treatments with 1.0% ascorbic acid and 0.1% calcium chloride effectively inhibited browning in apple slices. The combination of 1.0% ascorbic acid with 1.0% calcium lactate inhibited discoloration of Anjou pear slices, yet caused loss of firmness and tissue leakage under partial vacuum packaging condition (Fig. 2). The CIE L* and hue angle values of the slices treated with 1.0% calcium lactate and 0.5% AA were significantly higher than those of the control or 1.0 % calcium lactate alone.

However, even within one day after slicing, the CIE L* and hue angle values had decreased from time 0 (fresh) of 76.3 and

90.3 to 71.8 and 85.8, respectively, and continued to decrease. Some browning was noticeable immediately after partial vacuum packaging. Increasing the ascorbic acid concentration to 1.0% and combining with 1.0 % calcium lactate more effectively inhibited browning.

The softening and leakage of Anjou slices under partial vacuum packaging could be due to pectic acid undergoing acid hydrolysis with acidic solution dipping or osmotic leaking. Sapers and others (1992) also observed that treatment with dips containing AA-2-phosphate (which served as an AA reservoir) caused some leakage on cut potato surfaces.

Effect of sucrose ester treatments on browning inhibition

Anjou pear slices treated with sucrose ester in the presence of 0.5% AA and 1.0% calcium lactate had less browning than those treated with distilled water. However, some brown color was detected within one day after dipping treatment, and visual color became unacceptable as the storage time continued (Fig. 3). There were no significant color differences among the 3 sucrose ester concentration treatments. White precipitate was observed on the surface of some pear slices when higher concentrations of sucrose ester were applied as dipping solutions (0.5% and 1.0%). Similar observations were obtained with Bosc pear slices.

Effect of 4-HR treatments combined with 1.0% calcium lactate and 0.5% AA

Different concentrations of 4-HR were evaluated in combination with 1.0% calcium lactate and 0.5% ascorbic acid. It was found that 4-HR at 0.005% effectively inhibited browning of Bartlett slices for as long as 20 d in the presence of 0.5% AA and 1.0% calcium lactate. After 20 d, some browning was observed on the slices treated with 0.005% 4-HR. 4-HR at 0.005% was also as effective as higher concentrations in keeping Anjou slices from discoloration for 15 d. After 15 d, some brown color was noticed on Anjou pear slices for all concentration treatments, with the least browning with 0.01% 4-HR (Table 1).

All concentrations of 4-HR inhibited browning of Bosc slices equally well for up to 20 d. After 20 d, browning occurred slowly on the slices treated with 0.005% 4-HR. The concentration of 0.01% 4-HR effectively kept Bartlett and Bosc pear slices from browning for 30 d.

The same concentrations of 4-HR with 1.0% calcium lactate without 0.5% ascorbic acid were tested on Bosc pear slices. Browning for all these 4-HR treatments increased with time on Bosc pears (data not shown). It is evident that the synergistic browning inhibition was obtained by a combination of 4-HR with 0.5% ascorbic acid. Luo and Barbosa-Canovas (1995) reported similar results for apple slices and proposed that a mixed type of competitive and noncompetitive inhibition might be occurring. Suppression of PPO activity by 4-HR would limit quinone formation, while any quinones that might be formed would be reduced by AA and not further polymerized to brown melanoidin pigments.

Other browning inhibitor treatments

No satisfactory browning inhibition on fresh-cut pears was obtained with canned pineapple juice, 1.0% ascorbic acid com-

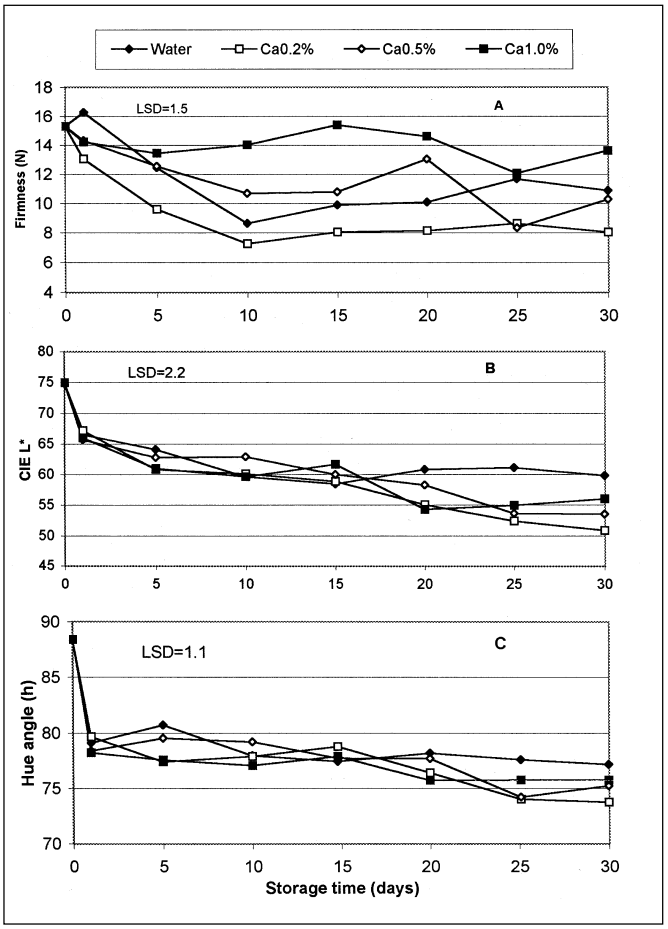

Fig. 1 Changes of firmness (A), CIE L* (B), and hue angle (C) values of sliced Bosc pears treated with different concentrations of calcium lactate and stored at 2 to 5 °C for 30 d. Pooled LSD is shown.

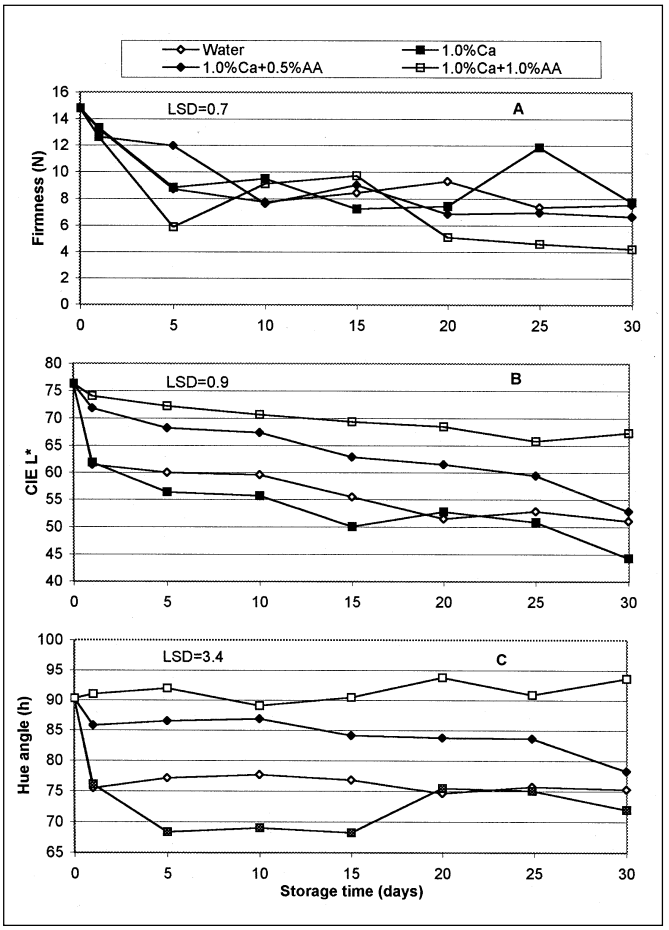

Fig. 2 Changes of firmness (A), CIE L* (B), and hue angle (C) values of sliced Anjou pears dipped in solutions containing 1.0% calcium lactate and various concentrations of ascorbic acid and stored at 2 to 5 °C for 30 d. Pooled LSD is shown.

Table 1— Mean values of CIEL*, a* and hue angle of Bartlett, Bosc, and Anjou pear slices dipped in solutions combining 1.0% calcium lactate, 0.5% ascorbic acid with various concentrations of 4-HR, and stored for 30 d at 2 to 5 oC

Varieties	Bartlett			Bosc			Anjou		
Treatments	CIE L*	CIE a*	Hue(h)	CIE L*	CIE a*	Hue(h)	CIE L*	CIE a*	Hue(h)
Fresh	75.1	0.3	88.5	75.0	0.7	88.4	76.3	-0.1	90.3
4-HR 0.005%	69.4	2.0	83.5	69.3	0.4	89.2	66.5	0.5	89.0
	(4.2)	(1.8)	(4.6)	(0.6)	(0.1)	(0.3)	(0.9)	(2.1)	(4.7)
4-HR 0.01%	74.6	0.1	89.9	69.4	0.1	89.8	64.8	0.5	88.9
	(0.5)	(0.4)	(0.9)	(0.8)	(0.2)	(0.5)	(0.8)	(1.4)	(3.3)
4-HR 0.02%	73.8	0.2	89.4	70.7	-0.4	90.9	64.0	1.2	87.3
	(2.3)	(1.0)	(2.5)	(1.2)	(0.1)	(0.2)	(0.6)	(0.8)	(1.6)
4-HR4-HR 0.03%	69.9	2.8	84.2	70.4	-0.5	91.1	64.8	0.5	88.9
	(2.3)	(2.0)	(4.3)	(1.2)	(0.5)	(0.9)	(0.8)	(1.4)	(3.3)

Standard deviations in parenthesis.

bined with 1.0% citric acid, or 0.2% cysteine, all of which have been reported to be effective for apple or avocado browning inhibition (Lozano-De-Gonzalez and others 1993; Santerre and others 1988; Dorantes-Alvarez and others 1996).

Effect of ripeness at slicing on browning and texture

The combination of 0.01% 4-HR, 0.5% ascorbic acid, and 1.0% calcium lactate was found to be the most effective treatment for fresh-cut pear browning inhibition. Therefore, it was applied as a dipping solution to test the effect of ripeness at slicing on color and texture change during 30 d storage. Bartlett pears sliced at 36 N were too soft for mechanical slicing with our equipment. Browning at this firmness was inhibited for 20 d (Table 3). However, the texture was unacceptably soft and mushy. The firmness of 49 N (range 45 to 67 N) was appropriate for slicing Bartlett. After 30 d, the color of the slices was almost as good as on the day of slicing, with acceptable texture (Table 3). This result is in agreement with the observation of Sapers and Miller (1998) that fruit firmness values of at least 5 Kg (49 N) were required for successful treatment of Bartlett pears.

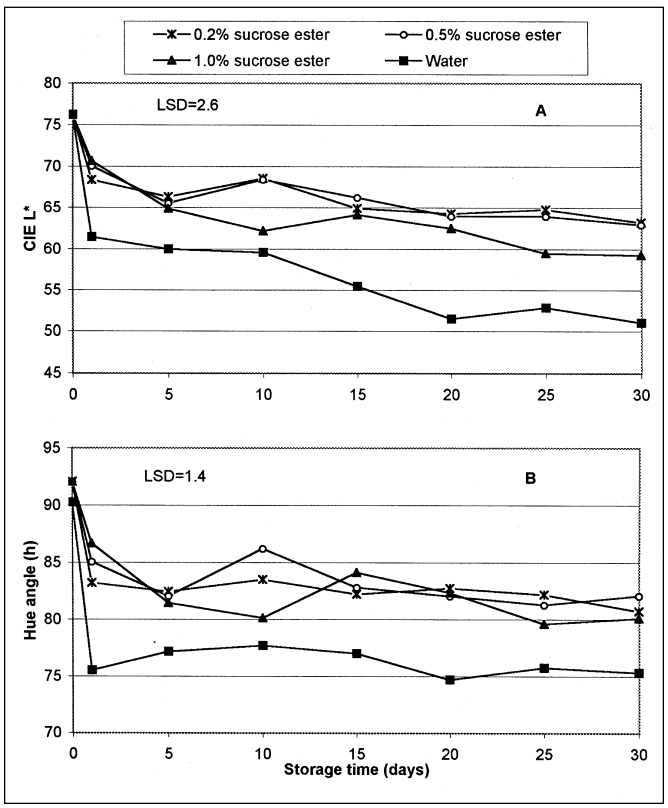

Fig. 3 Changes of CIE L* (A) and hue angle (B) values of sliced Anjou pears treated with solutions of 0.5% ascorbic acid and 1.0% calcim lactate combined with different concentrations of sucrose ester and stored at 2 to 5 °C for 30 d. Pooled LSD is shown.

Table 2—Extraction recovery of 4-HR from treated pear slices

Replicate	Conc. of 4-HR spiked	% of Recovery
1	4 ppm	89.6
	8 ppm	86.6
	16 ppm	84.1
2	4 ppm	93.4
	8 ppm	88.6
	16 ppm	88.3
3	4 ppm	96.5
	8 ppm	91.1
	16 ppm	91.1
Average		89.9

Bosc pears at 38 N (range of 27 to 45 N) sliced well and had acceptable color and texture after 30 d storage (Table 3). The texture of Bosc slices did not change over time as much as did Bartlett slices. Slicing at higher firmness (85 N for Bartlett, 60 N or 70 N for Bosc) resulted in lack of browning and high firmness retention. However, at 30 d the slices had too firm a texture for fresh eating, and lacked flavor.

4-HR residual content analysis

4-HR is approved for use as an inhibitor of shrimp melanosis (Iyengar and others 1991; King and others 1991; McEvily and others 1991). It is also approved for pharmaceutical use as a cough suppressant, where at a concentration of 2400 ppm it serves as the active ingredient in cough lozenges. It is presently not approved for use as a browning inhibitor in fresh-sliced fruits and vegetables. Measurement of 4-HR residual and determination of the sensory properties of treated samples are needed by processors and regulatory agencies for evaluation of its possible approval for wider food use as an anti-browning agent.

4-HR residual content in pear slices

4-HR concentrations of 0.005% and 0.01%, with dipping times of 1 and 2 min were evaluated for residual determination experiments since those levels were found to be effective for preventing browning. A major objective was to determine the minimum 4-HR residual that would also provide an acceptable shelf-life. We observed that all 4-HR treatments gave a visually acceptable appearance for up to 14 d at 2 to 5 °C storage. With respect to the analytical method, extraction recovery of 4-HR from spiked samples ranged from 84% to

Table 3-Effect of whole pear ripeness on sliced Bartlett and Bosc pear texture and color changes during the storage (2 to 5 °C)

Varieties	Level of ripeness	Storage time (days)	0	15	20	30
Bartlett	36 N	Slice firmness(N)	14.0 3.4	12.5(3.0)	7.1(3.2)	7.7(2.6)
	(22 to 44N)	CIE L*	75.1 1.1	75.2(0.8)	71.6(1.6)	67.4(1.7)
		CIE a*	0.3 0.4	-0.2(0.5)	1.7(0.4)	4.0(1.1)
		Hue angle (h)	89.5(0.8)	90.5(1.1)	85.0(1.7)	80.5(2.8)
	49 N	Slice firmness(N)	18.9(4.2)	10.6(4.0)	11.6(4.3)	11.9(3.5)
	(45 to 67N)	CIE L*	75.1(1.1)	75.1(1.0)	74.7(0.5)	73.5(0.8)
		CIE a*	0.3(0.4)	0.2(0.2)	0.6(0.2)	0.8(0.6)
		Hue angle (h)	89.5(0.8)	90.4(0.5)	88.8(0.3)	88.6(1.1)
	85N	Slice firmness(N)	33.1(3.7)	32.9(3.4)	33.4(2.6)	31.6(3.0)
	(over 67N)	CIE L*	75.1(1.1)	76.0(1.4)	76.5(1.2)	75.6(0.3)
		CIE a*	0.3(0.4)	-0.2(0.2)	0.1(0.2)	-0.3(0.6)
		Hue angle (h)	89.5(0.8)	89.8(1.2)	90.0(0.5)	90.7(0.4)
Bosc	38N	Slice firmness(N)	14.3(2.8)	12.5(2.4)	12.7(3.6)	12.9(2.0)
	(27 to 45N)	CIE L*	75.0(0.8)	70.5(1.3)	71.8(0.9)	69.1(1.2)
		CIE a*	0.7(0.3)	0.7(0.4)	0(0.3)	0(0.1)
		Hue angle (h)	88.4(0.7)	88.5(1.0)	90.1(0.6)	89.8(0.3)
	59 N	Slice firmness(N)	25.3(3.8)	21.1(2.9)	21.7(2.7)	21.9(2.4)
	(45 to 62N)	CIE L*	75.0(0.8)	73.5(0.7)	73.1(1.0)	72.5(1.0)
		CIE a*	0.7(0.3)	0.6(0.2)	0.1(0.5)	0.6(0.2)
		Hue angle (h)	88.4(0.7)	88.7(0.6)	88.9(0.5)	88.5(0.6)
	73 N	Slice firmness(N)	24.2(4.8)	19.4(3.2)	20.6(2.4)	19.4(3.2)
	(over 62N)	CIE L*	75.0(0.8)	74.4(1.5)	74.0(1.1)	73.8(0.5)
		CIE a*	0.7(0.3)	0.4(0.4)	0.2(0.2)	0.2(0.2)
		Hue angle (h)	88.4(0.7)	89.9(1.0)	89.6(0.6)	

89.5(0.5)* Standard deviations in parenthesis

96% (Table 2) with an average recovery of 90% from 3 replicates. Good separation and resolution of 4-HR was obtained with HPLC, and the UV spectrum confirmed its identity. The amount of 4-HR in slices treated with 0.005% for 2 min was 7 ppm at storage time 0 day and 16 ppm when the dipping concentration of 0.01% was applied. The residual of 4-HR also increased from 6 to 7 ppm, and 13 to 16 ppm, respectively, for both concentrations as the dipping time was increased from 1 to 2 min. Concentration, however, was the major determining factor for residual content. The residual 4-HR content decreased with storage time for all the treatments, e.g., from 16 to 7 ppm and from 7 to 4 ppm , respectively, for both concentrations with 2 min dipping after 14 d storage.

Sensory evaluation

Panelists detected flavor differences between 0.01% 4-HR treated samples and controls for both Bartlett and Anjou with the Difference-from-Control tests ($P < 0.01$). Further tests would be required to determine whether this difference was due to 4-HR itself or some other treatment factor.

Conclusions

4-HR WAS AN EFFECTIVE BROWNING INHIBITOR OF FRESH sliced pears in the presence of 0.5% ascorbic acid. Without AA, 4-HR alone did not inhibit browning of Bosc pear slices. The treatment of 1.0% AA in combination of 1.0% calcium lactate effectively maintained Anjou pear slices free from browning, but also induced texture softening and leakage under the partial vacuum packaging system. Initial whole pear firmness of 45 to 67 N for Bartlett, 27-45 N for Bosc and 36-45 N for Anjou were essential for mechanical slicing and successful color and texture maintenance. Bosc and Bartlett pear slices with appealing color and acceptable texture were obtained by 2 min dipping in the solution of 0.01% 4-HR, 0.5% ascorbic acid and 1.0% calcium lactate, partial vacuum packaging and 2 to 5 °C storage for 30 d. Anjou pear slices could be stored for 15 to 20 d under the same treatment conditions. Sucrose ester concentrations of 0.2, 0.5 and 1.0% combined with 0.5% ascorbic acid and 1.0% calcium lactate, 1.0% AA combining with 1.0% citric acid, 1.0% calcium lactate alone, 0.2% cysteine or canned pineapple juice, did not satisfactorily inhibit discoloration of pear slices.

4-HR residual content increased with concentration and dipping time, the former being the major factor. The residual content of 4-HR decreased with storage time for all the treatments. Sensory tests on 0.01% 4-HR treated pears indicated that panelists detected a flavor difference between treated samples and the controls for both Bartlett and Anjou.

Materials & Methods

Reagents and ingredients

Reagent grade 4-hexylresorcinol, L-cysteine, ascorbic acid and calcium lactate were purchased from Sigma Chemical Co. (St. Louis, Mo., U.S.A.) and used for browning inhibition and 4-HR residual analysis. Sucrose ester was obtained from Agricoat (A Mantrose-U.K. Co.). Food grade 4-HR was received from Cultor Food Science, Inc. (Ardsley, N.Y., U.S.A.), ascorbic acid, and calcium lactate from EM Science (A Division of EM Industries Inc., Darmstadt, Germany) for use in sensory studies.

Raw materials

Three pear varieties, Bartlett, Bosc, and Anjou were harvested at optimum maturity at the Southern Oregon Research and Extension Center, Medford, Ore., U.S.A., and stored at 0 °C until transported to Corvallis, Ore., for treatments. Pears were stored at 2 to 5 °C before processing in Corvallis. Prior to treatments, pears were brought to room temperature (20 to 25 C) for 2 to 3 d to partially ripen. Pear ripeness was determined by randomly taking 10 pears and measuring the firmness during the ripening. The firmness of whole pears was measured with a McCormick Fruit Tester (Model FT 327; McCormick Fruit

Technology, Yakima, Wa.) with an 8-mm diameter probe. The firmness between 45-67 N for Bartlett, 27-45 N for Bosc, and 36-45 N for Anjou was used for all treatments except when studying the effect of ripeness of whole pears at slicing on color and texture change.

Pear slice preparation

Partially ripened pears were rinsed with 0.02% sodium hypochlorite to reduce the surface microbial load before cutting. Pears were then cored, peeled, and sliced to obtain rings 5 mm thick. A manual corer-peeler-slicer (White Mountain Freezer Inc., Winchendon, Mass., U.S.A.) was used to prepare pear rings. Pear slices were obtained by cutting the fruit along the stem-calyx axis with 3 cuts evenly around the fruit rings with a stainless steel knife. Slices from 2 pears were placed in the inner bowl of a salad spinner and dipped in 3 L of a test solution for 2 min and drained in a perforated plastic container for 1 min. Slices were then placed into 3-mil thick nylon coated 15.5 cm × 21.5 cm plastic pouches (Kapak Corp., Minneapolis, Minn., U.S.A.), partially vacuumed, heat sealed, and stored at 2 to 5 °C. Color and texture were evaluated every 5 d during 30 d storage. All processing operations were conducted at 2 to 5 °C.

Pear slice firmness was determined by measuring the force required for a 3-mm probe to penetrate the surface of the slices. Two pear slices were laid on top of each other to prevent the probe touching the metal stand of the firmness tester and held perpendicular to the probe. Firmness was measured to a depth of 5 mm using a University of California firmness tester (Western Industrial Supply Co., San Francisco, Calif., U.S.A.). One measurement per slice was performed. The penetration strength of 20 slices was averaged and considered as the firmness of the treatment.

Color measurement

Color characteristics (CIE L*, a*, b*, chroma, and hue angle) were measured using a ColorQuest Hunter colorimeter (HunterLab, Hunter Associates Laboratories Inc., Reston, Va., U.S.A.). The equipment was set up for reflectance 45/0 with specular included, illuminant C, 10° observer angle. The plastic pouches containing pear slices were opened and the slices were evenly placed in an optical glass cell (13 cm dia 5 cm ht). Color values of CIE L* (lightness), CIE a* (red to green), CIE b* (yellow to blue), chroma (color intensity), and hue angle (color itself, 0° = red-purple, 90° = yellow, 180° = bluish-green, and 270° = blue) were measured. Nine readings were obtained for each treatment from 3 replicates with 3 readings for each replicate by changing the position of the pear slices in the optical glass cell to get uniform color measurements. Color and firmness values measured just after slicing without any treatments (considered as original flesh color and texture values) and within 24 hours of treatments were recorded as time 0 and 1, respectively. Measurements were taken every 5 d for 30 d.

Testing solutions for browning inhibition and texture maintenance

Calcium lactate treatments. Bartlett and Bosc pear slices were dipped in solutions containing different concentrations of calcium lactate at 0, 0.2, 0.5, and 1.0%.

Combination of calcium lactate with AA. Since the treatments of calcium lactate alone were not effective in inhibiting browning of cut Bartlett and Bosc pears, combinations of calcium lactate with different concentrations of AA at 0, 0.5% and 1.0% were tested on cut Anjou pears.

Sucrose ester treatments. Anjou and Bosc pear slices were treated with solutions containing 0.5% ascorbic acid and 1.0% calcium lactate combined with sucrose ester at 0.2, 0.5, and 1.0%.

AA and calcium lactate combined with 4-HR. Bartlett, Bosc and Anjou pear slices were dipped in solutions of 0.5% AA and 1.0% calcium lactate combined with 0.005, 0.01, 0.02, and 0.03% 4-HR. Solutions of 1.0% calcium lactate plus the four concentrations of 4-HR listed above without AA were also tested on Bosc pear slices.

Other browning inhibitor treatments. Anjou, Bartlett and Bosc pear slices were treated with the following solutions: 1) canned pineapple juice (Dole); 2) 1.0% ascorbic acid and 1.0% citric acid; 3) 0.2% L-cysteine. Distilled water was used as a control.

Effect of ripeness of whole pears at slicing on color and texture

Anjou pears were stored at 2 to 5 °C for 1 to 2 months prior to the treatments, during which time the texture softened to about 36 to 45 N. This level of ripeness was found to be appropriate for mechanical slicing and good color and texture retention during the storage from the preliminary experiment and used for all the treatments. Bartlett and Bosc pears were placed in room temperature (20 to 25 °C) for a varied length of time to obtain different ripeness stages. Bartlett and Bosc pears were sliced at three levels of firmness. Bartletts were sliced at an average of 85 N (no ripening), or ripened to an average firmness of 49 N (range of 45 to 67 N) and 37 N. Bosc pears were sliced at an average of 71 N (no ripening), or ripened to 60 and 38 N (range of 27 to 45 N). Slices were dipped in the solution containing 0.01% 4-HR, 0.5% AA and 1.0% calcium lactate.

4-HR residual content analysis

4-HR extraction recovery. Bartlett pears were partially ripened at room temperature until the whole pear firmness was 45 to 67 N. Fresh pear slices (9.5 to 10 g) without 4-HR treatments were cut into small dices, spiked with 4 mL of known concentrations (10, 20, and 40 ppm) of 4-HR solutions (in 50% aqueous methanol) and blended with 10 to 15 mL 100% methanol for 5 to 10 min. The contents were transferred to a 500 mL glass beaker. The blender was rinsed 3 to 4 times with 100% methanol until all the pear particles were washed out into the beaker. The sample was allow to stand for 30 to 60 min and then vacuum filtered through a Whatman No. 1 paper. The filter-cake residual was re-extracted twice with 100% methanol. The filtrates were combined and taken to dryness with a Buchi rotavapor at 35 °C. The residue was taken up in 4 mL of 60% aqueous methanol and transferred to a 10 mL volumetric flask. The Rotavapor flask was rinsed with 50% aqueous methanol and was added to the volumetric flask to bring the volume to 10 mL. This extract was filtered through a 0.45 mm HAVP millipore filter paper (Millipore Corp., Bedford, Mass., U.S.A.). The filtrate was subsequently analyzed by HPLC/UV. Four concentrations (1, 4, 8, and 20 ppm) of standard 4-HR solutions were used to make a standard calibration curve. The 4-HR content in samples was calculated from the regression formula of the standard curve. The extraction recovery was obtained from the amount of 4-HR extracted from spiked samples divided by the known added quantity. Each sample was duplicated. Percentage recovery for three replicated extractions averaged 90%.

4-HR extraction. Bartlett pears were sliced, trimmed,

mixed, and separated into 4 portions for the following browning inhibition treatments: (1) 0.005% 4-HR with 1 min dipping; (2) 0.005% 4-HR with 2 min dipping; (3) 0.01% 4-HR with 1 min dipping; (4) 0.01% 4-HR with 2 min dipping. Dipping solutions contained 0.5% AA and 1.0% calcium lactate. After each dipping treatment, the slices were drained in a perforated plastic container for 1 min. Slices with the same treatment were separated into 3 portions: 2 were placed into plastic pouches, partially vacuum packaged and stored at 2 to 4 °C for 7 and 14 d, respectively, for 4-HR residual analysis. The other portion was analyzed immediately (considered as storage time 0). The extraction procedures were the same as those used for 4-HR recovery experiment. 4-HR extraction and measurement for each sample were replicated.

4-HR separation with HPLC/UV

Apparatus. A Perkin-Elmer Series 400 liquid chromatograph equipped with a Hewlett-Packard 1040A photodiode array detector and a Hewlett-Packard 9000 computer system were used. Detection was set at 280 nm. The spectra (detection wavelength from 200 to 600 nm) were recorded for 4-HR standard and samples to ascertain the 4-HR peak identity.

Column and mobile phase. Supelcosil LC-18 column (Supelco Inc., Bellefonte, Pa., U.S.A.) (5 micron particle size), 250 mm × 4.6 mm i.d., 1.5cm × 4.6mm i.d. guard column. Solvent A: HPLC grade methanol, solvent B: deionized water. Flow rate: 1 mL/min. 4-HR was analyzed isocratically with 60% methanol; retention time of 4-HR = 12.6 min.

Quantification of 4-HR

4-HR standard solutions of 1, 4, 16, and 20 ppm were distributed and run as external standards with samples with 2 injections for each vial. A standard curve of concentration versus peak area was obtained. 4-HR concentrations in the samples were calculated from the regression formula of the standard calibration curve and normalized with 90% extraction recovery.

Sensory evaluation

Sample preparation. Bartlett and Anjou pears were used for the sensory evaluation. The pears were purchased from a local grocery store and partially ripened at room temperature (20 to 25 °C) to 45 to 67 N for Bartlett) and 36 to 45 N for Anjou before slicing. Bartlett and Anjou samples were prepared by dipping pear slices in the solution containing 0.01% 4-HR, 0.5% AA, and 1.0% calcium lactate for 2 min, draining for 1 min, partial vacuum packaging in plastic pouches and stored at 2 to 5 °C for sensory analysis the following morning. Control samples were prepared just before sensory tests by dipping pear slices in drinking water for 2 min and draining for 1 min.

Sensory tests. The Difference-from-Control tests were conducted in the sensory science laboratory in the Department of Food Science and Technology at Oregon State University. A disclosure and agreement sheet of some testing samples being treated with 4-HR was signed before the sensory test. Samples were prepared and tested immediately after being taken out of cold storage (2 to 5 °C). Each sample contained 4 to 6 pieces of pear slice. The panelists were instructed to taste the labeled control first and then compare the testing sample and the blind control sample to give a difference score from 0 (no difference) to 9 (extremely different). The 3 samples (one labeled control, one blind control and one testing sample) were served to each panelist simultaneously. All the samples were coded with random 3 digit numbers and served in a randomized order. Each panelist performed the sensory tests individually in the separated booths. Tests were conducted under red lights to mask possible color differences between samples and controls. The Difference-from-Control tests for both Bartlett and Anjou pears were conducted one immediately after the other and the order was randomized. A total of 70 panelists participated in the tests and 68 valid ballots were collected. The ballots were decoded for statistical analysis.

Statistical analysis

All the data was submitted to Analysis of Variance and Tukey multiple comparison with significant level at $P \leq 0.05$. The statistical analyses were done with SAS 6.12 for Windows software using the general linear models (GLM) procedure. The model of treatments, storage time and interaction of treatments and storage time (error) was used for color and texture data analysis. The model of treatments, panelist and interaction of treatments and panelist (error) was used for sensory data analysis.

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