

Application of Browning Inhibitors to Cut Apple and Potato by Vacuum and Pressure Infiltration

ABSTRACT

Vacuum and pressure infiltration were investigated as means of applying ascorbate- or erythorbate-based enzymatic browning inhibitors to apple and potato cut surfaces. Apple plugs infiltrated at 34 kPa pressure showed more uniform uptake of treatment solution and less extensive water-logging than plugs vacuum-infiltrated at 169–980 mB. Delicious and Winesap plugs and dice gained 3–7 days of storage life at 4°C when treated by pressure infiltration, compared to dipping. However, infiltrated dice required dewatering by centrifugation or partial dehydration to prevent water-logging. Pressure infiltration at 108 kPa extended the life of potato plugs by 2–4 days, compared to dipping, but was ineffective with potato dice.

INTRODUCTION

BECAUSE of recent restrictions in the use of sulfites as inhibitors of enzymatic browning in raw fruits and vegetables (Anon., 1986, 1987), a number of sulfite substitutes have been introduced (Andres, 1985; Duxbury, 1987, 1988; Langdon, 1987; Dziezak, 1988). A serious shortcoming of these products, which usually contain ascorbic acid (AA) or erythorbic acid (EA) or their sodium salts in combination with citric acid (CA) and other adjuncts, is their limited penetration into the fruit or vegetable piece, compared to that of sulfite (Taylor et al., 1986).

Vacuum deaeration and infiltration techniques, employing relatively high vacuum, have been used as freezing pretreatments to prevent enzymatic browning in apple slices by replacing tissue gases with aqueous solutions of AA, AA in sugar sirup, or sodium chloride (Grab and Haynes, 1948; Guadagni, 1949; Knight and Paul, 1949). However, Ponting and Jackson (1972) reported vacuum infiltration of solutions into apple slices resulted in a translucent or water-logged appearance that would not be acceptable in a fresh product.

Solutions containing calcium salts have been applied to unpeeled apples by vacuum or pressure infiltration to increase firmness (Hills et al., 1947; Archer, 1962; Drake and Spayd, 1983), prolong storage life (Poovaiah, 1986), reduce decay (Conway and Sams, 1983), prevent internal breakdown (Bangerth et al., 1972), and reduce bitter pit (Scott and Wills, 1979). Poovaiah and Moulton (1982) patented a mobile vacuum or pressure infiltration unit for such treatments. Arteca (1982) obtained elevated calcium levels in potato tubers infiltrated under vacuum with CaCl_2 solution. McGuire and Kelman (1984) reduced the severity of *Erwinia* soft rot in inoculated potatoes by vacuum infiltration of calcium. However, pressure and vacuum infiltration have not been reported as means of applying browning inhibitors to potato.

Previously, we investigated the control of enzymatic browning in apple with dips containing AA, stable AA derivatives or combinations of these compounds with complexing agents or polyphenol oxidase inhibitors (Sapers et al., 1989). Our objective in the study reported here was to determine whether

browning inhibitors could be applied to the cut surfaces of raw apple and white potato by pressure or vacuum infiltration to provide increased protection against enzymatic browning during refrigerated storage over that afforded by conventional dipping treatments with sulfite substitutes.

MATERIALS & METHODS

Raw materials

Sound, ripe Delicious (known colloquially as Red Delicious), Golden Delicious, and Winesap apples and Russet potatoes were obtained from local food stores during 1987–89 and stored for no more than 5 days at 2°C prior to treatment. Russet Burbank and Katahdin potatoes, used in pressure infiltration trials, were obtained from the Aroostook Experimental Farm, Presque Isle, ME) in the fall of 1987 and stored at 3°C and 80% RH until March, 1988. These cultivars were selected to provide samples that would be subject to severe enzymatic browning at cut surfaces during storage. Apple and potato samples were held at room temperature for ca 1 hr before peeling and further treatment.

Preparation of plugs and dice

Individual apples were cut in half along the stem axis, and plugs were bored from each half at preselected locations with an electric cork borer, using a 22 mm stainless steel cutting tube. Plugs were used instead of slices or wedges to permit application of browning inhibitor solutions to a well-defined surface, representing a specific location and orientation in the fruit, and to facilitate reproducible color measurements during storage. The plugs were cut transversely at their midpoints with a sharp knife, yielding two half-plugs, each about 15–20 mm in length, sharing a common cut surface. One half-plug (the control) was dipped in water for 10 sec to remove adhering juice, while the other half was immersed in the treatment solution and held for various times at atmospheric pressure or under vacuum or pressure. Each experiment was run with replicate plugs cut from a single apple to minimize response variability between fruits.

Apples used to prepare dice were peeled and cored with a Norpro Apple Parer, Slicer and Corer (Norpro, Mountlake Terrace, WA 98043) and immersed in 0.25% NaCl solution to prevent browning during dicing. Strips (0.95 cm × 0.95 cm) were cut with a Veg-O-Matic Food Preparer (Popeil Bros., Inc. Chicago, IL 60607), dipped for about 30 sec in 0.25% NaCl, and drained in a plastic colander. The strips were cut into 0.95-cm dice by hand, excluding core tissue and pieces with bruises or other defects. Potato plugs and dice were prepared as described above with the omission of a coring step.

Infiltration procedures

Vacuum infiltration treatments were applied to apples by placing half-plugs or 100-g portions of dice in beakers containing the treatment solution, underneath an inverted Büchner funnel so that the pieces (which float) would be completely submerged. The beakers were placed in a vacuum oven (VWR Model 1430, VWR Scientific) which was operated at room temperature. The oven was evacuated to 169–980 mB and held at the desired vacuum for 0.5 to 2 min until the vacuum was broken by admission of air.

Pressure treatments were applied by placing beakers containing the plug or dice samples, submerged in treatment solution, in a 19-L pressure canner (National Presto Industries, Inc., Eau Claire, WI 54701), operated at room temperature (the gasket was preheated in boiling water to permit sealing). The samples were pressurized under N_2 , introduced through the vent pipe in the canner cover, to a pressure of

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Table 1—Application of browning inhibitors to apple dice by vacuum infiltration vs dipping at atmospheric pressure

Cultivar	Formulation ^a	Treatment	Weight gain ^b (%)	Ascorbic acid (mg/kg)
Golden Delicious	A	Control	—	50 ^a
		Dip - 2 min	2.4	1360 ^f
		169 mB - 2 min	4.7	1510 ^e
		339 mB - 2 min	10.3	1920 ^d
		508 mB - 2 min	14.5	2170 ^c
Delicious	B	Control	—	10 ^a
		Dip - 2 min	1.5	2410 ^f
		169 mB - 2 min	4.2	2590 ^e
		339 mB - 2 min	8.8	3140 ^d
		508 mB - 2 min	14.2	4150 ^c

^a Formulation A: 1.12% Na ascorbate + 0.2% CaCl₂ (pH 7.7); Formulation B: 2.25% Na ascorbate + 0.2% CaCl₂ (pH 7.8).

^b After draining.

^{c-g} Means of triplicate determinations; means within columns for each cultivar, followed by different superscripts, are significantly different at $p < 0.05$ by the Bonferroni LSD test.

34–103 kPa for 1–5 min. The pressure was released quickly following treatment by depressing the automatic air vent in the cover.

Immediately following treatment (or dipping in H₂O for controls), plugs were drained in a plastic colander for about 30 sec and then blotted by rolling on four layers of absorbent tissue to remove excess liquid from the circumferential surface. In some experiments the plugs or dice were weighed before treatment and after dewatering to determine their uptake of browning inhibitor solution. Apple dice were further dewatered after draining in a colander by blotting as with plugs, by spinning in a salad spinner (Copco Div., Wilton Enterprises, Inc., Woodridge, IL 60517) for 1 min at ca 600 rpm (measured with a tachometer), or by spinning in a basket centrifuge (modified Acme Juicerator, Model 6001, Acme Juicer Mfg. Co., Lemoyne, PA) for 2 min at a maximum speed of ca 1700 rpm (reached after 1 min). Alternatively, the drained dice were partially dehydrated in a mechanical convection oven (Precision Scientific, Model 625), operated at 50–60°C, to a weight equal to 95% of the sample weight before infiltration. After dewatering, the plugs were stored in covered crystallizing dishes to prevent dehydration. Dice samples were stored in closed plastic bags (Baggies®, Mobil Chemical Co., Pittsford, NY 14534). Potato plugs and dice were infiltrated by the same procedure used for apple but did not require the use of an inverted funnel to be kept submerged because of their greater density.

Antibrowning agents, applied by the aforementioned infiltration procedures or by dipping at atmospheric pressure, comprised aqueous solutions of sodium erythorbate (Pfizer; food grade) calcium ascorbate (Sigma Chemical Co., St. Louis, MO 63178), sodium ascorbate (Sigma), or AA used individually or in combinations with CA and/or calcium chloride. (The latter three chemicals were reagent grade, obtained from J. T. Baker Chemical Co., Phillipsburg, NJ 08865.) The magnesium salt of ascorbic acid-2-phosphate (AAP), provided by Prof. Paul Seib, Kansas State University, was included in some potato treatments.

Treatment evaluation

Colorimetry was performed on the transversely cut surface of treated and control half-plugs with a Gardner XL-23 tristimulus colorimeter (Pacific Scientific Co., Silver Spring, MD 20910), as described previously (Sapers and Douglas, 1987). The color of apple and potato dice was evaluated with a spectrophotometer (The Color Machine, Pacific Scientific Co.). Approximately 50-g portions of dice were placed in a cylindrical optical glass beaker (57.1 mm i.d.) over a 32-mm aperture at the sample port. L- and a-values (for C illuminant) were determined using the averaging mode with four replications, initially and during storage for as long as 24 hr at 20°C or 3 wk at 4°C. Changes in appearance induced by infiltration treatments, i.e., darkening or water-logging, were evaluated by comparing initial differences between treated samples and corresponding controls in L-values ($\Delta L_{\text{treatment}} = L_{\text{treatment}} - L_{\text{control}}$) since a decrease in L-value would be indicative of such changes. The effectiveness of treatments in controlling browning was evaluated by determining the change in a-values during storage of treated samples and controls (increasing a-values indicating browning in apple and potato tissue) and then calculating the percent inhibition value from these measurements, as described previously (Sapers and Douglas, 1987). Visual observations

of sample appearance were made by two of the investigators at the same time as the instrumental measurements.

AA was determined in treated and control plug and dice samples by the 2,6-dichloroindophenol (DCIP) titrimetric method (AOAC, 1984). Plug samples weighing ca 20g or dice samples weighing ca 50g were blended with 150 mL HPO₃-HOAC solution for 2 min at high speed with a Waring Blendor, diluted to 250 mL with additional HPO₃-HOAC solution used to rinse the blender jar, and filtered through Whatman No. 541 paper under vacuum. To control foaming during blending, 0.2 mL Antifoam A Emulsion (Sigma) was added to the apple and 0.5 ml to the potato samples after blending for 1 min. Aliquots of the filtrates were titrated with DCIP to determine the AA content.

Statistical analyses

Infiltration trials were carried out with at least two replications, except as noted otherwise. Each experiment was subjected to analysis of variance to determine treatment effects on responses. The Bonferroni LSD test (Miller, 1981) was used to separate means. Correlations between responses and treatment levels or other sample parameters also were investigated. Only correlations significant at $p < 0.05$ were reported.

RESULTS & DISCUSSION

Vacuum infiltration

Preliminary attempts to apply 1% calcium ascorbate solutions to apple plugs by vacuum infiltration at 677–980 mB resulted in the development of a dark, water-logged appearance during infiltration, similar to that reported by Ponting and Jackson (1972). Such changes were distinct from enzymatic browning, occurring immediately rather than during storage, and producing no change in a-values or brown coloration. The uptake of browning inhibitor solutions by apple plugs resulted in weight gains of 10–30% and was highly variable within treatments, with coefficients of variation as high as 41%. Weight gains did not correlate with the degree of vacuum employed. The extent of darkening, measured by changes in the L-value, was inversely related to the weight gain ($r = 0.82$).

At lower vacuum levels (169–508 mB), weight gains in Golden Delicious and Delicious plugs, infiltrated with a solution containing 2.25% sodium ascorbate + 0.2% CaCl₂, were smaller than 8%, and darkening was less extensive. Both the weight gain and decrease in L-value, an indication of darkening, were correlated with the vacuum level (weight gain: $r = 0.99$ and 0.97 for Golden Delicious and Delicious, respectively; ΔL : $r = 0.98$ for both cultivars). Differences in browning between vacuum-infiltrated and dipped plugs, based on changes in the a-value during storage, were small. Similar results were obtained with vacuum-infiltrated apple dice (Table 1). Weight gains by infiltrated dice and corresponding AA contents increased with increasing vacuum level and tended to be larger than were obtained in apple plugs. However, measured AA contents were substantially greater than the calculated uptake of AA, based on the weight of absorbed treatment solution. Presumably, this discrepancy was due to solids lost during infiltration. Consequently, weight gain data may be useful in demonstrating the effects of changing treatment conditions, but such data should not be used to estimate browning inhibitor uptake. Excessive water-logging occurred in samples infiltrated at the higher vacuum levels. Therefore, subsequent trials were carried out only at 169 mB. AA uptake measurements indicated that, under these conditions, differences between dipped and vacuum infiltrated samples in AA content were too slight to impact storage stability. For this reason, no further work was done on the vacuum infiltration of apple plugs or dice.

Infiltration of Russet potato plugs with solutions of AA, AAP and CA at vacuums as high as 980 mB for 5 min resulted in no additional weight gain or improvement in storage life at 4°C over that obtained by dipping. Artega (1982) and McGuire and Kelman (1984) demonstrated Ca uptake by potato tubers,

vacuum-infiltrated with calcium salts at 912 mB for 30 min and at 880 mB for 1 hr, respectively. However, treatment times of this duration would not be compatible with a food processing operation.

Pressure infiltration of apple plugs and dice

The application of browning inhibitor solutions by pressure infiltration was investigated to determine if gains in storage life could be realized without objectionable sample darkening or water-logging. Weight gains in pressure-infiltrated apple plugs were correlated with the application pressure ($r = 0.92$) but not with infiltration time (2 vs 5 min). Decreases in L-values during infiltration, indicative of darkening, were smaller than those resulting from vacuum infiltration and were correlated with the weight gain ($r = 0.80$ and 0.86 for Delicious and Winesap, respectively) and infiltration pressure ($r = 0.82$ for both cultivars). Weight gains at 34 kPa were smaller than those obtained by vacuum infiltration and were relatively uniform from plug to plug; coefficients of variation for the weight gains in Delicious and Winesap plugs were 18 and 25%, respectively.

These results suggested that the infiltration of browning inhibitors into apple tissue at pressures of about 34 kPa should result in substantial uptake of browning inhibitor solution without greatly affecting the initial sample color. Pressures of 34–69 kPa have been used to infiltrate CaCl_2 into whole apple fruits (Conway and Sams, 1983; Drake and Spayd, 1983), but pressure has not been reported previously to infiltrate browning inhibitors into cut apple. The advantage of pressure over vacuum infiltration may be explained by comparing the response of apple tissue to the two treatments. Apple tissue contains about 25% occluded gas by volume in the intercellular void space (Wiley and Binkley, 1989). With vacuum infiltration, much of gas is removed (depending on the vacuum level) and then rapidly replaced by treatment solution when the vacuum is broken. With pressure infiltration, this gas is compressed, permitting the absorption of a much smaller amount of treatment solution and resulting in less water-logging.

Comparisons of plugs, treated with solutions containing 2.25 or 4.5% sodium erythorbate, applied by dipping at atmospheric pressure vs infiltration at 34 kPa for 5 min, indicated that the latter sample contained about 50–60% more EA than the former, irrespective of concentration or cultivar (Table 2). Pressure infiltration resulted in decreases in the L-value during treatment, more so with Winesap plugs than with Delicious. During storage, however, the L-values of pressure-infiltrated samples increased, in some cases approaching the initial L-values of control plugs. This apparent reversal of infiltration-induced darkening may be due to the redistribution of absorbed treatment solution by diffusion during storage. Percent inhibition values, indicative of the effectiveness of the treatments in preventing browning during storage, showed little difference between the pressure-infiltrated and dipped samples initially. The dipped samples showed significantly more browning than the pressure-infiltrated samples during the second week of storage with 4.5% sodium erythorbate (equivalent to 4% AA) and after day 3 or 4 with the less concentrated formulation. Similar results were obtained with plugs treated with 4.4% and 2.2% solutions of calcium ascorbate (data not shown).

Additional pressure infiltration trials were conducted with apple dice. Preliminary observations with samples that had been drained after infiltration and then packaged in plastic bags indicated the dice gradually became more water-logged and decreased in L-value (in the absence of browning) during storage. Based on the assumption that this defect resulted from inadequate dewatering during draining, additional dewatering procedures were compared (Table 3). Blotting infiltrated dice on absorbent tissue or "spin-drying" in a salad spinner were partially effective in controlling water-logging. High-speed spinning in a basket centrifuge completely eliminated water-

logging but resulted in significant weight loss, due to tissue damage and the loss of cellular fluids and solids as well as excess treatment solution during spinning. This resulted in a substantial reduction in AA content in the centrifuged dice, compared to the drained samples, and a tendency for the centrifuged dice to brown during extended storage (data not shown). Changes in L-value in the dewatered samples were too variable to be useful in monitoring the extent of water-logging. As an alternative to centrifugal dewatering, infiltrated samples were briefly air-dried at 50–60°C to remove the excess moisture with minimal losses of browning inhibitors. Samples infiltrated at 34 kPa and then "air-dewatered" at 60°C for different times were compared. A weight reduction to 95% of the original weight before infiltration was usually sufficient to prevent serious water-logging without causing shriveling, tissue breakdown or browning due to excessive dehydration.

Weight gains and AA uptake in Golden Delicious dice, treated to determine the effects of infiltration and air-dewatering conditions, were not greatly influenced by immersion time during dipping or pressure infiltration (Table 4, Expt. 1). They were significantly greater with pressure treatment, the dice containing about 30% more AA than the dipped samples. This difference is not as great as that obtained with plugs (60%), suggesting pressure infiltration may be advantageous with larger pieces. This is a consequence of the larger surface-to-volume ratio of dice which would facilitate rapid diffusion of AA into the piece, with or without the application of pressure. During air-dewatering, the AA content of infiltrated samples increased in proportion to the decrease in sample weight. No significant loss of AA occurred during dewatering. The AA content of samples agreed with calculated values (based on the AA content after draining and the weight change during dewatering) within 3%, even when net weight losses were as high as 9%. Increasing the infiltration pressure from 34 to 69 kPa (Expt. 2) resulted in increased weight gains and AA uptake by dice samples. Increasing the ascorbate concentration of the treatment solution resulted in a proportionate increase in AA of the infiltrated dice.

Storage life data for the infiltrated Golden Delicious dice, based on the appearance of browning, accompanied by an increase in the a-value (or a decrease in the percent inhibition value) are given in Table 5. Samples infiltrated with 1.12% sodium ascorbate + 0.2% CaCl_2 at 34 kPa did not brown and showed only minor water-logging for 15 days at 4°C. Samples that were dipped in this solution became brown between day 8 and day 10. Dice infiltrated at the higher pressure were not brown after 20 days but developed an unacceptable level of water-logging during storage. When the concentration of sodium ascorbate in the treatment solution was reduced by 50%, both the pressure-infiltrated and dipped samples became brown within a few days. Ponting et al. (1972) reported the storage life of refrigerated Golden Delicious slices, treated by dipping in solutions of 1% AA and 0.1% Ca at pH 7 for 3 min, was substantially longer than we obtained. The discrepancy between these studies may be due to differences in AA uptake (not reported in the earlier study) and/or the tendency of the apples to undergo browning. Delicious dice failed within a few days when infiltrated with 1.12% sodium ascorbate + 0.2% CaCl_2 . When the ascorbate concentration was doubled, the dice infiltrated at 34 kPa remained free of browning for about 1 wk after browning appeared in the dipped sample. Infiltration at 69 kPa provided no greater protection against browning than treatment at the lower pressure and resulted in severe water-logging.

Our results with plugs and dice indicate that the storage life of cut apple can be extended with browning inhibitors applied by pressure infiltration. There is probably a trade-off between concentration of browning inhibitor used and choice of method of application; e.g., pressure infiltration would permit the use of smaller concentrations of ascorbate to control browning than needed with dipping at atmospheric pressure. Proper evalua-

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Table 2—Effects of browning inhibitors, applied to apple plugs by pressure infiltration at 34 kPa vs dipping at atmospheric pressure for 5 min

Cultivar	Formulation ^a	Treatment	Erythorbic acid (mg/kg)	ΔL^b		Percent inhibition (a-value)		
				Infiltration	Storage	3/4 ^c	Days	
							7	14
Delicious	C	Dip	2470 ^e	-0.7 ^{de}	0.6 ^e	93 ^d	84 ^d	66 ^e
		34 kPa	3590 ^d	-4.0 ^e	2.3 ^d	92 ^d	86 ^d	82 ^d
	D	Dip	1250 ^f	0.9 ^d	-0.4 ^e	66 ^e	54 ^f	--
		34 kPa	1910 ^f	-3.3 ^e	1.8 ^{de}	80 ^d	70 ^e	--
Winesap	C	Dip	2850 ^e	-2.3 ^{de}	2.0 ^e	92 ^d	74 ^d	63 ^d
		34 kPa	4170 ^d	-7.6 ^f	5.6 ^d	84 ^{de}	79 ^d	77 ^d
	D	Dip	1340 ^g	-2.0 ^d	-0.7 ^e	53 ^f	34 ^f	--
		34 kPa	2220 ^f	-5.0 ^{ef}	1.2 ^e	72 ^e	52 ^e	--

^a C = 4.5% Na erythorbate + 0.2% CaCl₂ (pH = 7.8); D = 2.25% Na erythorbate + 0.2% CaCl₂ (pH = 7.8).

^b $\Delta L_{infiltration} = L_{treatment} - L_{control}$ at zero time; $\Delta L_{storage} = L_{treatment}$ at day 7 - $L_{treatment}$ at zero time.

^c 3 days for formulation C; 4 days for D.

^{d-g} Means of 4 replicates; means within columns for each cultivar, followed by different superscripts, are significantly different at p < 0.05 by the Bonferroni LSD test.

Table 3—Effect of dewatering on weight gain, ascorbic acid content, L-value and appearance of pressure-infiltrated Golden Delicious apple dice

Treatment ^a	Net weight change ^b (%)	Ascorbic acid (mg/kg)	L-value			Appearance ^c		
			0	Day		0	Day	
				1	8		1	8
Drained	10.3	3070 ^d	52.4 ^d	51.7 ^d	48.8 ^d	SI WL	Mod WL	WL
Blotted	3.3	2270 ^f	52.0 ^d	53.2 ^d	52.6 ^d	SI WL	SI WL	SI WL
Spun	7.8	2610 ^e	52.4 ^d	51.3 ^d	53.5 ^d	SI WL	SI WL	Mod WL
Centrifuged	-7.2	1590 ^g	55.9 ^d	56.4 ^d	55.1 ^d	Not WL	Not WL	Not WL

^a Infiltrated at 34 kPa with 2.25% Na ascorbate + 0.2% CaCl₂ (pH 7.8) for 2 min.

^b Based on weight of dice before infiltration.

^c SI = slight; Mod = moderate; WL = water-logged.

^{d-g} Means of 4 replicates; means within columns, followed by different superscripts, are significantly different at p < 0.05 by the Bonferroni LSD test.

Table 4—Effects of pressure infiltration conditions and air-dewatering on the weight and ascorbic acid content of Golden Delicious dice

Expt. ^a	Treatment	Weight change (%)		Ascorbic acid after dewatering (mg/kg)
		After draining	Net after dewatering ^b	
1	Dip - 1 min	3.5 ^e	-9.4 ^e	2380 ^{gh}
	Dip - 2 min	3.5 ^e	-9.5 ^e	2690 ^{efg}
	Dip - 5 min	4.0 ^e	-8.6 ^{de}	3190 ^{def}
	34 kPa - 1 min	7.5 ^d	-5.0 ^{cd}	3340 ^{cde}
	34 kPa - 2 min	8.6 ^d	-3.9 ^c	3690 ^{cd}
2	34 kPa - 5 min	10.0 ^d	-3.2 ^c	4080 ^c
	Dip - 1 min	3.5 ^e	-4.8 ^{cd}	1110 ^j
	34 kPa - 1 min	9.9 ^d	-4.7 ^{cd}	1730 ^{hi}
	69 kPa - 1 min	14.2 ^c	-5.4 ^{cde}	2160 ^{gh}

^a Samples in Expt. 1 trials treated with 2.25% Na ascorbate + 0.2% CaCl₂ (pH = 7.8); samples in Expt. 2 trials treated with 1.12% Na ascorbate + 0.2% CaCl₂ (pH = 7.7).

^b Based on sample weight before infiltration.

^{c-j} Means of duplicate (Expt. II) or triplicate (Expt. I) trials; means within columns, followed by different superscripts, are significantly different at p < 0.05 by the Bonferroni LSD test.

tion of economic feasibility of pressure infiltration, would require balancing this against equipment and handling costs, solids lost, and AA consumption with infiltration. If feasible, pressure infiltration would afford apple processors a means of improving performance of conventional sulfite substitutes as an interim step until more effective browning inhibitors are available.

Pressure infiltration of potato plugs and dice

In preliminary studies, Russet potato plugs, infiltrated with a solution containing 4% AA + 1% CA at 103 kPa for 5 min, showed weight gains between 1.0 and 2.2% (coefficient of variation = 46%); samples infiltrated at lower pressures did not increase in weight. The infiltrated plugs did not appear water-logged, as would apple tissue infiltrated at this pressure.

The storage life of Russet Burbank and Katahdin plugs was evaluated following pressure infiltration or dipping at atmospheric pressure with two promising browning inhibitor formulations (Table 6). The AA content of treated plugs was increased significantly by pressure infiltration, compared to dipping at atmospheric pressure. Some darkening occurred during pressure infiltration, as indicated by the decrease in L-value. Percent inhibition values, based on the increase in a-value (an indication of browning), indicate the pressure infiltration treatments extended the storage life of the samples by about 2 days with Russet Burbank and 4 days with Katahdin. The two formulations were similarly effective.

Attempts to improve the storage life of potato dice by pressure infiltration were not successful. Samples of Russet Burbank and Katahdin dice, infiltrated with 4% AA + 1% CA + 0.2% CaCl₂ at 103 kPa for 1 or 2 min, showed similar AA content and storage life (based on the increase in a-value and appearance of browning) as samples treated by dipping.

The contrasting response of potato plugs and dice to pressure

Table 5—Effect of pressure infiltration on storage life of Golden Delicious dice

Trial	Treatment ^a	Percent inhibition ^b			Water-logging ^c		
		8	10	15	8	Day	
						15	20
1	Dip - 1 min	93 ^d	70 ^d	54 ^e	N	N	SI
	34 kPa - 1 min	99 ^d	88 ^d	83 ^d	N	SI	SI
	69 kPa - 1 min	98 ^d	89 ^d	92 ^d	VSI	SI/Mod	Mod
2	Dip - 1 min	78 ^d	64 ^e	41 ^e	N	N	N
	34 kPa - 1 min	86 ^d	90 ^d	79 ^d	VSI	SI	VSI
	69 kPa - 1 min	74 ^d	73 ^{de}	78 ^d	SI	SI/Mod	SI/Mod

^a Infiltrated with 1.12% Na ascorbate + 0.2% CaCl₂ (pH 7.7).

^b Based on change in a-value.

^c N = none; SI = slight VSI = Very slight; Mod = moderate.

^{d-f} Means of four replications; means within columns, followed by different superscripts, are significantly different at p < 0.05 by the Bonferroni LSD test.

Table 6—Effect of browning inhibitors applied to potato plugs by pressure infiltration vs dipping at atmospheric pressure

Cultivar	Formulation	Treatment	Ascorbic acid (mg/kg)	ΔL treatment ^b	Percent inhibition (a-value)		
					2	day 4	6
Russet Burbank	E	Dip-5 min	1280 ^a	-1.7 ^c	78 ^{cd}	42 ^d	29 ^d
		103 kPa-5 min	1890 ^c	-2.8 ^c	86 ^c	60 ^{cd}	44 ^{cd}
Katahdin	F	Dip-5 min	1320 ^e	-2.3 ^c	72 ^d	44 ^d	35 ^d
		103 kPa-5 min	1710 ^d	-4.7 ^d	85 ^c	68 ^c	55 ^c
	E	Dip-5 min	1010 ^d	-1.3 ^c	81 ^d	55 ^d	51 ^c
		103 kPa-5 min	1330 ^c	-3.9 ^d	94 ^c	80 ^c	71 ^c
F	Dip-5 min	1120 ^d	-2.2 ^c	71 ^e	52 ^d	49 ^c	
	103 kPa-5 min	1350 ^c	-4.4 ^d	92 ^c	83 ^c	75 ^c	

^a E = 4% ascorbic acid + 1% citric acid + 0.2% CaCl₂ (pH = 2.1); F = 4% ascorbic acid + 1% citric acid + 0.8% ascorbic acid 2-phosphate (pH = 3.0).
^b ΔL treatment = L treatment - L control at zero time.

^c Means of 6 replicates; means within columns for each cultivar, followed by different superscripts, are significantly different at $p < 0.005$ by the Bonferroni LSD test.

infiltration may be due to the lower surface-to-volume ratio of the plugs which would limit the quantity of treatment solution that adhered to surfaces after dipping. While there is no advantage in applying browning inhibitors to 3/8-in. dice by pressure infiltration, this technique may be advantageous with larger pieces or even prepeeled tubers. Improvements in the storage life of pressure-infiltrated potatoes might be realized by vacuum-packaging the treated product, as practiced by Langdon (1987) and O'Beirne and Ballantyne (1987).

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