

Enzymatic Browning in Atlantic Potatoes and Related Cultivars

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ABSTRACT

The extent of enzymatic browning at cut surfaces of Atlantic potato, its siblings and parents, and Russet Burbank was investigated. Browning, measured by tristimulus colorimetry, was compared with cultivar variation in polyphenol oxidase (PPO), PPO substrates, and ascorbic acid. Atlantic potato was much less subject to browning at cut and peeled surfaces than Russet Burbank. Browning in Atlantic potato could be almost eliminated by dipping in water. Belchip and Chipbelle (siblings) and Wauseon and Lenape (parents) were similar to Atlantic potato in browning behavior. The tendency to brown in these cultivars and Russet Burbank was correlated with total phenolic compounds, tyrosine, and to a lesser extent, PPO activity.

INTRODUCTION

BECAUSE of possible restrictions in the use of sulfites to inhibit enzymatic browning in fresh potatoes (Anon, 1987), new approaches are needed to control this discoloration. Various formulations of ascorbic or erythorbic acids and citric acid have been developed as sulfite substitutes for potato products (Langdon, 1987; Duxbury, 1987; Andres, 1985), but these treatments generally are less effective than sulfites in controlling enzymatic browning. We have investigated the use of novel ascorbic acid derivatives as browning inhibitors (Sapers and Douglas, 1987; Sapers et al., 1989). However, another approach was suggested by preliminary observations in our laboratory that tubers of Atlantic potato undergo little or no browning when peeled or sliced. This cultivar was released in 1976 and was described as being resistant to pests, high in solids, and suitable for processing and fresh market (Webb et al., 1978; Leach, 1978; Gould et al., 1979). Belchip, a sibling of Atlantic released in 1978, also exhibits these characteristics (Webb et al., 1980; Santerre et al., 1986). Browning in potato has been correlated with PPO activity and the concentrations of PPO substrates (Matheis and Belitz, 1978; Brudzynski and Zawidzka-Okoniewska, 1979; Stark et al., 1985; Matheis, 1987). Mondy et al. (1985) reported that Atlantic tubers contained lesser amounts of phenolic compounds and browned less following grinding and exposure to air than Russet Burbank, Katahdin or Superior tubers. The browning characteristics of the Atlantic potato under conditions more closely simulating storage after prepeeling or slicing have not been reported. If this potato or related cultivars could be shown to resist browning under such conditions, their use by processors might obviate or minimize the need for sulfite substitutes. Therefore, our objectives in this study were to characterize the tendency of Atlantic potatoes and some related cultivars to undergo less browning than most cultivars at cut surfaces, and to explain this behavior in terms of cultivar variation in the compositional factors involved.

MATERIALS & METHODS

SAMPLES of Atlantic potatoes were obtained from commercial growers in Florida (May, 1986; May, 1987) and North Carolina (June, 1986). Additional samples of Atlantic, Belchip (sibling), Chipbelle (sibling), Lenape (parent), Wauseon (parent), and Russet Burbank tubers, all grown at the same location, were obtained from Aroostook Experimental Farm, Presque Isle, Maine, in September 1986 and September, 1987. Russet Burbank tubers, that were compared with Atlantic in experiments performed during the summer of 1986, were grown at Aroostook Experimental Farm in 1985 and stored at 3.3°C (38°F), 100% RH.

Browning rate measurements were made by the procedure of Sapers and Douglas (1987). Briefly, a potato was cut in half along the longitudinal axis, and duplicate 22 mm diameter plugs were bored from the upper potato half, on either side of the longitudinal axis near its midpoint, with an electric cork borer, using a stainless steel cutting tube. A transverse cut was made in the plugs, about half way between the center of the potato and the skin, yielding a pair of plug halves sharing a common cut surface. In some experiments, one half-plug from each pair was dipped in water for 10 sec and then blotted dry by rolling on absorbent tissue. Immediately after cutting or dipping and drying, half-plugs were placed with the transverse cut face down over the sample port (19 mm aperture) of a Gardner XL-23 Tristimulus Colorimeter, standardized against a white tile. L- and a- values were measured at various times over 24 hr; samples were stored in covered crystallizing dishes at ca 20°C between measurements. The tristimulus coordinates were plotted against the logarithm of time, and the lag time (initial flat region of curve before onset of browning) and browning rate (slope of linear region of browning curve) were obtained. The extent of browning in potato samples was indicated by the change in L or a after 6 or 24 hr.

In determining the response of Atlantic and Russet Burbank potatoes to different methods of peeling, the tubers were either peeled by hand with a sharp knife, steam peeled for 15.5 sec at 1400 kPa in a high pressure steam peeler (Type DSA 45, Paul Kunz & Co., Döttesfeld, West Germany) and washed with a high pressure water spray in a rod/reel washer, or abrasion peeled with a Toledo Vegetable Peeler, (Model A1-15, Rochester Div., Toledo Scale Co., Toledo, OH). Immediately following peeling, a pair of half-plugs was prepared from the tubers by the procedure described above and dipped in H₂O for 10 sec. Reflectance measurements were made on the peeled surface of one half-plug and on the transversely cut surface of the other half-plug (control) during storage.

Composition studies carried out in September 1987 with samples of Atlantic, Atlantic relatives and Russet Burbank were performed using 6 plugs cut from each of 6 tubers per cultivar so that the relationship between browning and composition could be studied both between cultivars and within cultivars. Duplicate plugs for tristimulus colorimetry were cut from either side of the long axis of the tuber at its midpoint. Reflectance measurements were made at a transversely cut surface that had not been dipped in H₂O. The bottom halves of these plugs, weighing about 10g, were assayed for PPO activity by the procedure of Hsu et al. (1984) which employs L-β-3,4-dihydroxyphenylalanine (L-DOPA) as the substrate. Total polyphenols were extracted from two additional plugs, cut from opposite ends of each tuber and weighing about 20g, by blending with 100 mL 80% methanol for 2 min at high speed in a stainless steel semi-micro blending container, making the homogenate volume up to 200 mL with additional 80% methanol, adding 2g Celite Analytical Filter Aid (Fisher Scientific, Pittsburgh), and filtering through Whatman No. 541 paper under suction. Polyphenols were determined colorimetrically with Folin-Ciocalteu reagent by the method of Chien and Snyder (1983). Chlorogenic acid in the potato extract was determined with a Waters HPLC system employing a 4.6 mm (i.d.) by 25 cm C-18 column (5 μm), gradient elution with an acetonitrile-5% acetic acid mixture, and dual

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wavelength detection at 254 and 280 nm. Free tyrosine in the potato extract was determined with a Beckman 119CL amino acid analyzer, using the standard 90 min protein hydrolysate program. Ascorbic acid (AA) was extracted from the last 2 plugs, taken from opposite ends of each tuber and weighing about 20g. The plugs were blended with 50 mL metaphosphoric acid-acetic acid solution (AOAC, 1984) for 2 min at high speed in a stainless steel semi-micro blending container, and the resulting extract was filtered through Whatman No. 541 paper under suction and then made up to 100 mL with additional extractant. Aliquots (2 mL) of extract were titrated with 2,6-dichloroindophenol reagent, as described in AOAC 43.064.

Data were analyzed for differences in these composition factors and the extent of browning within and between cultivars by ANOVA using a randomized complete block design. The Bonferroni LSD test (Miller, 1981) was used to separate means. In addition, simple and multiple correlations between browning behavior and composition were examined for values of R^2 significantly different from zero at $P < 0.05$ by the F-test. All statistical analyses were performed with the SAS/STAT software (SAS Institute, Inc., Cary, NC).

RESULTS & DISCUSSION

Enzymatic browning at cut surface of Atlantic potato

Quantitative measurements of the rate and extent of enzymatic browning in Atlantic potato were carried out to confirm qualitative observations that this cultivar does not brown after slicing. Samples of Atlantic tubers representing different growing locations and seasons were compared with Russet Burbank tubers, which are known to brown after slicing, by the reflectance procedure used previously with apples and pears (Sapers and Douglas, 1987). Preliminary studies (unpublished data) indicated that the L-value, but not the a-value, was negatively correlated with the extent of browning at the cut surface of potato. The data in Table 1, which are based on measurements of the L-value at the transversely cut surface of potato plugs, show that browning in Atlantic potato was preceded by a significantly longer lag time, occurred more slowly (significantly smaller slope), and was less extensive (smaller ΔL) than browning in Russet Burbank potato. This behavior was observed in Atlantic samples obtained from growing locations as different as Florida and Maine, over two seasons, 1986 and 1987.

We have observed previously (unpublished data) that a brief water dip treatment, such as might be used to remove free juices and starch from cut surfaces, will decrease the extent of browning in apple and potato plugs. In the present study (Table 2), browning in Russet Burbank plugs was greatly reduced by a 10 sec dip in water but not eliminated. Because of the minimal extent of browning in the Atlantic potatoes, differences between the dipped and undipped samples were not significant. These samples exhibited virtually no browning over 6 hr and only a marginal change in L over 24 hr.

Enzymatic browning at peeled surface of Atlantic potato

Quantitative measurements of browning at the peeled surface of Atlantic and Russet Burbank plugs (Table 3) revealed a large difference in the response of these cultivars to peeling. With Atlantic potato, peel removal by three different procedures—peeling with a sharp knife, steam peeling and abrasion peeling—induced relatively little browning, based on browning rates (slopes) and ΔL values. Differences in lag times were of little consequence at the low browning rates obtained. Controls, which were dipped in water for 10 sec, showed no evidence of browning over 6 hr. In contrast, steam and abrasion peeling induced extensive browning with Russet Burbank potatoes. Peeling with a knife induced substantially less browning (although still severe), similar to that seen with Russet Burbank controls. Lag times were shorter for peeled samples than for controls. These results confirm our previous observations that peeled Atlantic potatoes were slow to brown.

Peeling might be expected to induce browning because of the extensive disruption of cell layers at the peeled surface by shearing, compression and heat (with steam peeling) which would result in leakage of PPO and PPO substrates from the damaged tissue as well as oxidation of endogenous AA, both favoring the browning reaction. Steam peeling also might induce "after-cooking darkening," the nonenzymatic formation of a colored complex between ortho-diphenols such as chlorogenic acid and ferric ion (Talbert and Smith, 1987). Additional enzymatic browning might be induced by the disruptive effects of the high pressure water spray used after steam peeling. Our data for Russet Burbank indicate that the steam-peeled tubers were darker than the abrasion-peeled tubers. Abrasion peeling should produce more disruption, and consequently more browning, than peeling with a sharp knife.

Cultivar variation in browning and composition

The large difference between Atlantic and Russet Burbank potatoes in enzymatic browning at cut or peeled surfaces probably reflects composition differences which may be genetic. To shed more light on this possibility, we compared the browning behavior and composition of Atlantic, Belchip (Atlantic sibling), Chipbelle (Atlantic sibling), Lenape (Atlantic parent), Wauseon (Atlantic parent) and Russet Burbank tubers (Table 4). Atlantic and its siblings showed similar lag times before the onset of browning which were significantly greater than lag times obtained with Lenape, Wauseon, and Russet Burbank. Differences among the Atlantic relatives in browning rate (slope) and extent (ΔL) were small, and with the possible exception of Lenape, not significant. Atlantic, its siblings, and

Table 1—Enzymatic browning in Atlantic and Russet Burbank potatoes

Cultivar	Sample	Source ^a	Harvest season	No. tubers	Lag time ^b (min)	Slope ^b (min ⁻¹)	ΔL	
							6 hr	24 hr
Atlantic	A	FL	Spring 86	4	315 ^c	-0.7 ^c	0.4 ^c	—
	B	NC	Summer 86	4	225 ^c	-0.8 ^c	-0.4 ^c	-0.3 ^c
	C	ME	Fall 86	1	150 ^c	-1.0 ^c	-0.2 ^c	-1.2 ^{cd}
	D	FL	Spring 87	6	330 ^c	-0.5 ^c	0 ^c	-2.2 ^{cd}
	E	ME	Fall 87	6	127 ^c	-2.9 ^c	-2.1 ^c	-3.7 ^d
Russet Burbank	F	ME	Fall 85	4	10 ^d	-12.5 ^c	-10.4 ^c	—
	G	ME	Fall 85	4	12 ^d	-7.4 ^c	-10.7 ^c	-10.0 ^c
	H	ME	Fall 86	1	15 ^d	-10.2 ^c	-12.9 ^c	-12.9 ^c
	I	ME	Fall 87	6	41 ^c	-10.6 ^c	-12.6 ^c	-14.2 ^c
Atlantic	E	ME	Fall 87	6	127 ^c	-2.9 ^c	-2.1 ^c	-3.7 ^d
Russet Burbank	I	ME	Fall 87	6	41 ^d	-10.6 ^d	-12.6 ^d	-14.2 ^d
Atlantic	Mean	All	1986	9	257 ^c	-0.8 ^c	-0.4 ^c	-0.5 ^c
	Mean	All	1987	12	228 ^c	-1.7 ^c	-1.0 ^c	-2.9 ^d
Atlantic	Mean	FL	All	10	324 ^c	-0.6 ^c	-0.1 ^c	-2.1 ^d
		NC	All	4	225 ^{cd}	-0.7 ^c	-0.4 ^c	-0.3 ^c
		ME	All	7	130 ^d	-2.6 ^d	-1.8 ^d	-3.3 ^d

^a FL = Florida; NC = North Carolina; ME = Maine.

^b Based on measurement of L-value.

^{c-d} For each comparison, means within columns followed by different superscripts are significantly different at $P < 0.05$.

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Table 2—Effect of dipping on enzymatic browning in Atlantic and Russet Burbank potatoes

Cultivar	Samples ^a	Treatment	No. tubers	Lag time ^b (min)	Slope ^b (min ⁻¹)	ΔL	
						6 hr	24 hr
Atlantic	A&B	Undipped	8	270 ^c	-0.8 ^c	-0.4 ^d	-0.3 ^c
		Dipped	8	360 ^c	0 ^c	0.2 ^c	-0.7 ^c
Russet Burbank	F&G	Undipped	8	11 ^d	-9.9 ^d	-10.6 ^d	-10.0 ^d
		Dipped	8	33 ^c	-1.6 ^d	-1.6 ^d	-2.7 ^c

^a See Table 1.

^b Based on measurement of L-value.

^{c-d} For each cultivar, means within columns followed by different superscripts are significantly different at $P < 0.05$.

Table 3—Effect of peeling on browning in Atlantic and Russet Burbank potatoes

Cultivar	Peeling method	No. tubers	Lag time ^a (min)	Slope ^a (min ⁻¹)	ΔL at
					6 hr
Atlantic	Knife	1	180 ^c	-2.9 ^b	-1.2 ^b
	Steam	1	15 ^a	-1.1 ^b	-1.2 ^b
	Abrasion	1	90 ^d	-1.8 ^b	-1.5 ^b
	Control ^f	3	>360 ^b	0 ^b	0.4 ^b
Russet Burbank	Knife	2	<10 ^a	-6.1 ^b	-9.7 ^c
	Steam	2	29 ^a	-31.2 ^d	-36.2 ^a
	Abrasion	2	30 ^a	-18.3 ^c	-18.7 ^d
	Control ^f	6	65 ^d	-6.4 ^b	-5.4 ^{bc}

^a Based on measurement of L-value.

^{b-c} Means within columns followed by different superscripts are significantly different at $P < 0.05$.

^f Control is transversely cut surface of plug having peeled surface.

Table 4—Extent of browning and composition of six potato cultivars — 1987 season

Cultivar	No. tubers	Extent of browning			PPO activity (units/kg)	Total phenolics (mg/kg)	Chlorogenic acid (mg/kg)	Tyrosine (mg/kg)	Ascorbic acid (mg/kg)	
		Lag time ^a (min)	Slope ^a (min ⁻¹)	ΔL						
				6 hr						24 hr
Atlantic	6	127 ^b	-2.9 ^b	-2.1 ^b	-3.7 ^{bc}	97 ^c	286 ^d	14.4 ^c	21.2 ^c	197 ^{bc}
Belchip	6	150 ^b	-3.0 ^b	-1.5 ^b	-3.2 ^b	115 ^c	308 ^{cd}	8.9 ^c	19.9 ^c	184 ^c
Chipbelle	6	148 ^b	-3.3 ^b	-2.2 ^b	-4.9 ^{bc}	243 ^{bc}	396 ^{cd}	22.8 ^c	21.3 ^c	194 ^{bc}
Lenape	6	48 ^c	-4.5 ^b	-5.4 ^b	-7.6 ^c	215 ^{bc}	533 ^c	64.6 ^b	31.3 ^c	184 ^c
Wauseon	6	55 ^c	-3.2 ^b	-3.3 ^b	-5.5 ^{bc}	131 ^c	409 ^{cd}	7.7 ^c	36.4 ^c	235 ^b
Russet Burbank	6	41 ^c	-10.5 ^c	-12.6 ^c	-14.2 ^d	372 ^b	881 ^b	23.3 ^c	148.2 ^b	200 ^{bc}

^a Based on measurement of L-value.

^{b-d} Means within columns followed by different superscripts are significantly different at $P < 0.05$.

its parents all browned more slowly and to a lesser extent than did Russet Burbank. These results are consistent with Mondy's observations of browning in ground Atlantic tissue (Mondy et al., 1985).

Russet Burbank contained significantly more PPO than did Atlantic, Belchip or Wauseon and more total phenolics and tyrosine than Atlantic or its siblings and parents. Mondy et al. (1985) also reported that Russet Burbank contained more phenolic compounds than did Atlantic, Belchip or Chipbelle. Levels of chlorogenic acid were higher in Lenape than in the other cultivars in this study. All cultivars were similar in ascorbic acid content.

Correlation of browning parameters and composition factors

Comparison of browning and composition data for the six cultivars suggests a possible association between the rate or extent of browning and tyrosine content, the content of total phenolic compounds and PPO activity. The significance of relationships between parameters of enzymatic browning and composition factors was tested by correlation analysis. For the entire sample of 6 cultivars, significant simple correlations were obtained between the four parameters of browning and tyrosine, total phenolic compounds, and to a lesser extent, PPO (Table 5). In most cases, correlations could be improved substantially by comparing browning parameters with more than one composition factor, i.e., tyrosine and total phenolic compounds or tyrosine and chlorogenic acid (which gave no simple correlation with browning). The possible role of endogenous AA in extending lag times or limiting the extent of browning, functions reported in the literature (Vamos-Vigyazo, 1981),

was obscured in this study by the narrow range of AA contents obtained for the 6 cultivars. Correlations between browning parameters and composition factors for individual cultivars generally were not significant because of the limited sample size and narrow range of analytical values obtained. However, some significant correlations were obtained with Atlantic and Wauseon potatoes which brown much less extensively than Russet Burbank. In Atlantic and Wauseon samples, correlations between browning and PPO activity or combinations of PPO with other factors were higher than in the larger sample of six cultivars. Aside from this difference, correlations between browning parameters and composition factors in Wauseon were similar to those obtained with the six-cultivar sample.

These correlations are consistent with reports in the literature that enzymatic browning in potato is highly correlated with the contents of tyrosine and total phenolic compounds (Stark et al., 1985; Mondy et al., 1979). Brudzynski and Zawidzka-Okoniewska (1979) obtained a correlation between browning and PPO activity in addition to the aforementioned factors; browning was correlated with chlorogenic acid content in only one of 3 cultivars compared. Matheis and Belitz (1978) concluded that enzymatic browning in potatoes was correlated with tyrosine turnover, a parameter which depends on the concentrations of PPO, tyrosine, chlorogenic acid and ascorbic acid, rather than on any single factor.

CONCLUSIONS

ATLANTIC POTATO and its siblings are much less subject to enzymatic browning at cut surfaces than Russet Burbank potato. Atlantic also browns less at peeled surfaces than Russet Burbank.

