

## **Prevention of Enzymatic Browning in Prepeeled Potatoes and Minimally Processed Mushrooms**

Gerald M. Sapers, Robert L. Miller, and Sang-Won Choi

**Eastern Regional Research Center, Agricultural Research Service, U.S.  
Department of Agriculture, 600 E. Mermaid Lane,  
Philadelphia, PA 19118**

Some minimally processed products do not respond well to treatment with browning inhibitors. Peeled potato surfaces are highly reactive because of thermal and mechanical damage during peeling. Digestion with 17% NaOH or 1-2% ascorbic and citric acids at elevated temperatures, followed by treatment with browning inhibitors, can extend potato storage life to 12-14 days. Treatment conditions must be designed to avoid textural defects and nonenzymatic discoloration. Washed mushrooms discolor due to reactions induced by bacterial growth as well as to typical enzymatic browning. Treatment with hydrogen peroxide prior to application of browning inhibitors will suppress bacterial spoilage and improve appearance. Clarified raw apple juice will not brown due to removal of particulate-bound polyphenol oxidase but may become yellow during storage because of nonenzymatic browning of added ascorbic acid. Effective treatment conditions for these products and guidelines for controlling enzymatic browning in other minimally processed commodities are discussed.

One of the major problems that limits the development of minimally processed fruits and vegetables is the occurrence of enzymatic browning at cut and peeled surfaces (1, 2). With many commodities, this problem is especially difficult because of the need to control browning without use of sulfite, which has been banned by the Food and Drug Administration for most fresh applications (3). Our laboratory at the USDA's Eastern Regional Research Center in Philadelphia has conducted research on preservation of minimally processed fruits and vegetables for a number of years. Much of our work has focused on development of methods to control enzymatic browning in apples (4, 5), potatoes (6, 7), mushrooms (8), and fresh juices (9). A wide variety of browning inhibitors, including various polyphenol oxidase inhibitors, reducing agents, acidulants, complexing agents, and proteolytic enzymes have been described at this symposium. In our experience, some products such as sliced apples

respond well to treatment with relatively simple browning inhibitor formulations, i.e., sodium erythorbate in combination with calcium chloride (5). On the other hand, browning of pre-peeled potatoes (6), washed mushrooms (8), and some raw juices (9) cannot be controlled by such treatments because of their unique physical and chemical characteristics, the contribution of other factors such as bacterial growth and non-enzymatic browning to the discoloration process, and the occurrence of treatment-induced defects.

Our experience with these products demonstrates the need to take a broad perspective in dealing with discoloration reactions in minimally processed fruits and vegetables. In this paper, some of the problems we encountered in controlling browning of potatoes, mushrooms, and fresh juices; the product characteristics that interfered with treatment; and approaches that were found to be effective in preventing discoloration will be described. Based on these case studies, some guidelines for treatment development that may be applicable to other commodities will be presented.

### **Pre-peeled Potatoes**

**Industry Needs.** In many locations throughout the United States, packers provide peeled raw potatoes to restaurants, other food service establishments, producers of french fries and potato chips, and other food processors (10). Without browning inhibitor treatment, pre-peeled raw potatoes would discolor within minutes, turning pink, brown, gray, or black. Use of sulfites to control discoloration, which was considered to be highly effective, was banned by the FDA in 1990 (11). This ban is not now in effect, however, because of successful legal challenges (12). The pre-peeled potato industry would like to be able to control browning for 14 days. Efforts to control browning of peeled surfaces with sulfite substitutes, usually formulations of ascorbic or erythorbic acid with such adjuncts as citric acid, sodium acid pyrophosphate and cysteine, have not yet met this requirement. Published shelf-life data for commercial sulfite substitutes indicate that a shelf-life no greater than 1 week can be expected unless the product is vacuum packed or stored submerged in a preservative solution (13-15). We obtained similar results with a "conventional" formulation containing 4% ascorbic acid, 1% citric acid, and 1% sodium acid pyrophosphate (7). We had no greater success with experimental dips containing ascorbic acid in combination with acidic polyphosphates or cyclodextrins (Sapers, G. M., Eastern Regional Research Center, Philadelphia, unpublished data). Combinations of ascorbic acid-2-monophosphate and ascorbic acid-2-polyphosphates showed some promise (6), but these compounds are expensive and would require FDA approval. Our goal was to control browning in pre-peeled potatoes for two weeks, using only FDA-approved browning inhibitors. To achieve this goal, we would have to overcome the tendency of pre-peeled potatoes to undergo rapid and severe browning.

**Basis for Instability of Pre-Peeled Potatoes.** Data obtained in 1989 with Russet Burbank potatoes demonstrated that the method of peeling had a large effect on the

extent of browning at the peeled surface (16). In this experiment, browning during storage was quantified by measuring the decrease in L-value at the peeled surface with a tristimulus colorimeter. The decrease in L-value was greater with steam or abrasion peeled potatoes than with potatoes peeled with a sharp knife (Table I). We attributed this result to extensive mechanical damage in cell layers at the surface of abrasion peeled potatoes, and to thermal injury that causes membrane leakage in cells at the surface of steam peeled potatoes.

**Table I. Effect of Peeling on Browning in Russet Burbank Potatoes During Storage at 4 °C**

Peeling Method	$\Delta L$ at 6 hr <sup>a</sup>
Knife	-9.7 <sup>c</sup>
Steam	-36.2 <sup>e</sup>
Abrasion	-18.7 <sup>d</sup>
Control <sup>f</sup>	-5.4 <sup>bc</sup>

Source: Adapted from ref. 16

<sup>a</sup>  $\Delta L = L_{6h} - L_{initial}$  at peeled or control surface.

<sup>b-e</sup> Means within columns, followed by different superscripts, are significantly different at  $P < 0.05$  by the Bonfessoni LSD test.

<sup>f</sup> Control is transversely cut surface of same potato plug for which peeled surface is measured.

These results and work done with lye peeled potatoes in the 1950's by Harrington and co-workers at the USDA's Western Regional Research Center (17) suggested that removal of unstable tissue at the peeled surface might make pre-peeled potatoes more responsive to treatment with browning inhibitors.

**Digestion Treatments for Pre-peeled Potatoes.** One of our approaches was to use the low temperature, lye digestion treatment developed by Harrington to remove surface tissues from abrasion, steam or lye peeled potatoes, and then, to treat the new surface with our ascorbic acid-based browning inhibitor dip (7). The effectiveness of this two-stage treatment was established by determining the extent of browning with a tristimulus colorimeter and then calculating a parameter we call the percent inhibition from the measured L- and a-values (18). Percent inhibition values approaching 100% would indicate that a treatment was highly effective in controlling browning, while values of 50-60% or lower would indicate treatment failure. Percent inhibition data obtained with high pressure steam peeled potatoes (Table II) demonstrated the effectiveness of the experimental lye digestion treatment, used in conjunction with a browning inhibitor dip. Both Russet and round-white

types of potatoes, given this treatment, were still acceptable after 13-15 days at 4 °C, while controls, given only the browning inhibitor dip, failed within 3-6 days. Addition of nonionic or anionic detergents to the digestion solutions did not significantly improve treatment effectiveness. Similar results were obtained with abrasion peeled potatoes (7).

**Table II. Effect of Digestion with NaOH and Tween 80 on Browning in High Pressure Steam-Peeled Potatoes During Storage at 4 °C**

Potato	Treatment <sup>a,b</sup>	Percent Inhibition			
		3	6	10	13
Russet	None	2 <sup>d</sup>	2 <sup>d</sup>	-9 <sup>d</sup>	-29 <sup>d</sup>
	NaOH	90 <sup>c</sup>	82 <sup>c</sup>	69 <sup>c</sup>	51 <sup>c</sup>
	NaOH + Tween 80	93 <sup>c</sup>	90 <sup>c</sup>	79 <sup>c</sup>	67 <sup>c</sup>
Round-white	None	86 <sup>c</sup>	20 <sup>d</sup>	6 <sup>d</sup>	6 <sup>d</sup>
	NaOH	92 <sup>c</sup>	89 <sup>c</sup>	80 <sup>c</sup>	73 <sup>c</sup>
	NaOH + Tween 80	94 <sup>c</sup>	92 <sup>c</sup>	86 <sup>c</sup>	81 <sup>c</sup>

Source: Adapted from ref. 7

<sup>a</sup> 4 min at 49 °C in 17% NaOH.

<sup>b</sup> Digested samples and undigested controls dipped 5 min in browning inhibitor solution containing 4% ascorbic acid, 1% citric acid, 1% sodium acid pyrophosphate, and 0.2% calcium chloride.

<sup>c-d</sup> Means within columns for each potato type, followed by different superscripts, are significantly different at P<0.05 by the Bonferroni LSD test.

The digestion treatment did result in a weight loss of 15-25% because of removal of digested tissue and also created a potential waste disposal problem, namely, disposal of spent lye and digested potato tissue. For these reasons, we investigated alternative digestion treatments that also might remove or, in some way, neutralize unstable tissue at the peeled surface but be less costly and more environmentally benign.

**Digestion with Hot Ascorbic Acid/Citric Acid Solutions.** Preliminary attempts at enzymatic digestion suggested another approach (Sapers, G. M.; Miller, R. L., Eastern Regional Research Center, Philadelphia, unpublished data). The enzyme treatments themselves were ineffective, but immersion of peeled potatoes in water heated to 55 °C for 15 minutes, followed by application of a browning inhibitor dip, showed some promise. Better results were obtained when ascorbic and

citric acids were added to the hot water (Table III). Apparently, "digestion" with the two acids at an elevated temperature resulted in partial inactivation of polyphenol oxidase as well as leaching of the enzyme and its substrates at the peeled surface. Thus, the peeled surface was less reactive, and browning could be controlled by ascorbic acid and other browning inhibitors, applied in the final dip. Abrasion peeled Russet and round-white potatoes, given both the hot ascorbic/citric acid digestion treatment and conventional ascorbic acid-based browning inhibitor dip, showed significantly less browning than potatoes given only the browning inhibitor dip (Figure 1). A shelf-life of about two weeks was obtained with both Russet and round-white potatoes, given the combination treatment (19).

**Table III. Effect of Digestion and Browning Inhibitor Treatments on Browning of Abrasion Peeled Russet Potatoes at 4 °C.**

Digestion <sup>a</sup>	Browning Inhibitor Dip <sup>b</sup>	$\Delta L^c$			Appearance <sup>g</sup>		
		Days			Days		
		5	9	12	5	9	12
None	No	-22.1 <sup>f</sup>	-23.0 <sup>f</sup>	-23.6 <sup>f</sup>	+++	+++	+++
None	Yes	-2.2 <sup>e</sup>	-6.8 <sup>e</sup>	-8.3 <sup>e</sup>	++	+/+++	++
1% AA+	Yes	3.0 <sup>d</sup>	2.4 <sup>d</sup>	1.2 <sup>d</sup>	-	-	-/+++
1% CA							
1% AA+	Yes	2.4 <sup>d</sup>	1.6 <sup>d</sup>	0.0 <sup>d</sup>	-	-	-
2% CA							
1% AA+ 2% CA+ 1% SAPP	Yes	0.9 <sup>d</sup>	0.8 <sup>d</sup>	-1.2 <sup>d</sup>	-	-	+

Source: Adapted from ref. 19

<sup>a</sup> 15 min at 55 °C. AA=ascorbic acid; CA = citric acid; SAPP = sodium acid pyrophosphate.

<sup>b</sup> 5 min dip in 4% AA + 1% CA + 1% SAPP + 0.2% CaCl<sub>2</sub>.

<sup>c</sup>  $\Delta L = L_{\text{storage}} - L_{\text{initial}}$  at peeled surface.

<sup>d-f</sup> Means within columns, followed by different superscripts are significantly different at P<0.05 by the Bonferroni LSD test.

<sup>g</sup> Severity of discoloration: +, slight; ++, moderate; +++, severe; +++, very severe; -, none.

Use of the ascorbic acid/citric acid digestion treatment greatly improved the shelf-life of pre-peeled potatoes but introduced new problems that had to be addressed. One such problem was the occurrence of gray spots during storage of some digested potatoes. Graying appeared to be more prevalent when raw material showed softening, was bruised, or was subjected to overheating during digestion. Less graying was seen when potatoes were stored for several weeks at 20 °C, prior to peeling and treatment, rather than at 4 °C (19).

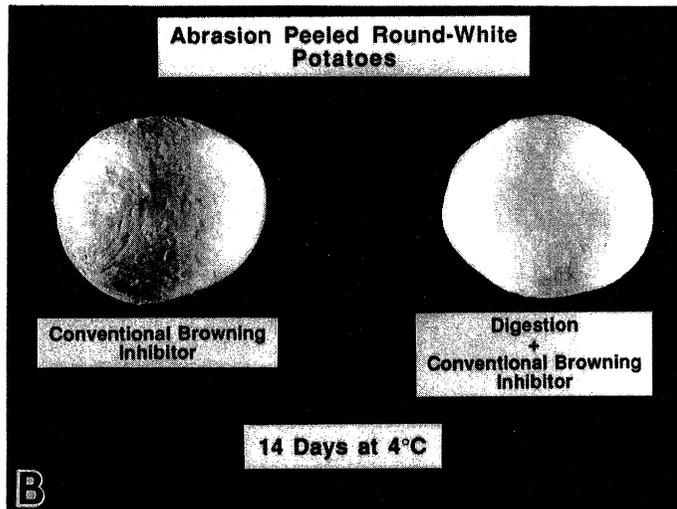
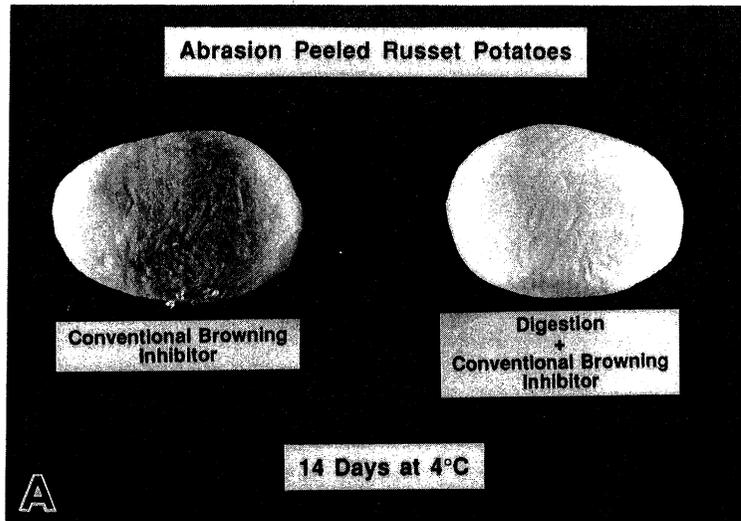
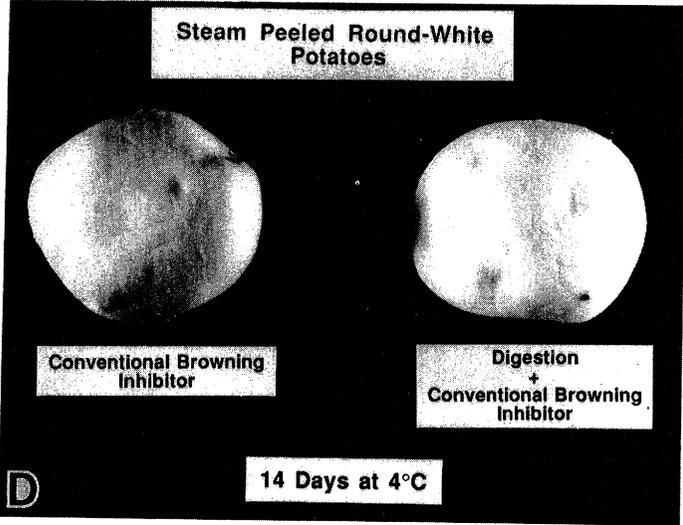
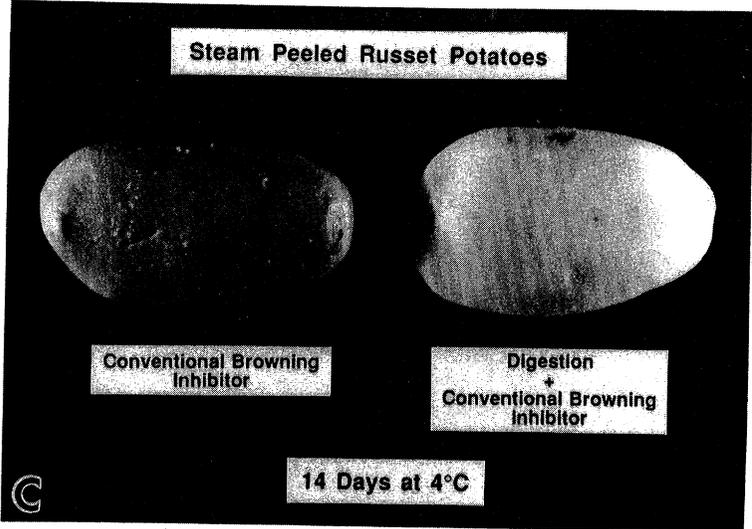


Figure 1. Pre-peeled potatoes digested in 1% ascorbic acid + 2% citric acid for 20 min at 45 °C and/or dipped 5 min in conventional browning inhibitor solution containing 4% ascorbic acid + 1% citric acid + 1% sodium acid pyrophosphate; samples stored at 4 °C for 14 days. A, abrasion peeled Russet; B, abrasion peeled round-white; C, high pressure steam peeled Russet; D, high pressure steam peeled round-white.



A second defect associated with the digestion treatment was surface toughening, which became evident after cooking and sometimes produced a separated layer or interfered with mashing (Figure 2). Surface toughening may have resulted from activation of pectin methylesterase followed by cross-linking of liberated carboxyl groups by endogenous calcium ion (20). This defect was more severe when calcium chloride was added to the browning inhibitor dip and less severe when the digestion temperature and time were decreased and EDTA was added to the digestion solution. These modifications had little effect on product shelf-life (19).

A third defect, sometimes seen in steam peeled potatoes that had been digested in hot ascorbic/citric acid solution, was the development of browning at the peeled surface during or after cooking (Figure 3). This discoloration occurred only in samples that were near the end of their shelf-life, i.e., after storage at 4 °C for two weeks, but still showed little or no browning in the raw state. In experiments carried out to establish the cause of this defect, we found that browning was suppressed by cooling the cooked potatoes in a vacuum or by cooking potatoes in water containing sulfite. Browning could not be induced by application of 2% dehydroascorbic acid to the surface of fresh peeled potatoes prior to cooking. We had speculated that this compound might be involved since it accumulates when added ascorbic acid undergoes oxidation during storage (21) and will undergo nonenzymatic browning (22). Therefore, browning induced by cooking appears to be caused by accumulation of enzymatic browning intermediates during storage and prior to inactivation of polyphenol oxidase by heat. These intermediates probably undergo oxidation and condensation reactions during cooking and cooling to form melanin pigments. Abrasion peeled potatoes were not subject to this defect. This difference may be due to the greater content of polyphenol oxidase and its substrates at the steam peeled surface since these constituents are present in greater concentrations near the potato skin (23).

We believe that the hot ascorbic/citric acid digestion treatment represents a viable alternative to use of sulfites to control browning of pre-peeled potatoes. Further studies to scale up the treatment and establish its economic feasibility are planned. Our experience with potatoes clearly shows the complexity of the browning inhibition problem and the need to take a broad view in developing effective control measures.

### **Minimally Processed Mushrooms**

**Defects Induced by Washing.** Our experience with minimally processed mushrooms illustrates the need to consider microbiological implications of browning inhibitor treatments as well as the occurrence of discolorations induced by treatment. Fresh mushrooms are subject to severe enzymatic browning during handling and storage but do not respond well to treatment with browning inhibitor dips since washing and application of dips greatly increase product perishability (8, 24). This is due largely to absorption of water during treatment which creates an internal environment favorable to bacterial growth. If mushrooms could be washed, treated with browning inhibitors, and sliced without excessive spoilage, their value would

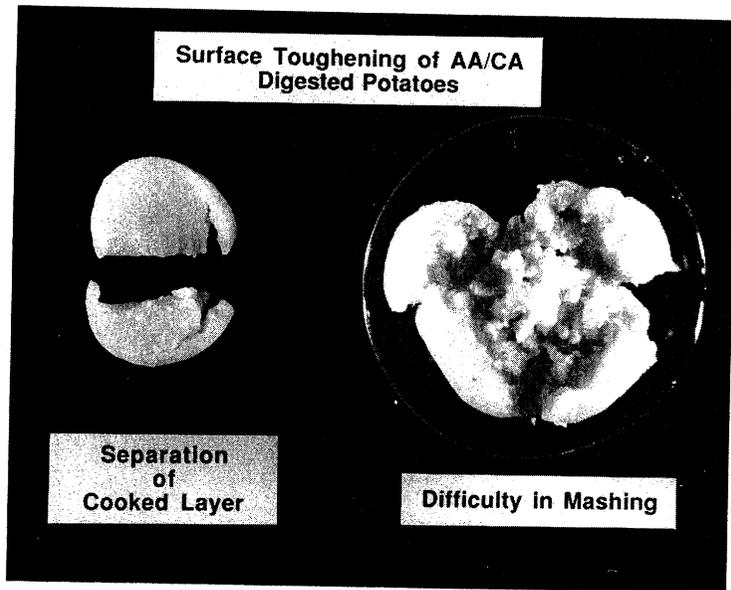


Figure 2. Surface toughening effects in cooked potatoes treated by ascorbic acid/citric acid digestion.

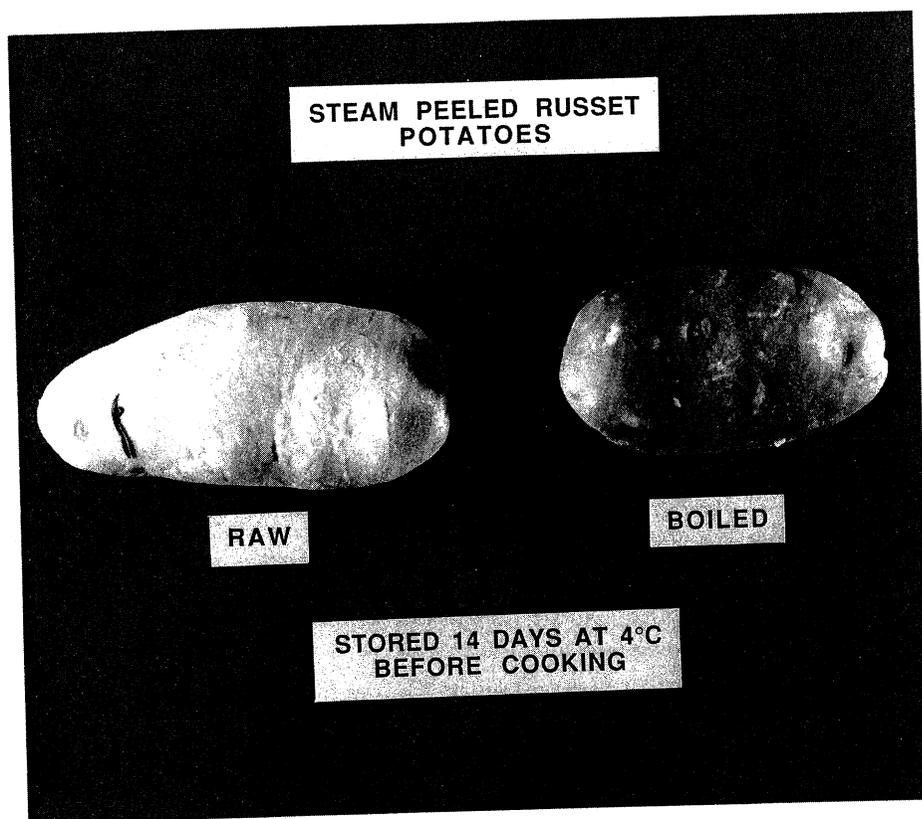


Figure 3. Browning induced by boiling steam peeled Russet potatoes, treated by ascorbic acid/citric acid digestion and stored for 14 days at 4 °C.

be enhanced because they could be used directly in salad bars, sauces, toppings for pizza or burgers, and other food service or consumer product applications.

Several years ago, we became involved with a company that attempted to produce a washed mushroom product and observed purple or gray-colored blotches on mushroom surfaces after 4-6 days of storage. Subsequently, these blotches evolved into sunken brown lesions similar to those produced by the mushroom pathogen, *Pseudomonas tolaasii*. Examination of the lesions by scanning electron microscopy revealed indications of mechanical damage to mushroom hyphae, probably caused by washing, and the presence of large numbers of bacteria (Figure 4). Blotch development could be suppressed by addition of antibiotics such as streptomycin.

The purple discoloration appeared to be related to enzymatic browning since it could be induced by application of a drop of L-DOPA solution to the surface of a washed mushroom. L-DOPA is a well known polyphenol oxidase substrate, found in mushrooms, which turns red and then black when applied to the surface of an unwashed mushroom.

Studies carried out in model systems (25) indicated that a stable purple compound could be produced by reaction of indole-5,6-quinone, a short-lived intermediate in the enzymatic browning of L-DOPA, with a quinone derived from sinapic acid, another phenolic compound found in mushrooms (Figure 5). These reactions might be triggered by injury to mushroom hyphae during washing and/or by metabolic activity of bacteria growing on the damaged surface.

**Control of Bacterial Spoilage in Washed Mushrooms.** In order to wash or apply browning inhibitor dips to fresh mushrooms without promoting purpling or spoilage, one must suppress the growth of spoilage bacteria. One approach was to reduce water uptake by modifying treatment conditions, for example, by shortening dipping times. A second approach was to reduce the bacterial load on mushroom surfaces. Chlorine, applied as sodium hypochlorite solution, is widely used as a bactericide. However, we found that browning was induced at bactericidal concentrations of chlorine (8). This appears to be due to direct nonenzymatic oxidation of polyphenol oxidase substrates to form enzymatic browning intermediates (26).

Hydrogen peroxide vapor has been used experimentally to control spoilage of table grapes (27). We found that treatment of fresh mushrooms by exposure to hydrogen peroxide vapor or by dipping in a dilute hydrogen peroxide solution could suppress spoilage, even in mushrooms inoculated with *Pseudomonas tolaasii* at levels as high as 3 million bacterial cells per mushroom cap (8, 28). Because mushrooms have a high level of endogenous catalase activity, residual hydrogen peroxide in treated samples was rapidly broken down to oxygen and water. Hydrogen peroxide vapor treatment did induce browning of mushrooms under some treatment conditions. This may have been the result of a peroxidase-catalyzed reaction. However, browning could be controlled by application of a browning inhibitor dip, immediately following the hydrogen peroxide treatment.



**Control of Enzymatic Browning in Mushrooms.** In the course of our research on minimally processed mushrooms, we tested a number of browning inhibitors and combinations of browning inhibitors with antimicrobial compounds (Table IV). Many of these inhibitors were ineffective with mushrooms or had adverse effects on quality (8). Treatment of mushrooms with 4-hexylresorcinol, a compound that is reputed to be highly effective with shrimp and apples (29), actually induced discoloration. Acidic browning inhibitor dips tended to cause cut edges of mushroom slices to turn yellow. One of our most effective browning inhibitor formulations was the combination of 4.5% sodium erythorbate, 0.1% cysteine-HCl, and 1000 ppm EDTA (disodium salt), adjusted to pH 5.5 with 10% NaOH. Sodium erythorbate has been used commercially as a browning inhibitor for mushrooms. The other ingredients are classified by the Food and Drug Administration as GRAS (Generally Recognized as Safe) for certain food applications (30). The effectiveness of this formulation in controlling browning of mushroom external and cut surfaces was determined by measuring the change in L-value at the treated surface with a spectrophotometer. The decrease in L-value during storage, indicative of browning, was much greater for untreated controls than for treated mushrooms (Figure 6).

**Table IV. Browning Inhibitors and Antimicrobials Evaluated for Preservation of Minimally Processed Mushrooms**

Browning Inhibitors	Antimicrobials
Ascorbic acid and Na ascorbate	Streptomycin sulfate
Erythorbic acid and Na erythorbate	Hydrogen peroxide
Ascorbic acid-2-phosphate	Sodium hypochlorite
Ascorbic acid-2-triphosphate	Sodium benzoate
Citric acid	Potassium sorbate
Cysteine · HCl	
N-Acetyl cysteine	
4-Hexylresorcinol	
EDTA (disodium salt)	
Sodium acid pyrophosphate	
Sodium hexametaphosphate	
Sporix	
Hydroxypropyl β-cyclodextrin	
Zinc chloride	
Source: Adapted from ref. 8	

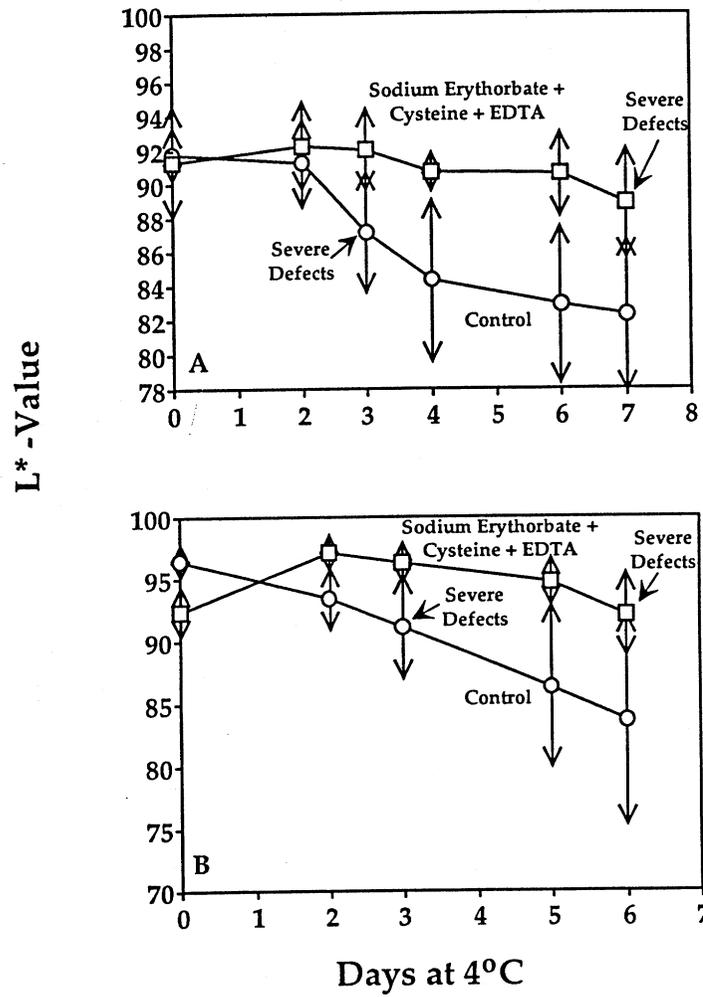


Figure 6. Effectiveness of browning inhibitor treatment in controlling enzymatic browning of mushrooms. A, External surface of mushroom cap; B, Cross-sectional cut surface of mushroom cap.

In more recent experiments, we have obtained equally good results with a somewhat simpler browning inhibitor dip containing 4.5% sodium erythorbate and 0.1% sodium chloride (28). A shelf life of at least one week can be realized for washed mushrooms if they are treated first with a 3-5% hydrogen peroxide solution to control spoilage and then with the new dip formulation to inhibit browning.

### Clarified Raw Juices

Our experience with clarified raw apple juice illustrates an important constraint on the use of ascorbate or erythorbate to control browning of minimally processed products. Previously, we found that polyphenol oxidase in raw apple juice was bound to suspended particulates making up the juice cloud (9). Removal of this cloud by filtration or centrifugation would eliminate the capacity of the juice to undergo enzymatic browning. However, in order to prevent browning in the freshly prepared raw juice prior to clarification, it was necessary to dip the cut up apples in 1% ascorbic acid solution before juicing. This would result in an ascorbic acid concentration of about 500 ppm in the juice. Lower ascorbic acid concentrations could be used with apples that browned less. With Granny Smith apples, for example, we added about 100 ppm ascorbic acid to the juice.

Clarification was able to prevent browning in refrigerated raw juices stored for several weeks. However, juices stored for longer periods of time sometimes developed a yellow color, which over time became gold and, in some cases, brown. We didn't know whether this discoloration was due to an enzymatic browning reaction resulting from residual polyphenol oxidase in the juice, a nonenzymatic browning reaction, or the metabolic activity of microorganisms in the unpasteurized raw juice.

In a series of experiments designed to establish the cause of this discoloration, we showed that yellowing was not prevented by microfiltration of raw juice through an 0.45  $\mu\text{m}$  membrane. This largely ruled out microbial activity during storage as a source of the discoloration. Yellowing was not prevented by boiling the juice before membrane filtration. This eliminated an enzymatic reaction as the source of the discoloration.

Yellowing was reduced by storage of juice in vacuum and by addition of 100 ppm  $\text{SO}_2$  (as sodium bisulfite) or 1% polyvinylpyrrolidone to juice. Yellowing was associated with the presence of at least 500 ppm added ascorbic acid. At very low levels of added ascorbic acid, i.e., 100 ppm, juices did not become yellow but tended to brown slowly. Yellowing was greatly enhanced by addition of 1000 ppm dehydroascorbic acid to the juice.

These results suggests that yellowing of raw apple juice, treated with ascorbic acid to prevent enzymatic browning, was due largely to nonenzymatic browning of dehydroascorbic acid which was generated by nonenzymatic oxidation of added ascorbic acid. Nonenzymatic oxidation of phenolic compounds also contributed to this discoloration. Thus, use of ascorbic acid to control enzymatic browning in some minimally processed products may actually result in unforeseen nonenzymatic discolorations. Yellowing of apple juice could be minimized as a problem by

reducing the level of added ascorbic acid and by bottling juice with minimal headspace volume.

### Conclusions

The problem of controlling enzymatic browning in minimally processed fruits and vegetables is not a simple case of choosing the best browning inhibitor formulation for each commodity. Our experiences with pre-peeled potatoes, washed mushrooms, and fresh apple juice, demonstrate the importance of taking a broader view in developing treatments to control browning. From these case studies, we can identify several principles or guidelines that may be applicable to other commodities.

First, consider the characteristics of the cut or peeled surface to be treated: the extent of mechanical or thermal injury, occurrence of membrane leakage, and presence of degradative enzymes and their substrates. Second, consider the possibility that secondary nonenzymatic reactions may contribute to product discoloration, if enzymatic browning is controlled. Such reactions even may be a consequence of the browning inhibitor treatment. Third, consider the possibility that product discoloration may be due in part to metabolic activity of microorganisms in the product. Fourth, consider possible adverse effects of browning inhibitor treatments on product flavor and texture. Fifth, consider microbiological implications of browning inhibitor treatments - whether such treatments might actually favor growth of spoilage microorganisms or even human pathogens.

With this holistic approach, we believe that effective and practical solutions can be found for most enzymatic browning problems encountered with minimally processed fruits and vegetables.

### Literature Cited

1. Sapers, G. M.; Hicks, K. B. In *Quality Factors of Fruits and Vegetables: Chemistry and Technology*; Jen, J. J., Ed.; ACS Symposium Series 405; American Chemical Society: Washington, DC, 1989; pp. 29-43.
2. Sapers, G. M. *Food Technol.* 1993, 47 (10), 75-83.
3. FDA. *Fed. Register* 1986, 51, 25021-25026.
4. Sapers, G. M.; Hicks, K. B.; Phillips, J. G.; Garzarella, L. G.; Pondish, D. L.; Matulaitis, R. M.; McCormack, T. J.; Sondey, S. M.; Seib, P. A.; El-Atawy, Y. S. *J. Food Sci.* 1989, 54, 997-1002, 1012.
5. Sapers, G. M.; Garzarella, L.; Pilizota, V. *J. Food Sci.* 1990, 55, 1049-1053.
6. Sapers, G. M.; Miller, R. L. *J. Food Sci.* 1992, 57, 1132-1135.
7. Sapers, G. M.; Miller, R. L. *J. Food Sci.* 1993, 58, 1076-1078.
8. Sapers, G. M.; Miller, R. L.; Miller, F. C.; Cooke, P. H.; Choi, S.-W. *J. Food Sci.* 1994, 59, 1042-1047.
9. Sapers, G. M. *J. Food Proc. Preserv.* 1992, 15, 443-456.
10. Feinberg, B.; Olson, R. L.; Mullins, W.R. In *Potato Processing*; Talburt, W. F.; Smith, O., Eds.; AVI-Van Nostrand Reinhold: New York, NY, 1987, pp. 697-726.

11. FDA. *Fed. Register* 1990, 55, 9826-9833.
12. Anonymous. *Food Chemical News* 1991, 33(13), 2.
13. Langdon, T. T. *Food Technol.* 1987, 41(5), 64-67.
14. O'Beirne, D.; Ballantyne, A. *J. Food Sci. Technol.* 1987, 22, 515-523.
15. Santerre, C. R.; Leach, T. F.; Cash, J. N. *J. Food Sci.* 1991, 56, 257-259.
16. Sapers, G. M.; Douglas, F. W., Jr.; Bilyk, A.; Hsu, A.-F.; Dower, H. W.; Garzarella, L.; Kozempel, M. *J. Food Sci.* 1989, 54, 362-365.
17. Harrington, W. O. 1957, U.S. Patent 2,797,165.
18. Sapers, G. M.; Douglas, F. W., Jr. *J. Food Sci.* 1987, 52, 1258-1262, 1285.
19. Sapers, G. M.; Miller, R. L. 1994 IFT Annual Meeting. Book of Abstracts.
20. Bartolome, L. G.; Hoff, J. E. *J. Agr. Food Chem.* 1972, 20, 266-270.
21. Sapers, G. M.; Miller, R. L.; Douglas, F. W., Jr.; Hicks, K. B. *J. Food Sci.* 1991, 56, 419-422, 430.
22. Löscher, J.; Kroh, L., Westphal, G.; Vogel, J. *Z. Lebensm. Unters Forsch.* 1991, 192, 323-327.
23. Reeve, R. M. *Am. Potato J.* 1969, 46, 374-386.
24. Guthrie, B. D.; Beelman, R. B. *Mushroom Science* 1989, XII (Part II), 689-700.
25. Choi, S. W.; Sapers, G. M. *J. Agric. Food Chem.* 1994, 42, 1183-1189.
26. Choi, S. W.; Sapers, G. M. *J. Agric. Food Chem.* 1994, 42, 2286-2290.
27. Forney, C. F.; Rij, R. E.; Denis-Arrue, R.; Smilanick, J. L. *HortScience* 1991, 26, 1512-1514.
28. Sapers, G. M.; Miller, R. L.; Wells, J. M.; Simmons, G.; Miller, F. C. *J. Food Sci.* Submitted.
29. McEvily, A. J.; Iyengar, R. *Critical Reviews in Food Science and Nutrition* 1992, 32, 253-273.
30. Code of Federal Regulations 21; Parts 170-199; Sections 172.120, 172.135, 184.1271, 184.1272. April 1, 1992. U.S. Government Printing Office.