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Control of After-Cooking Darkening in Potatoes with Edible Film-Forming Products and Calcium Chloride

G. Mazza* and H. Qi

Food Research Laboratory, Agriculture Canada Research Station, Morden, Manitoba R0G 1J0, Canada

Potential alternative after-cooking darkening inhibitors were evaluated on water-blanched potato strips using quantitative measurements of color changes to assess treatment effectiveness. Purified spray-dried gum acacia (Spraygum) and gum acacia and gelatin (Sealgum) showed considerable promise as inhibitors of after-cooking darkening of potatoes. Coatings composed of starch/corn syrup solid blends (N-Lok, Purity gum, Melojel, and Clearjel), Crystal gum, amylose, potato starch, α,β-cyclodextrins, pullulans, locust bean gum, gum guar, agar, and gum arabic, however, had little effect on percent inhibition. The combination of gum acacia, gelatin, and calcium chloride represented an effective treatment for the prevention of after-cooking darkening of water-blanched potatoes. Inhibition of darkening by these products was comparable to inhibition values obtained with 0.5% sodium acid pyrophosphate solutions at pH 5 and 20 °C.

INTRODUCTION

The bluish gray discoloration that occurs after potatoes have been cooked is usually referred to as after-cooking darkening. The darkening is generally more intense at the stem end than at the bud end of the tuber. The reaction responsible for this darkening is nonenzymatic and has no known detrimental effect on flavor or nutritive value. The pigment responsible for the discoloration is a complex of ferric iron (Fe^{3+}) with chlorogenic acid, an *o*-hydroxyphenol (Muneta and Kaisaki, 1985). In freshly cooked potatoes, a colorless chlorogenic acid–ferrous iron (Fe^{2+}) complex is formed which is oxidized in air to the colored chlorogenic acid–ferric iron complex. The formation of this pigmented complex can be affected by pH and by the presence of naturally occurring chelating or complexing agents in the tubers (Hughes and Swain, 1962). Heisler et al. (1964) reported highly significant correlations between low citric acid, orthophosphoric acid, and oxalic acid content and blackening. Hughes and Evans (1969) reported correlation values of 0.814 and 0.830 between after-cooking darkening and the ratio of chlorogenic acid/citric acid of Majestic and Ulster Beacon potatoes, respectively. Thomas et al. (1979) attributed the induction of after-cooking darkening in irradiated potatoes to decreased citric acid levels and enhanced polyphenols in the tuber tissue.

Products that have been reported to reduce or prevent after-cooking darkening include sodium acid pyrophosphate ($Na_2H_2P_7O_7$ or SAPP) (Smith, 1958; Smith and Davis, 1960, 1961, 1962a–d; Davis and Smith, 1964), ethylenediaminetetraacetic acid (EDTA) and its salts (Smith and Muneta, 1954), gluconic acid, citric acid, sodium gluconate, sodium citrate, ammonium gluconate, and sodium bisulfite (Smith, 1987). It is believed that in most instances these chemicals reduce darkening by sequestering or chelating the iron in the tubers so that it is held in a nonionizable form and cannot take part in a reaction with chlorogenic acid, thereby preventing formation of the dark colored pigment. pH is known to influence after-cooking darkening of potatoes (Smith, 1958; Hughes and Swain, 1962) and the effectiveness of SAPP treatment (Ng and Weaver, 1979). However, very little has been published on the effect of pH on the effectiveness of other products tested to control after-cooking darkening in potatoes. Fellers and Morin (1962) obtained a patent on the prevention of after-cooking darkening with several chemicals of the EDTA group.

With the exception of SAPP, however, none of these chemicals, to our knowledge, has been used commercially for the prevention of discoloration of French fries. Most French fry processors, however, now use SAPP as a routine treatment of blanched potato products before frying and freezing. SAPP-treated potato products can develop a bitter chemical taste (Ng and Weaver, 1979; Smith 1987), and more recently it has been reported to be a concern to chemical additive conscious consumers.

Alternative products/processes to SAPP and other chelating or complexing agents are highly desirable. The concept of coating the cooked potatoes with an edible material to prevent oxidation of the colorless chlorogenic acid–Fe^{2+} complex and the subsequent development of bluish gray discoloration has not been explored. Edible food coatings made from starches, gums, proteins, dextrins, lipids, and derivatives have, however, been suggested for protection of foods such as meat, fish, and dairy products against moisture and oxygen (Guilbert, 1986; Gennadios and Weller, 1990). The use of dextrins, starches, and gums in flavor encapsulation has been recently reviewed (Reineccius, 1990). Most interesting is the reported oxygen-barrier and film-forming characteristics of pullulan, a water-soluble polysaccharide synthesized by *Aureobasidium pullulans* (LeDuy et al. 1988; Sugimoto, 1990). The purpose of the present investigation was to assess the performance of selected gums, pullulans, and starches as inhibitors of after-cooking darkening in potatoes.

MATERIALS AND METHODS

System for Evaluation of After-Cooking Darkening. Russet Burbank potatoes grown and stored commercially in southern Manitoba in 1989–1990 were used. For each experiment, 8–10 tubers were taken out of 5 °C and 90% relative humidity storage, quickly peeled and trimmed by hand, immersed into a cold water bath, and mechanically cut into 1 × 1 cm strips. The strips were then immediately placed in a cool water bath to avoid enzymatic discoloration.

For each test, about 1.0 kg of potato strips was water blanched at 83 °C (±2 °C) for 8 min (ratio of potato to water, 1/10 w/v). After blanching, the strips were rinsed with cold water for about 10 s and dipped into a Fe^{2+}–chlorogenic acid aqueous solution for 1 min to standardize development of bluish gray discoloration.

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Table I. Percent Inhibition of After-Cooking Darkening in Potatoes by Selected Gums, Pullulans, Starches, Cyclodextrin, and Calcium Chloride[a]

treatment	% inhibition 2 h	4 h	6 h	8 h	10 h
2% Spraygum	50.2 ± 9.6^{cd}	59.6 ± 5.1^{cde}	63.1 ± 4.6^{c}	67.9 ± 2.4^{b}	58.7 ± 4.6^{b}
2% Spraygum + 1% $CaCl_2$	82.1 ± 7.7^{ab}	90.7 ± 4.5^{a}	91.2 ± 5.3^{a}	94.5 ± 5.8^{a}	88.8 ± 3.7^{a}
2% Sealgum	58.4 ± 8.5^{cd}	67.1 ± 9.5^{cd}	69.4 ± 3.4^{bc}	70.8 ± 9.1^{b}	66.4 ± 1.6^{b}
2% Sealgum + 1% $CaCl_2$	91.1 ± 6.8^{a}	83.4 ± 6.7^{ab}	81.8 ± 11.4^{ab}	86.9 ± 10.2^{a}	79.8 ± 6.6^{a}
2% acacia + 1% $CaCl_2$	49.9 ± 6.4^{cd}	36.7 ± 4.3^{fg}	41.9 ± 7.7^{d}	38.1 ± 2.8^{defg}	24.9 ± 3.9^{de}
5% PF-10	34.9 ± 10.4^{e}	27.1 ± 2.9^{g}	28.7 ± 3.1^{d}	18.8 ± 4.4^{i}	17.7 ± 7.3^{de}
5% PF-10 + 1% $CaCl_2$	67.7 ± 1.8^{bc}	65.3 ± 10.2^{cde}	64.5 9.6^{c}	50.6 ± 7.5^{cd}	40.2 ± 1.2^{c}
5% PF-30	67.1 ± 7.6^{bc}	54.4 ± 7.5^{de}	30.1 ± 6.4^{d}	25.1 ± 3.4^{ghi}	23.9 ± 8.1^{de}
5% PF-30 + 1% $CaCl_2$	61.9 ± 0.8^{c}	55.2 ± 5.8^{de}	59.3 ± 7.0^{c}	53.7 ± 4.8^{c}	30.0 ± 5.5^{cd}
2% Melojel + 1% $CaCl_2$	67.9 ± 7.1^{bc}	73.7 ± 10.1^{bc}	64.7 ± 6.4^{c}	45.3 ± 9.9^{cde}	41.3 ± 8.8^{c}
2% N-Lok + 1% $CaCl_2$	78.5 ± 6.2^{ab}	48.2 ± 11.7^{ef}	43.7 ± 2.9^{d}	39.9 ± 1.8^{def}	13.9 ± 2.4^{e}
2% Purity + 1% $CaCl_2$	42.3 ± 6.9^{e}	52.6 ± 5.3^{def}	29.1 ± 6.8^{d}	29.7 ± 5.2^{fghi}	21.4 ± 2.9^{de}
2% cycldex[b] + 1% $CaCl_2$	55.1 ± 6.6^{cd}	48.7 ± 7.9^{ef}	44.5 ± 6.8^{d}	35.0 ± 5.6^{efgh}	26.8 ± 8.3^{de}
1% $CaCl_2$	52.4 ± 5.9^{cd}	37.3 ± 4.7^{fg}	31.4 ± 3.1^{d}	23.1 ± 5.8^{hi}	15.5 ± 3.5^{de}
0.5% SAPP	80.8 ± 2.1^{ab}	83.6 ± 1.6^{ab}	80.4 ± 4.5^{ab}	89.7 ± 2.7^{a}	56.0 ± 7.6^{b}

[a] Means of three to five replicates; means in each column followed by different superscripts are significantly different at $p \leq 0.05$. [b] Cyclodextrin.

Table II. Inhibition of After-Cooking Darkening in Potatoes by Spray-Dried Gum Acacia (Spraygum)[a]

treatment	% inhibition 2 h	4 h	6 h	8 h	10 h
0.5% Spraygum	30.7 ± 8.4^{c}	27.0 ± 7.9^{c}	24.8 ± 8.9^{d}	20.7 ± 7.7^{d}	26.0 ± 5.6^{d}
1% Spraygum	47.0 ± 7.5^{c}	53.8 ± 8.2^{b}	46.8 ± 2.2^{c}	46.3 ± 5.4^{c}	34.6 ± 6.8^{b}
2% Spraygum	50.2 ± 9.6^{b}	59.6 ± 5.1^{b}	63.1 ± 4.6^{b}	67.9 ± 2.4^{b}	58.7 ± 4.6^{a}
5% Spraygum	53.3 ± 6.8^{b}	64.4 ± 4.4^{b}	69.4 ± 7.5^{b}	70.1 ± 3.8^{b}	61.4 ± 9.2^{a}
0.5% SAPP	80.8 ± 2.1^{a}	83.6 ± 1.6^{a}	80.4 ± 4.5^{a}	89.7 ± 2.7^{a}	56.0 ± 7.6^{a}

[a] Means of three to five replicates; means in each column followed by different superscripts are significantly different at $p \leq 0.05$.

Table III. Inhibition of After-Cooking Darkening by Combination of Spraygum and Calcium Chloride[a]

treatment	% inhibition 2 h	4 h	6 h	8 h	10 h
2% Spraygum + 0% $CaCl_2$	50.2 ± 9.6^{b}	50.6 ± 5.1^{c}	63.1 ± 4.6^{b}	67.9 ± 2.4^{b}	58.7 ± 4.6^{c}
2% Spraygum + 0.25% $CaCl_2$	59.6 ± 6.5^{b}	74.3 ± 2.0^{b}	83.6 ± 8.9^{a}	73.0 ± 6.5^{b}	62.1 ± 2.0^{c}
2% Spraygum + 0.5% $CaCl_2$	63.8 ± 3.1^{b}	84.2 ± 4.4^{a}	80.9 ± 1.7^{a}	87.1 ± 4.2^{a}	80.7 ± 2.5^{b}
2% Spraygum + 1% $CaCl_2$	82.1 ± 7.7^{a}	90.7 ± 4.5^{a}	91.2 ± 5.3^{a}	94.0 ± 5.8^{a}	88.8 ± 3.7^{a}
0% Spraygum + 1% $CaCl_2$	52.4 ± 5.9^{b}	37.3 ± 4.7^{d}	31.4 ± 3.1^{c}	23.1 ± 5.8^{c}	15.5 ± 3.5^{d}
0.5% SAPP	80.8 ± 2.1^{a}	83.6 ± 1.6^{a}	80.4 ± 4.5^{a}	89.7 ± 2.7^{a}	56.0 ± 7.6^{c}

[a] Means of three to five replicates; means in each column followed by different superscripts are significantly different at $p \leq 0.05$.

Table IV. Influence of pH of Sealgum and Spraygum Solutions on Percent Inhibition of After-Cooking Darkening in Potatoes[a]

treatment	% inhibition 2 h	4 h	6 h	8 h	10 h
2% Sealgum + 1% $CaCl_2$					
pH 3	83.3 ± 7.7^{a}	82.7 ± 1.8^{b}	85.9 ± 3.3^{a}	83.4 ± 9.9^{a}	78.1 ± 6.1^{ab}
pH 4	88.5 ± 3.5^{a}	91.2 ± 4.4^{ab}	89.7 ± 2.3^{a}	87.3 ± 8.1^{a}	76.6 ± 5.7^{ab}
pH 5	91.1 ± 6.2^{a}	83.4 ± 6.7^{b}	81.8 ± 1.4^{a}	86.9 ± 0.3^{a}	79.8 ± 9.2^{ab}
pH 6	92.6 ± 6.6^{a}	79.2 ± 5.8^{b}	71.9 ± 2.7^{b}	78.0 ± 6.1^{a}	71.6 ± 3.6^{b}
2% Spraygum + 1% $CaCl_2$					
pH 3	95.8 ± 6.8^{a}	87.7 ± 5.0^{ab}	86.3 ± 6.8^{a}	87.6 ± 6.4^{a}	85.9 ± 1.2^{ab}
pH 4	94.8 ± 10.4^{a}	97.3 ± 4.9^{a}	87.8 ± 7.9^{a}	87.8 ± 5.5^{a}	86.3 ± 2.3^{ab}
pH 5	82.1 ± 7.7^{a}	90.7 ± 4.5^{ab}	91.2 ± 5.3^{a}	94.0 ± 5.8^{a}	88.8 ± 3.7^{a}
pH 6	86.2 ± 9.9^{a}	77.7 ± 6.7^{b}	73.6 ± 3.9^{b}	74.5 ± 7.3^{a}	73.5 ± 2.6^{b}

[a] Means of three to five replicates; means in each column followed by different superscripts are significantly at $p \leq 0.05$.

The Fe^{2+}–chlorogenic acid solution was prepared by dissolving 1.25×10^{-2} g of chlorogenic acid (Sigma Chemical Co.) in 1 L of 0.1% aqueous oxygen-free ferrous iron (Aldrich Chemical Co., Inc.). This Fe^{2+}–chlorogenic acid solution was prepared just prior to use and kept under N_2 to prevent oxidation. After pretreatment with Fe^{2+} and chlorogenic acid, the blanched potato strips were quickly blotted with paper toweling and coated by dipping the samples in aqueous solutions of gums, pullulans, and starches for 1 min. A sample dipped in distilled water served as control.

Instrumental Color Measurement. Color of samples was measured with a Hunterlab tristimulus colorimeter (Model D25L-9, Hunter Associates Laboratory, Reston, VA). Color parameters in different systems (i.e., *Y*, *X*, and *Z*; *Y*, *x*, and *y*; *L*, *a*, and *b*; and L^*, a^*, and b^*) were recorded at regular intervals over a 10-h cooling–storage period. In preliminary experiments, all color parameters were correlated with storage time and degree of discoloration of samples, and the Hunterlab parameter *b* value was selected for the evaluation of the degree of discoloration of samples and effectiveness of treatments. Color measurements

Table V. Percent Inhibition of After-Cooking Darkening in Potatoes by Pullulans (PF) and Combination of Pullulan and Calcium Chloride[a]

treatment	% inhibition				
	2 h	4 h	6 h	8 h	10 h
2% PF-10	34.9 ± 9.4[d]	29.1 ± 4.7[d]	22.6 ± 3.9[d]	14.5 ± 1.5[c]	10.6 ± 2.4[d]
5% PF-10	34.9 ± 10.4[d]	27.1 ± 2.9[d]	28.7 ± 3.1[cd]	18.8 ± 4.4[c]	17.7 ± 7.3[d]
8% PF-10	52.0 ± 6.1[c]	40.4 ± 11.0[cd]	31.1 ± 6.4[cd]	30.3 ± 9.6[c]	20.4 ± 8.9[bc]
10% PF-10	60.8 ± 4.1[bc]	46.1 ± 9.1[c]	36.3 ± 7.9[cd]	34.2 ± 7.2[c]	28.6 ± 5.3[bc]
2% PF-30	36.3 ± 1.3[d]	30.0 ± 4.5[d]	26.7 ± 6.6[cd]	28.6 ± 9.8[c]	17.7 ± 11.1[d]
5% PF-30	67.1 ± 7.6[b]	54.4 ± 7.5[bc]	30.1 ± 6.4[cd]	25.1 ± 3.4[c]	23.9 ± 8.1[bc]
8% PF-30	62.6 ± 0.3[bc]	50.6 ± 5.3[bc]	43.6 ± 2.0[c]	34.7 ± 7.6[c]	23.2 ± 6.1[bc]
10% PF-30	60.7 ± 3.1[bc]	58.0 ± 7.2[bc]	44.9 ± 13.4[c]	31.9 ± 6.8[c]	24.3 ± 4.5[bc]
5% PF-10 + 1% $CaCl_2$	67.7 ± 1.8[b]	65.3 ± 10.2[b]	64.5 ± 9.6[b]	50.6 ± 7.5[b]	40.2 ± 1.2[b]
5% PF-30 + 1% $CaCl_2$	61.9 ± 0.8[bc]	55.2 ± 5.8[bc]	59.3 ± 4.8[b]	53.7 ± 4.8[bc]	30.0 ± 5.5[bc]
0.5% SAPP	80.8 ± 2.1[a]	83.6 ± 1.6[a]	80.4 ± 4.5[a]	89.7 ± 2.7[a]	56.0 ± 7.6[a]

[a] Means of three to five replicates; means in each column followed by different superscripts are significantly different at $p \leq 0.05$.

were taken 1, 2, 4, 6, 8, and 10 h after treatment. Samples were stored at 21 ± 1 °C. All experiments were carried out at least three times.

Treatments. Various compounds, their derivatives, and combinations of these were screened in preliminary experiments and, if promising, were evaluated further in the later experiments. Compounds tested included Melojel (corn starch), Clearjel (waxy maize starch), Purity gum (instant starch), Crystal gum, and K-4484 (specialty dextrin), all from NaCan Products Limited (Brampton, ON); locust bean, gum guar, and agar; α,β-cyclodextrins, sodium hexametaphosphate, sodium tetraborate, and potassium biborate (Sigma); potato starch, amylose, and citric acid (Fisher Scientific Co.); gum acacia, Sealgum, and Spraygum (Colloides Naturels Inc.); pullulans (PF-10, MW 100 000; PF-30, MW 300 000; Hayashibara Biochemical Laboratories, Inc.); SAPP (Carnation Foods Ltd.); and calcium chloride (J. T. Baker Chemical Co.). The pH of each dipping solution was adjusted to the desirable level by addition of 10 M HCl or 10 M NaOH.

Data Analysis. The b values from Hunterlab measurements were plotted against time, yielding almost linear curves, at times having an initial region of zero slope indicating the absence of after-cooking darkening. The extent of darkening in the potato samples was indicated by the change in b value after 2 and 10 h.

The effectiveness of treatments, the percent of inhibition, was calculated from the b values for treated samples and corresponding distilled water dipped controls according to the equation (Sapers and Douglas, 1987)

$$\%\ \text{inhibition at time } t = \frac{\Delta b_{\text{control}} - \Delta b_{\text{treatment}}}{\Delta b_{\text{control}}} \times 100$$

where $\Delta b = b_t - b_{\text{initial}}$.

Data were analyzed for differences of percent inhibition within or between the treatments with SAS/STAT software (SAS Institute, Inc.) using a randomized complete block design.

RESULTS AND DISCUSSION

The degree of after-cooking darkening in potatoes varies within and between tubers and with storage time (Hughes and Swain, 1962). Therefore, to be able to compare potential inhibitors for their ability to control the darkening, the degree of darkening had to be reproducible and measurable with a colorimeter. Preliminary experiments with chlorogenic acid dissolved in an oxygen-free aqueous ferrous iron solution indicated that dipping of cooked potatoes in a solution containing 0.1% Fe^{2+} and 0.0125% chlorogenic acid for 1 min gave a uniform reproducible and measurable bluish gray color, resembling severe after-cooking darkening. The degree of darkening was monitored by reflectance measurements of the potato strips immediately after application of darkening inhibitor and after storage of the strips for 1–10 h at room temperature.

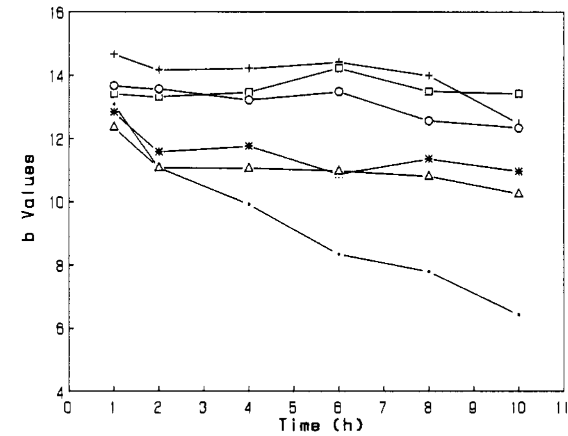

Figure 1. Effect of selected treatments on after-cooking darkening of potatoes: (+) 0.5% SAPP; (□) 2% Spraygum and 1% $CaCl_2$; (○) 2% Sealgum and 1% $CaCl_2$; (*) 2% Spraygum; (△) 2% Sealgum; (·) water.

Table I shows percent inhibition values, calculated from changes in b values of blanched potato strips dipped in 2% solutions of gums (Spraygum, Sealgum, and acacia gum), pullulans (PF-30 and PF-10), starches (N-Lok, Purity, and Melojel), cyclodextrin, and 1% calcium chloride. Purified spray-dried gum acacia (Spraygum) and coprocessed acacia gum and gelatin (Sealgum) showed considerable promise as inhibitors of after-cooking darkening in potatoes when used in combination with calcium chloride. The combination of Spraygum or Sealgum with calcium chloride was significantly more effective as a darkening inhibitor than the gums or calcium chloride alone (Table I; Figure 1). Also, $CaCl_2$ provided more protection during the first 3–4 h after treatment, and the gums were more effective after 4–5 h of treatment.

Tables II and III show effect of concentration of Spraygum alone and in combination with calcium chloride on percent inhibition. Dips containing 2% gum and 1% calcium chloride (pH 5) were as effective darkening inhibitors as the commercially used dip containing 0.5% disodium acid pyrophosphate (SAPP). The pH of Spraygum and Sealgum solutions had no significant effect on percent inhibition (Table IV).

The ability of Sealgum–$CaCl_2$ and Spraygum–$CaCl_2$ combinations to inhibit after-cooking darkening in potatoes probably resulted from (i) the ability of the gum to guard against oxidation of the colorless chlorogenic acid–Fe^{2+} complex and (ii) the ability of Ca^{2+} to compete with Fe^{2+} for chlorogenic acid, thereby preventing/reducing the formation of the colored chlorogenic acid–Fe^{3+} complex. Newer generation acacia gums are recommended flavor-encapsulating agents used to protect oxidizable flavor components against oxidative and photochemical degradation (Reineccius, 1990), and chlorogenic acid is a well-known calcium-chelating agent (Mabrouk and Deatherage, 1956; Rendleman, 1987). Rendleman (1987) showed that chlorogenic acid contributes importantly to the formation of soluble calcium complexes in coffee brew. Thus, it should not be surprising that the combination of spray-dried gum acacia and coprocessed acacia gum–gelatin and calcium chloride provided over 80% inhibition of after-cooking darkening. What is somewhat surprising, however, is the finding that dextrins, pullulans, or starches were not highly effective inhibitors of after-cooking darkening (Tables I and V). Table V shows inhibition values of blanched potato strips by dips containing 2–10% pullulan and pullulan plus calcium chloride. The pullulans used in this experiment had molecular weights of 100 000 (PF-10) and 300 000 (PF-30). According to LeDuy et al. (1988), pullulan solutions at concentrations of 5–10% when applied to food products form colorless, transparent, tasteless, odorless, nontoxic, oxygen-impermeable films. The results presented in Table V, however, show that molecular weight and concentration of pullulan had little effect on percent inhibition. Percent inhibition decreased with storage time of samples. The combination of pullulan with calcium chloride was much more effective than pullulan alone; however, it too was time dependent, and after 10 h at room temperature, percent inhibition was near 30% and well below dips containing 0.5% SAPP. Reported oxygen permeabilities of pullulan films range from about 1 $mL/m^2/24\ h/20\ \mu$ at 5% moisture content to about 1000 $mL/m^2/24\ h/20\ \mu$ at 35% moisture content (Sugimoto, 1990). The moisture content of potato strips was about 80%. Thus, the observed low percent inhibition values probably resulted from the high moisture content of the potato strips causing a high oxygen permeability of the pullulan film.

CONCLUSIONS

Purified spray-dried gum acacia (Spraygum) and coprocessed gum acacia and gelatin in combination with calcium chloride showed considerable promise as inhibitors of after-cooking darkening of water-blanched potato strips. Inhibition of darkening by these products was comparable to inhibition values obtained with 0.5% SAPP solutions. Further studies should be carried out to optimize the most promising treatments using conditions more applicable to commercial practices and to evaluate the usefulness of these treatments to other food products.

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LITERATURE CITED

Davis, C. O.; Smith, O. Quality factors in the production of frozen french fries. *Quick Frozen Foods* **1964**, *27* (4), 76–79.

Fellers, J. C.; Morin, L. U.S. Pat. 3,049,427, Aug 14, 1962.

Gennadios, A.; Weller, C. L. Edible films and coatings from wheat and corn proteins. *Food Technol.* **1990**, *44* (10), 63–69.

Guilbert, S. Technology and application of edible protective films. In *Food Packaging and Preservation: Theory and Practices*; Mathlouthi, M., Ed.; Elsevier: London, 1986; pp 371–393.

Heisler, E. G.; Siciliano, J.; Woodward, C. F.; Porter, W. L. After-cooking discoloration of potatoes. Role of the organic acids. *J. Food Sci.* **1964**, *29*, 555–564.

Hughes, J. C.; Evans, J. L. Studies on after-cooking blackening. V. Changes in after-cooking blackening and the chemistry of Majestic and Ulster Beacon tubers during the growing season. *Eur. Potato J.* **1969**, *12*, 16–40.

Hughes, J. C.; Swain, T. After-cooking blackening in potatoes. II. Core experiments. *J. Sci. Food Agric.* **1962**, *13*, 229–236.

LeDuy, A.; Zajic, J. E.; Luong, J. H. T. Pullulan. In *Encyclopedia of Polymer Science and Engineering*. Mark, H. F., et al., Eds.; Wiley: Toronto, 1988; Vol. 3, pp 650–660.

Mabrouk, A. F.; Deatherage, F. E. Organic acids in brewed coffee. *Food Technol.* **1956**, *10*, 194–197.

Muneta, P.; Kaisaki, F. Ascorbic acid-ferrous iron (Fe^{++}) complexes and after-cooking darkening of potatoes. *Am. Potato J.* **1985**, *62*, 531–536.

Ng, K. G.; Weaver, M. L.; Effect of pH and temperature on hydrolysis of disodium acid pyrophosphate (SAPP) in potato processing. *Am. Potato J.* **1979**, *56*, 63–69.

Reineccius, G. A. Role of carbohydrates in flavour encapsulation. Presented at the Annual Meeting of the IFT, Anaheim, CA, June 16–20, 1990; Paper 652.

Rendleman, J. A. Complexation of calcium by melanoidin and its role in determining bioavailability. *J. Food Sci.* **1987**, *52*, 1699–1705.

Sapers, G. M.; Douglas, F. W. Measurement of enzymatic browning of cut surfaces and in juice of raw apple and pear fruit. *J. Food Sci.* **1987**, *52*, 1258–1262.

Smith, O. Potato quality. X. Post harvest treatments to prevent after-cooking darkening. *Am. Potato J.* **1958**, *35*, 573–584.

Smith, O. Effect of cultural and environment conditions on potatoes for processing. In *Potato Processing*; Talbot, W. F., Smith, O., Eds.; AVI: Westport, CT, 1967, 1987.

Smith, O.; Davis, C. O. Preventing discoloration in cooked and French fry potatoes. *Am. Potato J.* **1960**, *37*, 352.

Smith, O.; Davis, C. O. Potato quality. IV. Prevention of graying in dehydrated potato products. *Potato Chipper* **1961**, *21* (3), 84, 99.

Smith, O.; Davis, C. O. Potato quality. XIV. Prevention of graying in dehydrated potato products. *Am. Potato J.* **1962a**, *39*, 135–148.

Smith, O.; Davis, C. O. Potato quality. XIII. Preventing after-cooking discoloration in oil-blanched French fries. *Am. Potato J.* **1962b**, *39*, 45–56.

Smith, O.; Davis, C. O. A better way to prevent tattle tale gray in potatoes. *Cornell Hotel Restaurant Admin. Q.* **1962c**, *3* (1), 71–74.

Smith, O.; Davis, C. O. Prevention of graying in frozen French fries. *Quick Frozen Foods* **1962d**, *24* (9), 69–72.

Smith, O.; Muneta, P. Potato quality. VIII. Effect of foliar applications of sequestering and chelating agents on after cooking darkening. *Am. Potato J.* **1954**, *31*, 404–409.

Sugimoto, K. Pullulan production and applications. *J. Ferment. Assoc. Jpn.* **1990**, *36* (2), 98–108.

Thomas, P.; Adam, S.; Diehl, J. F. Role of citric acid in the after-cooking darkening of γ-irradiated potato tubers. *J. Agric. Food Chem.* **1979**, *27*, 519–523.

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