After-Cooking Darkening of Spartan Pearl Potatoes As Influenced by Location, Phenolic Acids, and Citric Acid

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Significant differences in after-cooking darkening, phenolic acids, and citric acid levels were observed in the potato cultivar Spartan Pearl grown at nine Michigan locations in 1988 and 1989. Phenolic acids among locations ranged from 16.4 to 49.6 mg/100 g of tuber fresh weight in 1988 and from 15.1 to 42.5 mg/100 g of fresh weight in 1989. Citric acid ranged from 76.5 to 712.5 mg/100 g of tuber fresh weight in 1988 from 203.9 to 403.2 mg/100 g of fresh weight in 1989. After-cooking darkening was highly correlated with phenolic acid content ($r = 0.85$, $p < 0.01$). The correlation coefficient between after-cooking darkening and citric acid was negative and not significant ($r = -0.47$, $p > 0.1$). The correlation coefficient between after-cooking darkening and the ratio of citric/phenolic acid was also negative but significant ($r = -0.65$, $p < 0.05$). In any given year, locations that produced higher levels of after-cooking darkening were characterized by lower citric acid/phenolic acid ratios.

INTRODUCTION

After-cooking darkening (ACD) is an undesirable trait in potatoes intended for fresh market. This defect appears when susceptible varieties are boiled or steamed and intensifies with subsequent cooling. The flesh color may range from normal white of the unaffected potatoes through shades of gray to almost black. It detracts from the appearance of the cooked potato and renders it less appealing for consumption. In the fresh processing markets, this type of discoloration is particularly noticeable in canned, prepeeled, and potato salad products. After-cooking darkening has been reported from practically every potato-growing area of the world and undoubtedly has had a negative effect on fresh potato consumption.

It is generally accepted that the pigment responsible for ACD is a complex formed by the reaction of *o*-dihydroxyphenols and iron (Hughes, 1962). This complex substance is formed during cooking and is oxidized to a ferric complex when cooled in air to produce a darkened flesh. After-cooking darkening is greatest at the stem end and decreases in intensity toward the apical end.

Several other factors, namely pH, iron concentration, absence of iron chelating agents (citric acid, malic acid, phosphates), and the presence of other phenolic compounds, such as caffeic acid and tyrosine, have all been implicated as contributing to dark pigment formation during cooking (Muneta, 1959; Smith, 1958, 1976; Smith et al., 1942). The chelating agents compete with the phenols for the iron, so that less of the dark pigment is formed (Hughes, 1962). It has been reported that of the substances which compete with chlorogenic acid for iron, citric acid was by far the most effective (Gray and Hughes, 1978). Citric acid is also the most abundant organic acid in the potato, and its concentration is higher at the apical end, where little ACD occurs. Hughes and Swain (1962a,b), using tuber core tissue, found that the distribution of ACD from the stem to apical end of a tuber was mostly determined by the relative concentrations of chlorogenic and citric acid. In addition to varietal effect, the synthesis of these compounds in the potato tuber has been shown to depend on edaphic factors such as soil type, fertility, and season (Mulder, 1956; Muneta, 1959; Smith et al., 1942; Smith and Nash, 1942).

Spartan Pearl (MS700-83), a recent release from Michigan State University, is intended for fresh market and chipping. Its tubers have attractive external characteristics sought for the fresh market. In Michigan, this cultivar has shown varying degrees of ACD depending on the season and location (Michigan Potato Research Report 1986, 1987, 1988). This defect has limited its full potential in Michigan. The purpose of this study was to investigate how ACD differed among several Michigan locations and to possibly correlate the occurrence of ACD to the levels of phenolic acids and citric acid in Spartan Pearl potatoes grown in different locations.

MATERIALS AND METHODS

Spartan Pearl potato samples from seven locations were studied in 1988 and six in 1989 (Figure 1). All potatoes were harvested in September. From each location, a tuber sample of approximately 15–20 kg of U.S. No. 1 grade was taken and stored until January at 7.2 °C and used for analysis.

After-Cooking Darkening. To evaluate darkening, four medium-sized tubers (120–180 g) were peeled and cut in half longitudinally. Half of each tuber was placed in a stainless steel container and steamed with deionized water until soft (usually 25–30 min). The steamed potatoes were placed in aluminum foil and air-cooled for 1 h. After cooling, each tuber was rated on a scale of 1–4 by visual inspection (1 = no color; 4 = black overall). Three separate boiling tests were conducted with tubers, and a mean ACD value was calculated for each location.

Phenolic Acids. For each measurement, four medium-sized tubers were washed, and a core tissue sample 1 cm in diameter extending from the stem end to the apical end was taken from each tuber. The skin was removed, and the cores were sliced into 1-mm disks. A known weight of disks (about 20 g) was boiled in 100 mL of 95% ethanol in 250-mL flasks for 30 min. Flasks were cooled to room temperature, and the contents were thoroughly blended at high speed and filtered. The extract was diluted to 200 mL with 95% ethanol. Absorbance at 320 nm was measured against an ethanol blank for three subsamples of the extract (Hanson and Zucker, 1963). A standard curve was established by using serial dilutions of a 1 mg of chlorogenic acid/1 mL of ethanol solution. The types of phenolic acids in

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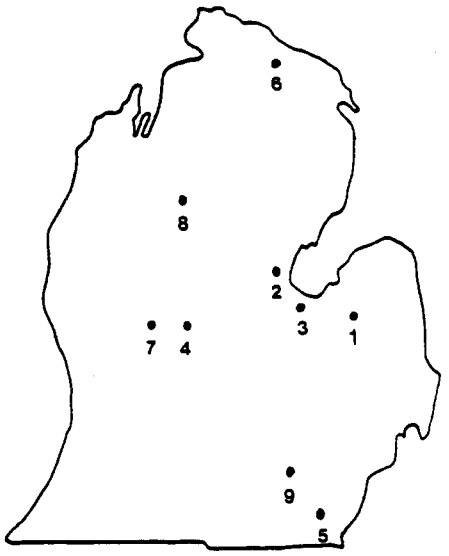

Figure 1. Lower peninsula of Michigan showing locations where Spartan Pearl potatoes were studied.

the extract were qualitatively determined by one-dimensional thin-layer chromatography on 0.25 mm thick silica gel plates (Whatman) developed with ethyl acetate/formic acid/acetic acid/water (100:11:11:27 v/v) (Friedman et al., 1989). Standard compounds (chlorogenic acid, *p*-coumaric acid, ferulic acid, caffeic acid, and scopolin) were obtained from Sigma Chemical Co. Compounds were detected under ultraviolet light (254 and 366 nm) and by spraying with the folin phenol reagent (Harborne, 1984). The major phenolic acid present in the extract was chlorogenic acid. The average phenolic acid content of each location was calculated from an average of three separate measurements using 12 potatoes.

Citric Acid Assay. For each measurement, four medium-sized tubers were washed and peeled. Twenty-five grams of tissue taken from core samples 1 cm in diameter from stem to apical end was blended with 75 mL of distilled water. Eight grams of this blend was then mixed with 42 mL of 5% trichloroacetic acid (TCA). The sample mixture was heated in a water bath at 80 °C for 1 h and then centrifuged at 2500 rpm for 5 min; 0.5 mL of the centrifuged sample was pipetted into a dry tube, and 4 mL of anhydrous acetic anhydride were added. Sample tubes were stoppered and placed in a 60 °C water bath for 10 min; 0.5 mL of pyridine was added to each tube, which was restoppered and placed in 60 °C water bath for 40 min. Tubes were cooled in tap water, and the absorbance at 420 nm (Dr. J. N. Cash, 1990, personal communication) was read with a Spectronic 20 colorimeter for two sample extracts. The blank consisted of 0.5 mL of TCA to which acetic anhydride and pyridine were added in sequence. A standard curve was prepared in 5% TCA with 15–400 μg of citric acid/mL aliquots. The citric acid concentration for potatoes from each location was calculated as the average of results for three separate measurements using 12 potatoes.

RESULTS AND DISCUSSION

Significant differences in ACD scores of Spartan Pearl potatoes were observed among locations in 1988 and 1989 (Tables I and II). There was also wide variation in the tuber phenolic acids and citric acid levels among locations. In 1988, the tuber phenolic acids among locations ranged from 16.4 to 49.6 mg/100 g of fresh weight and in 1989 from 15.1 to 42.5 mg/100 g of fresh weight. The ACD score and phenolic acid levels were highly correlated for 2 years combined ($r = 0.85$, $p < 0.01$). Citric acid showed a much wider range in concentration in 1988 (76.5–712.5 mg/100 g of fresh weight) compared to 1989 (203.9–403.2 mg/100 g of fresh weight). In 1988, very high citric acid levels were found in locations where little ACD occurred compared to the levels in locations with high ACD.

Table I. ACD Score, Phenolic Acids, and Citric Acid Levels of Spartan Pearl Potatoes Grown in Seven Michigan Locations in 1988

		mg of acid/100 g of tuber fresh weight		
location	ACD[a]	phenolic acids[b] (*A*)	citric acid (*B*)	ratio *B*/*A*
1	1.2 d	16.4 d	704.5 a	43
2	1.3 cd	20.1 d	712.5 a	34
3	1.7 bcd	18.3 d	580.7 b	32
4	2.1 abc	31.3 c	560.0 b	17
5	2.3 ab	49.6 a	76.5 d	2
6	2.5 ab	31.6 c	112.5 d	4
7	2.7 a	40.3 b	175.0 c	4

[a] Means followed by the same letter are not significantly different by Duncan's multiple range test at 5% level. [b] Expressed as chlorogenic acid equivalents.

Table II. ACD Score, Phenolic Acids, and Citric Acid Levels of Spartan Pearl Potatoes Grown in Six Michigan Locations in 1989

		mg of acid/100 g of tuber fresh weight		
location	ACD[a]	phenolic acids[b] (*A*)	citric acid (*B*)	ratio *B*/*A*
1	1.1 c	15.1 e	212.6 c	14
3	1.2 c	21.3 d	316.8 b	15
6	1.2 c	16.7 e	203.9 c	12
8	1.7 b	34.4 b	403.2 a	12
4	2.1 ab	29.5 c	220.3 c	7
9	2.5 a	42.5 a	260.7 bc	6

[a] Means followed by the same letter are not significantly different by Duncan's multiple range test at 5% level. [b] Expressed as chlorogenic acid equivalents.

However, in 1989, this association was not clearly evident. Correlation between ACD and citric acid for the 2 years combined was negative but not significant ($r = -0.47$, $p > 0.1$). In both years, potatoes from locations that were susceptible to ACD clearly had lower citric/phenolic acid ratios compared to locations with little ACD. The correlation coefficient between ACD and the ratio of citric/chlorogenic acid was negative and significant ($r = -0.65$, $p < 0.05$). The differences in ACD for locations with similar levels of phenolic acids (locations 4 and 6, 1988) were likely due to differences in their citric acid levels. The low ACD scores (less than 2) for locations 1 and 3 in both years were associated with low and somewhat similar phenolic acid levels. A higher seasonal difference for ACD observed in location 6 was accompanied by a wide variation in the two organic acids.

The variation in the levels of organic acids in Spartan Pearl potatoes among locations was likely due to climatic and soil effects, and the modifying influence of agronomic practices, and agrees with reports of similar variation in other potato varieties (Kaldy and Lynch, 1983; Bushway et al., 1984). With the number of locations studied, it was not possible to establish any directional trends, such as from north to south, in the susceptibility to ACD, as was reported for the Russet Burbank variety in Alberta, Canada (Kaldy and Lynch, 1983). However, it was of interest to note that samples obtained from the east central region of Michigan (locations 1–3) produced no serious ACD in 2 consecutive years. If locations can be identified where the relative acid levels consistently favor undesirable levels of ACD, then such areas can be avoided or attempts can be made to possibly prevent or reduce ACD by treatment with safe chelating or sequestering agents before and after harvest (Greig and Smith, 1955; Smith and Muneta, 1954; Smith, 1958). Reducing the incidence of ACD in Spartan

Pearl potatoes will undoubtedly expand its adaptability and fresh market utilization in Michigan and other areas.

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