Effect of Maturity and Storage on Ascorbic Acid and Tyrosine Concentrations and Enzymatic Discoloration of Potatoes

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Ontario and Pontiac potatoes, representing cultivars susceptible and resistant to enzymatic discoloration, were examined for the effect of maturity and maturity–storage interactions on the concentrations of ascorbic acid and tyrosine. Both cultivars were harvested 7, 9, 11, 13, 15, and 17 weeks following planting and stored for 0, 4, 8, 12, and 24 weeks at 5 °C and 95% relative humidity prior to analyses. Ascorbic acid concentrations, of both cultivars increased significantly ($p < 0.05$) up to 11 weeks following planting and decreased thereafter. Following 24 weeks of storage tubers harvested at 11 weeks showed greatest decreases while those harvested at 7 weeks showed least decreases in ascorbic acid, suggesting significant maturity–storage interactions. Tyrosine decreased significantly ($p < 0.05$) up to 9 weeks following planting and increased thereafter. Following 24 weeks of storage tyrosine showed greatest increases in tubers harvested at 7 (Ontario) and 9 weeks (Pontiac). No consistent correlation between ascorbic acid and discoloration was observed. Although tyrosine was positively correlated with discoloration within a cultivar, it did not appear to be a predominant factor determining blackspot susceptibility of potatoes. The blackspot-susceptible cultivar, Ontario, had higher ascorbic acid and lower tyrosine concentrations than the resistant cultivar, Pontiac.

INTRODUCTION

The potato is one of the most widely consumed crops around the world and ranks first by weight among all vegetable crops consumed by humans in the United States (USDA, 1990). Its wide acceptance can be greatly attributed to its nutritive value as well as culinary properties. Enzymatic blackening or discoloration is an important factor detracting from the culinary acceptability of potatoes when it is present. Two important nutrients that can affect the acceptability of the potato are ascorbic acid and tyrosine. Variety, maturity, and storage conditions can greatly alter the concentrations of these compounds.

Ascorbic Acid. The potato is an important dietary source of ascorbic acid. Augustin et al. (1979) and McCay et al. (1975) have shown that cooked potatoes can contribute up to 20% of the U.S. Recommended Dietary Allowance (RDA) of this nutrient (RDA for adult males is 60 mg, and for females it is 65 mg). The Nutritional Food Survey Committee of Britain reported in 1983 that potatoes contribute up to 19.4% of the total household intake of ascorbic acid. According to Wills et al. (1984) potatoes grown in Australia provide 50–160% of the Australian daily requirement of ascorbic acid following an average consumption of 150 g per person.

Ascorbic acid can delay enzymatic discoloration in potatoes by reducing the quinones back to the corresponding phenols. However, once all of the ascorbic acid has been oxidized, the oxidation of phenols proceeds, resulting in the formation of the black pigment melanin (Matheis and Belitz, 1977).

The effect of tuber maturity on the ascorbic acid concentration of potatoes has not been studied to any great extent. Augustin et al. (1975) examined the effect of early and delayed harvests on the ascorbic acid concentration of Russet Burbank potatoes. "Normal" harvest time was considered to be 150 days following planting. Early harvests resulted in higher ascorbic acid values, while delayed harvests (those beyond 150 days following planting) resulted in lower ascorbic acid concentration. Perkins et al. (1990) found that ascorbic acid concentration was higher during prestorage than postharvest. The effect of maturity on the ascorbic acid retention during storage has not been studied.

Tyrosine. Free tyrosine is best known for its function in enzymatic discoloration. Tyrosine, a monohydroxyphenol, is enzymatically hydroxylated to 3,4-dihydroxyphenylalanine (Dopa) which is then oxidized, in the presence of oxygen, to Dopa-quinone. A series of nonenzymatic oxidation and polymerization reactions form the black pigment, melanin. Conflicting studies have been reported in the literature regarding the relationship between the tyrosine concentration and enzymatic discoloration of potatoes. While Starks et al. (1985) and Corsini et al. (1992) have shown that enzymatic discoloration is highly correlated with the tyrosine concentration of tubers, Schaller and Amberger (1974) did not find any significant correlation between the two. Mulder (1949) found that concentration of free tyrosine was partly responsible for enzymatic discoloration of potatoes. The same author also found that although *o*-dihydroxyphenols are converted by tyrosinase more easily than tyrosine is, the degree of discoloration ultimately reached the same with both compounds.

No reports were found in the literature on the effect of maturity on the tyrosine concentration of tubers. One paper by Mondy et al. (1960), for a 2-year study, reported that during 1 year total phenolic content decreased with maturity while during the other year there was no consistent trend with maturity, although potatoes in the final three harvests showed a lower total phenolic content than did those of the first three harvests. However, potatoes in the final harvests discolored more than those from early harvests.

The objective of this study was threefold: (1) to study the effect of maturity, starting at the time of tuberization,

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Table I. Effect of Harvest-Storage Interaction on the Ascorbic Acid Concentration (Milligrams per 100 g Fresh Weight) of Pontiac and Ontario Potato Tubers[a]

	weeks following planting											
	7		9		11		13		15		17	
weeks in storage	Pont[b]	Ont[c]	Pont	Ont	Pont	Ont	Pont	Ont	Pont	Ont	Pont	Ont
0	24.44	25.50	28.83	29.58	30.54	34.68	24.62	30.25	26.12	30.39	23.32	30.14
3	17.07	20.11	18.55	23.14	20.78	25.33	20.55	23.26	18.36	22.58	16.93	21.95
7	12.20	14.02	12.77	15.62	10.58	15.39	12.10	16.34	12.28	15.96	10.28	15.88
12	9.81	9.74	10.28	10.28	9.61	11.98	9.59	11.26	10.12	10.93	9.68	11.97
24	8.31	8.28	8.26	7.64	7.89	7.92	7.49	7.96	7.68	8.45	7.80	8.80

[a] Each value represents an average of 12 replicates. [b] Pontiac. [c] Ontario.

on the ascorbic acid and tyrosine concentrations of potatoes; (2) to investigate the effect of maturity-storage interactions on ascorbic acid and tyrosine concentrations of potatoes, i.e., to investigate the effect of maturity on the changes in concentrations of ascorbic acid and tyrosine during storage; and (3) to determine ascorbic acid-discoloration and tyrosine-discoloration correlations.

MATERIALS AND METHODS

Pontiac, which is resistant to discoloration, and Ontario, which is susceptible to enzymatic discoloration, grown at the Cornell Vegetable Research Farm, Ithaca, NY, were studied. A randomized block design was used with three replicates of each treatment. Nitrogen-phosphorus-potassium fertilizer (14-14-14) was banded to the soil at the rate of 168 kg/ha during planting. Seed potatoes were cut into two or three pieces with each piece containing at least three eyes and allowed to suberize at room temperature for 48 h prior to planting. Both the planting of seed potatoes and the banding of the fertilizer were performed mechanically. The tubers were harvested 7, 9, 11, 13, 15, and 17 weeks following planting and kept at room temperature for a week to allow the periderm to suberize. The tubers varied in size from 2.5 cm in diameter in the early harvests to 12.5 cm or more in diameter in the later harvests. Tubers were then washed carefully in tap water with a sponge, rinsed, air-dried, and stored in mesh bags at 5 °C and 95% relative humidity in the dark for 0, 4, 8, 12, and 24 weeks prior to analysis.

Ascorbic Acid Analysis. Ascorbic acid concentration was determined on potato tissue using the indophenol method as described by Horwitz (1970). Ascorbic acid was extracted using 1.25% oxalic acid solution. Ascorbic acid in 1% oxalic acid was the standard solution used to make the calibration curve.

Tyrosine Analysis. Tyrosine concentration was determined according to Bernhardt's modification of the Millon-Weiss method (Block and Bolling, 1951) adapted for use with potatoes by Van Middelem (1952). Trichloroacetic acid was used to precipitate the protein so that only the free tyrosine was determined.

Enzymatic Discoloration. Color (reflectance) measurements were made on potato tissue using the Hunter color difference meter as described by Mondy et al. (1967). Reflectance readings were measured 20 min following grinding. The discoloration of the two cultivars was also compared visually by bruising them in a bruising drum following removal of the periderm (Aller, 1958). The tubers were placed in a long cylindrical drum which could be turned at a particularly revolution so that the tubers completely revolved against each other and the side of the machine. Six revolutions of the drum were used since this produced slightly more bruising than would result from commercial handling.

Statistical Analysis. A completely randomized block design was utilized, and statistical significance and interactions were calculated using ANOVA (analysis of variance) as recommended by Steel and Torrie (1980).

RESULTS AND DISCUSSION

Ascorbic Acid. The concentration of ascorbic acid of both cultivars steadily and significantly ($p < 0.05$) increased from the first harvest to a maximum at the third harvest (11 weeks following planting), at which time it had increased 18% for the Ontario cultivar and 9% for

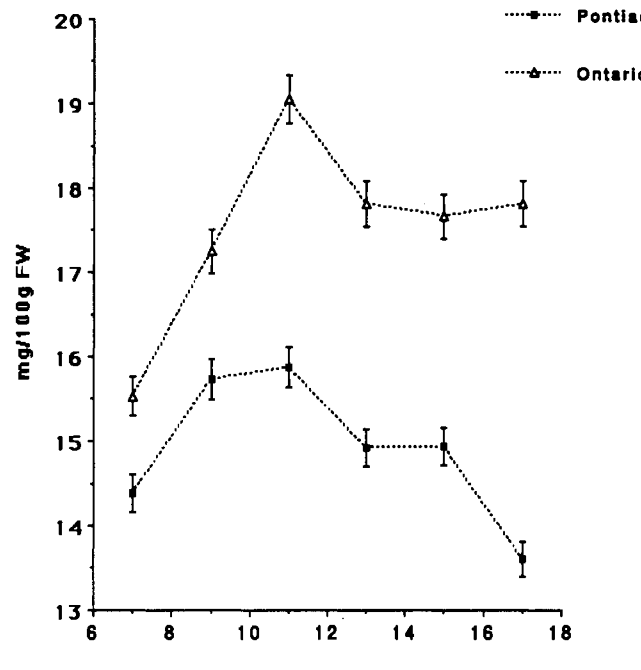

Figure 1. Effect of maturity on the ascorbic acid concentration of Pontiac and Ontario potatoes. Each data point is an average of 12 replicates.

the Pontiac cultivar (Figure 1). In the next harvest losses of approximately 6% for the Ontario cultivar and 7% for the Pontiac cultivar were observed; the ascorbic acid concentration of tubers in the final two harvests did not change significantly ($p < 0.05$) for the Ontario cultivar, but the final harvest resulted in significantly ($p < 0.05$) lower ascorbic acid concentration for the Pontiac cultivar. These results are in agreement with those of Yamaguchi et al. (1960), who found that the ascorbic acid content of tubers increased during growth and decreased during storage, and those of Shaker et al. (1978), who showed that during growth two distinct phases could be observed, the first phase showing an increase in ascorbic acid content with growth and development of tuber, followed by the second phase in which a decrease in ascorbic acid content was observed with increasing maturity.

The highly significant maturity-harvest interaction is illustrated in Table I. The concentration of ascorbic acid of the tubers in all of the harvest progressively decreased on storage but not at the same rate. All harvests of potatoes showed a similar trend in a rapid decline in ascorbic acid concentration during the first 7 weeks of storage and then a more gradual decline following this time. The potatoes in the third harvest (11 weeks following planting), which had initially contained the highest concentration of ascorbic acid, were observed to contain the lowest amount following 7 weeks of storage. Hence, differences in ascorbic acid concentrations of potatoes at different harvests observed at the beginning of the storage period became

Table II. Effect of Harvest–Storage Interaction on the Tyrosine Concentration (Milligrams per 100 g Fresh Weight) of Pontiac and Ontario Potato Tubers[a]

	weeks following planting											
	7		9		11		13		15		17	
weeks in storage	Pont[b]	Ont[c]	Pont	Ont	Pont	Ont	Pont	Ont	Pont	Ont	Pont	Ont
0	0.165	0.071	0.081	0.038	0.138	0.049	0.136	0.054	0.156	0.065	0.171	0.083
3	0.222	0.113	0.166	0.054	0.178	0.086	0.146	0.090	0.172	0.064	0.164	0.082
7	0.225	0.121	0.163	0.083	0.183	0.086	0.190	0.109	0.153	0.085	0.165	0.100
12	0.205	0.125	0.258	0.121	0.194	0.108	0.174	0.127	0.167	0.085	0.226	0.095
24	0.193	0.132	0.158	0.063	0.173	0.088	0.207	0.077	0.183	0.092	0.195	0.100

[a] Each value represents an average of 12 replicates. [b] Pontiac. [c] Ontario.

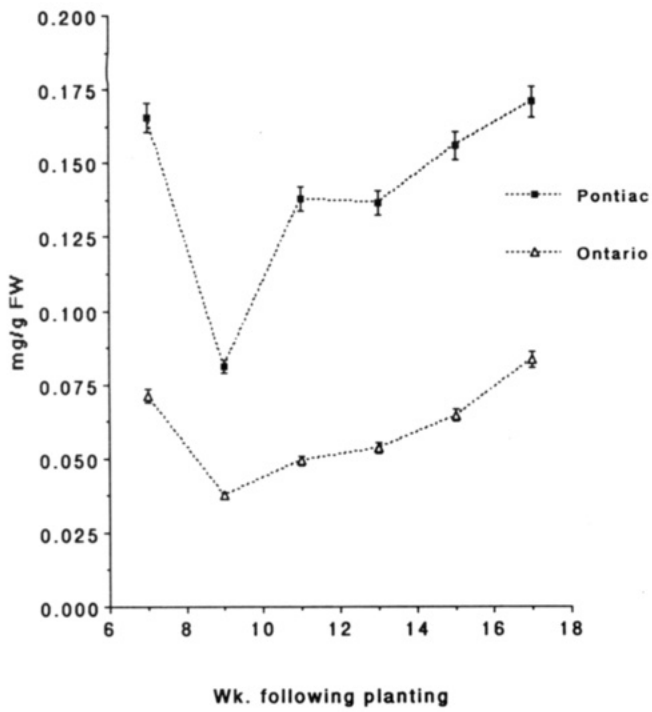

Figure 2. Effect of maturity on the tyrosine concentration of Pontiac and Ontario potatoes. Each data point is an average of 12 replicates.

significantly less following 7 weeks of storage. The big differences in tuber sizes during the different harvests would also account for the differences in ascorbic acid concentration.

Significant ($p < 0.01$) differences due to cultivar were observed. The mean ascorbic acid concentration of the Pontiac cultivar was 26 mg/100 g fresh weight (FW) and that of the Ontario cultivar was 30 mg/100 g FW, representing a difference of 15%.

Tyrosine. The tyrosine concentration decreased significantly ($p < 0.06$) from the first to the second harvest and then progressively increased in successive harvests (Figure 2). A highly significant interaction between maturity and storage was also observed (Table II). Before storage, tubers of the second harvest (9 weeks following planting) showed the lowest concentration of tyrosine initially, while the sixth harvest (17 weeks following planting) potatoes, showed the highest tyrosine concentration. The tyrosine concentration varied considerably with harvest and storage, reaching the highest level for the first three harvests following 12 weeks of storage. The final three harvests showed the greatest increases following 24 weeks of storage in most cases. The storage–maturity–cultivar interaction was also found to be highly significant.

The Pontiac cultivar was significantly ($p < 0.05$) higher in tyrosine concentration than were the Ontario cultivar at all harvests. The Pontiac cultivar was significantly ($p < 0.05$) higher in tyrosine at all storage periods than was the Ontario cultivar.

Table III. Effect of Maturity on Enzymatic Discoloration of Pontiac and Ontario Potatoes

	Rd[a]	
weeks following planting	Pontiac	Ontario
7		
9	42.5	40.7
11	34.3	36.9
13	35.2	33.9
15	31.8	35.8
17	29.8	27.3

[a] Higher reflectance (Rd) values indicate lesser discoloration and *vice versa*. Each data point is an average of two replicates of eight tubers.

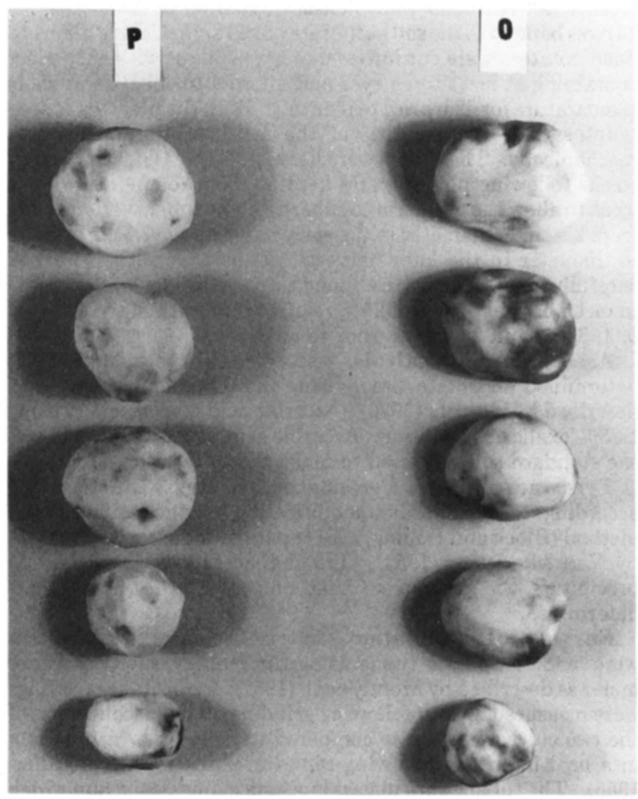

Figure 3. Discoloration of bruised Pontiac and Ontario potato tubers.

The effect of maturity on enzymatic discoloration was highly significant. Both cultivars showed greater tendency to discolor with increasing maturity (Table III). During the final harvest Ontario tubers showed the greatest tendency toward discoloration. Figure 3 clearly shows that the Ontario cultivar was more susceptible to blackspot than was the Pontiac cultivar.

Ascorbic Acid–Discoloration and Tyrosine–Discoloration Correlations. Correlations between ascorbic acid and discoloration were neither significant nor consistent (r for Pontiac = −0.704 and for Ontario = +0.071). One would not expect any correlation of enzymatic discoloration with ascorbic acid concentration because the ascorbic acid reduces the Dopa-quinone to Dopa. When the ascorbic acid is exhausted, the normal discoloration reaction would occur. The Ontario cultivar, which is susceptible to blackspot, showed highest concentrations of ascorbic acid, while the Pontiac, which is resistant to blackspot, showed the lowest. Thornton and Workman (1987) and Workman and Holm (1984) have also shown that there is no significant correlation between ascorbic acid concentration and blackspot susceptibility of potatoes. These papers, however, report the ascorbic acid concentration of tubers following bruising, and thus their method of assessment differed greatly from that reported in this paper. The tubers in our study were not bruised since ascorbic acid increases sharply immediately following bruising and decreases soon after, and this rapid change in the concentration of tuber ascorbic acid could interfere with correlation determination. Our results lend further support to the suggestion of Thornton and Workman (1987) that factors other than ascorbic acid content may determine differences in tuber susceptibility to blackspot.

Highly significant positive correlation between tyrosine and enzymatic discoloration was observed (r for Pontiac = +0.998 and for Ontario = +0.993). However, the Pontiac cultivar, which is resistant to blackspot, was significantly higher in tyrosine than was the Ontario cultivar, which is susceptible to blackspot, for all harvests and storage periods. A possible reason Pontiac is resistant to blackspot even though it has a higher tyrosine content is that the Pontiac tubers may be much more resistant to bruising than are Ontario tubers. If the potatoes are ground up, as they were in this experiment, enzyme activity is not limiting and blackening occurs with both varieties. Pontiac may discolor more because of its higher tyrosine content in the ground mixture. This observation clearly suggests that, although tyrosine participates in enzymatic discoloration, it may not be a predominant factor that influences the susceptibility of potatoes to blackspot. Earlier work of Mondy et al. (1960) showed that the phenolic content of the tuber is positively correlated with enzymatic discoloration and blackspot susceptibility.

Conclusions. Ascorbic acid and tyrosine concentrations of potatoes were significantly affected by maturity. Ascorbic acid peaked at 11 weeks following planting and decreased thereafter; tyrosine dropped after the first harvest up to 9 weeks following planting and increased thereafter. Concentrations of both ascorbic acid and tyrosine following storage were greatly dependent on the time of harvest, indicating highly significant maturity–storage interactions. These results are of great importance to the grower who has shown great interest in harvesting potatoes at various stages of maturity. Ascorbic acid concentration and enzymatic discoloration were not consistently correlated with each other even though the vitamin functions as an antioxidant in the process of discoloration. Within each cultivar tyrosine concentration and enzymatic discoloration were highly correlated. However, the blackspot susceptible cultivar, Ontario, showed lower tyrosine and higher ascorbic acid concentrations than the blackspot resistant cultivar, Pontiac.

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