Effect of Boron on Enzymatic Discoloration and Phenolic and Ascorbic Acid Contents of Potatoes

Nell I. Mondy*,† and Cyrus B. Munshi‡

Division of Nutritional Sciences, Institute of Food Science, and Institute of Comparative and Environmental Toxicology, and Department of Food Science, N231 MVR Hall, Cornell University, Ithaca, New York 14853

Boron (B)-treated and untreated Ontario potatoes were compared for enzymatic discoloration and phenolic and ascorbic acid concentration. The source of B was borax ($Na_2B_4O_7 \cdot 10H_2O$) which was sprayed on the leaves at the rate of 3.36 kg/ha at 10 and again at 13 weeks following plating of potatoes. Enzymatic discoloration was determined using the Hunter color difference meter. Ascorbic acid was determined using the indophenol method, and phenolic concentration was determined using Folin–Denis reagent. Discoloration of tubers was significantly decreased by boron application. The phenolic concentration was significantly decreased and the ascorbic acid concentration significantly increased by the application of boron foliar spray.

INTRODUCTION

Boron is an essential mineral element for all vascular plants (Lewis, 1980). It is the only element known to be required for higher plants for which there is no role in animals and humans. The functions of boron in plants are primarily extracellular and largely related to lignification and xylem differentiation.

Lee and Aronoff (1967) have proposed that the primary function of boron is based on its capacity to form stable 6-P-gluconate–borate complexes and hence restrict both the influx of substrate into the pentose–phosphate pathway and the synthesis of phenols resulting in increases in glycolysis and the synthesis of hemicellulose and other related cell wall material. Boron appears to regulate not only the flux of substrate into the pentose–phosphate cycle but also lignin biosynthesis via the formation of stable phenolic acid–borate complexes, particularly with caffeic acid. Hence, boron deficiency results in a shift toward an increase in the substrate flux into the pentose–phosphate pathway (Birnbaum et al., 1977).

Perkins and Aronoff (1956) reported the accumulation of caffeic and chlorogenic acids in boron-deficient sunflower, tomato, lettuce, and radish plants. These two compounds are the chief phenols of potatoes. Shkol-nik et al. (1981) suggested that the presence of phenolics could lead to enhanced activity of polyphenol oxidase (PPO), resulting in the formation of highly reactive intermediates such as caffeic quinone in the cell walls. The proposed role of boron in controlling phenol metabolism and lignification is presumed to be through the regulation of the pentose–phosphate pathway.

A significant proportion of the total boron content of vascular plants appears to be complexed as stable *cis*-borate esters in cell walls (Thellier et al., 1979). The boron requirement of dicotyledons is greater than that of monocotyledons. Lewis (1980) showed that monocotyledons contained higher quantities of *cis*-diol configuration in the cell walls than the dicotyledons.

Mondy et al. (1965), using three cultivars, Ontario, Katahdin, and Pontiac, found that foliar applications of boron significantly increased the lipid concentration and decreased discoloration of potatoes. Boron treatment also tended to increase the concentration of unsaturated and decrease the saturated fatty acids in the tubers. Owens (1961) found that boron applications significantly decreased the cytochrome oxidase and increased the polyphenol oxidase activities of potatoes. Firmness of tubers was also significantly increased by boron application. Mondy et al. (1967) showed that enzymatic discoloration was positively correlated with the phenolic concentration of potatoes. Corsini et al. (1992) later confirmed the findings of Mondy et al. (1967). The objective of this study was to investigate the effect of boron on enzymatic discoloration and phenolic and ascorbic acid concentration in potatoes.

MATERIALS AND METHODS

Ontario potatoes, grown at the Cornell Vegetable Research Farm at Riverhead, Long Island, were used for each of the 2 years of the study. The Ontario cultivar was used since tubers of this cultivar are susceptible to bruising and blackspot formation. Boron foliar spray (as borax, $Na_2B_4O_7 \cdot 10H_2O$) was applied twice during the growing season, at the time of tuberization and again 3 weeks later. The experimental design was a randomized block with three replicates of each treatment. Boron foliar spray was applied at the level of 3.36 kg/ha at 10 weeks and again at 13 weeks following planting. Fertilizer, N–P–K (13–13–13) 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, dusted with captan, and allowed to heal at room temperature for 48 h prior to planting. Simultaneous planting of seed potatoes and banding of the fertilizer was performed mechanically. The tubers were harvested 18 weeks following planting and kept at room temperature for a week to allow the periderm to suberize. 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 6 months prior to analysis.

The tubers (size C, 8.9–10.2-cm diameter) were cut longitudinally from bud to stem end to obtain uniform sampling from both apical and basal ends, and the slices (1–2 mm thick) were separated into the outer cortex and the inner pith sections along the vascular ring. The cortex tissue was used for determination of enzymatic discoloration, as well as phenolic and ascorbic acid concentration since it is the region highest in metabolic activity. The cortex is the region that discolors most following bruising.

Determination of Enzymatic Discoloration. Color measurements were made on potato tissue using the Hunter color difference meter as described by Mondy et al. (1967). In addition, a visual comparison of discoloration of bruised tubers was also performed. Bruising of tubers was carried out in a bruising drum.

† Division of Nutritional Sciences.
‡ Department of Food Science.

0021-8561/93/1441-0554$04.00/0

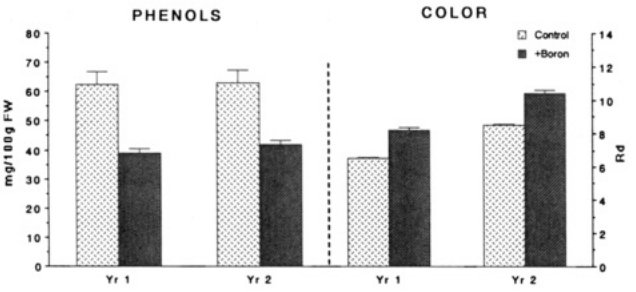

Figure 1. Effect of foliar applications of boron on the phenolic concentration and enzymatic discoloration (shown here as reflectance, Rd) of Ontario potato tubers for years 1 (Yr 1) and 2 (Yr 2) of the study. Error bars represent SD.

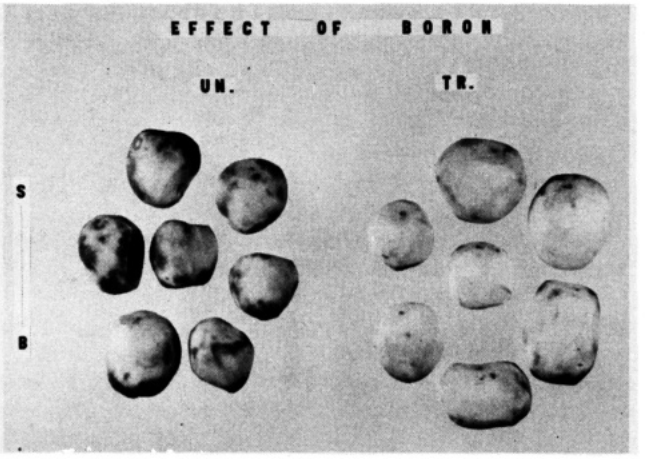

Figure 2. Effect of boron foliar spray on the discoloration of bruised Ontario potato tubers. UN., untreated; TR., boron-treated potatoes. Tubers are oriented so that the stem end (S) faces the top of the figure and the bud end (B) faces the bottom.

Determination of Total Phenolic Content. The spectrophotometric method described by Mondy et al. (1966) was employed using tannic acid as the standard.

Ascorbic Acid Analysis. The L-ascorbic acid concentration was determined on potato tissue using the indophenol method as described by Mondy and Ponnampalam (1986). Analyses were performed in triplicate.

Statistical Analysis. A completely randomized design was employed for data obtained from analysis of the samples, and statistical significance of data was determined by analysis of variance with protected LSD test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Enzymatic discoloration, as measured by reflectance, was significantly ($p < 0.01$) decreased by boron fertilization (Figure 1). Mondy et al. (1965) had reported that boron foliar spray (at the rate of 3.36 kg/ha) greatly decreased the discoloration of Ontario, Katahdin, and Pontiac potatoes. The effect of boron foliar spray on the enzymatic discoloration of bruised potatoes is compared visually in Figure 2. Potatoes from plants treated with boron showed less discoloration than the controls. A highly significant correlation ($r = 0.9$) was observed between enzymatic discoloration and phenol concentration of the tuber. This positive correlation of enzymatic discoloration and phenol concentration is in agreement with previous findings of Mondy et al. (1967) and Corsini et al. (1992).

Boron fertilization significantly ($p < 0.01$) decreased the phenolic concentration of tubers during both years of the study (Figure 1). Boron could have restricted the influx of substrate into the pentose–phosphate pathway and the synthesis of phenols (Lee and Aronoff, 1967), thereby reducing the total phenolic concentration in the tuber. These results are in agreement with those of Perkins and Aronoff (1956), who reported that phenolic concentration

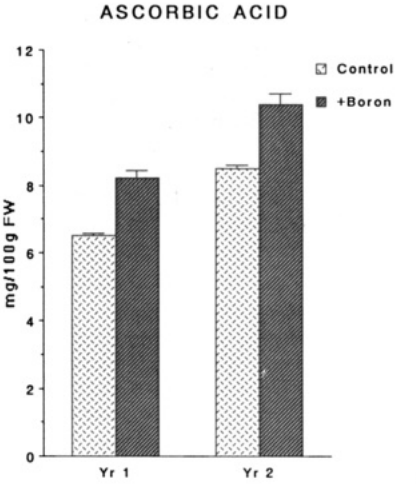

Figure 3. Effect of foliar applications of boron on the ascorbic acid concentration of Ontario potato tubers for years 1 (Yr 1) and 2 (Yr 2) of the study. Error bars represent SD.

of sunflower, tomato, lettuce, and radish plants is negatively correlated with the boron status of the plant.

Boron fertilization significantly ($p < 0.01$) increased the ascorbic acid concentration of potatoes during both years of the study (Figure 3). Govindan (1950) reported that the ascorbic acid concentration of tomatoes increased with increased boron uptake in the plant. Since boron plays an important role in the translocation of carbohydrates from leaves to other portions of the plant, greater concentrations of ascorbic acid may have been translocated to the tuber.

CONCLUSIONS

The use of boron foliar spray during the growth of potato plants significantly decreased enzymatic discoloration and phenolic concentration in the tubers. One of the chief nutrients in the potato, ascorbic acid, was also significantly increased by boron fertilization. The increase in ascorbic acid concentration due to boron fertilization also makes the tuber more nutritious, especially since the potato is known to supply up to 50% of the RDA of this vitamin. Thus, overall tuber quality was improved by boron fertilization through boron foliar spray.

LITERATURE CITED

Birnbaum, E. H.; Duggar, W. M.; Beasley, B. C. A. Interaction of boron with components of nucleic acid metabolism in cotton ovules cultured in vitro. *Plant Physiol.* **1977**, *59*, 1034.

Corsini, D. L.; Pavek, J. L.; Dean, B. Differences in free and protein-bound tyrosine among potato genotypes and the relationship to internal blackspot resistance. *Am. Potato J.* **1992**, *69*, 423.

Govindan, P. R. A note on the influence of boron on the yield and ascorbic acid content in the tomato fruit. *Curr. Sci.* **1950**, *19*, 319.

Lee, S. G.; Aronoff, S. Boron in Plants: A biochemical role. *Science* **1967**, *158*, 798.

Lewis, D. H. Boron, lignification and the origin of vascular plants—a unified hypothesis. *New Phytol.* **1980**, *84*, 209.

Mondy, N. I.; Ponnampalam, R. Potato quality as affected by source of magnesium fertilizer: Nitrogen, Minerals and Ascorbic Acid. *J. Food Sci.* **1986**, *51*, 352.

Mondy, N. I.; Bourque, A.; Breslow, B.; Mattick, L. R. The effect of boron on the lipid content and discoloration of potatoes. *J. Food Sci.* **1965**, *30*, 420.

Mondy, N. I.; Gedde-Dahl, S. B.; Owens-Mobley, E. Effect of storage temperature on the cytochrome oxidase and polyphenol oxidase activities and phenolic content of potatoes. *J. Food Sci.* **1966**, *31*, 32.

Mondy, N. I.; Owens-Mobley, E.; Gedde-Dahl, S. B. Influence of potassium fertilization on enzymatic activity, phenolic content and discoloration of potatoes. *J. Food Sci.* **1967**, *32*, 378.

Owens, E. P. The effect of storage temperature, fertilizer and discoloration inhibitors on the enzymatic activity and discoloration of potatoes. MS Thesis, Cornell University, 1961.

Perkins, H. J.; Aronoff, S. Identification of the blue fluorescent compounds in boron deficient plants. *Arch. Biochem. Biophys.* **1956**, *64*, 506.

Shkol-nik, M. Y.; Krupnikova, T. A.; Smirniv, Y. S. Activity of polyphenol oxidase and sensitivity to boron deficiency in monocots and dicots. *Sov. Plant Physiol (Engl. Transl.)* **1981**, *21*, 140.

Steel, R. G. D.; Torrie, J. H. *Principles and Procedures of Statistics*; McGraw-Hill: New York, 1980.

Thellier, M.; Duval, Y.; Demarty, M. Borate exchanges of *Lemna minor* L. as studied with the help of the enriched stable isotope and of a (n, α) nuclear reaction. *Plant Physiol.* **1979**, *63*, 283.

Received for review October 6, 1992. Revised manuscript received January 19, 1993. Accepted January 28, 1993.