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Received for review October 31, 1977. Accepted January 9, 1978. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

Influence of Nitrogen Fertilization on Potato Discoloration in Relation to Chemical Composition. 1. Lipid, Potassium, and Dry Matter Content

Nell I. Mondy* and Robert L. Koch

The effect of nitrogen fertilization on enzymatic darkening of potatoes was examined during a 2-year study. Ammonium nitrate was applied at rates of 100, 150, 200, and 250 lb/acre. Tubers were examined for susceptibility to enzymatic discoloration, lipid, potassium, and dry matter contents. Enzymatic darkening increased significantly as the level of nitrogen increased. A significant negative correlation ($r = -0.95$) was found between the degree of enzymatic discoloration and lipid content. Potassium content decreased and dry matter increased with increasing levels of nitrogen fertilization.

Heavy fertilization of potatoes is routinely done since the crop has high nutrient requirement and high gross value per acre. Although response to nitrogen fertilizers varies according to source of nitrogen, method of application, and the amount applied, increases in yields may be realized with increasing nitrogen application up to certain levels in most potato growing areas. An increase in yield, however, may not be accompanied by an increase in quality of the tuber. Early work by Van der Waal (1929), de Bruyn (1929), and Merkenschlager (1929) showed that the incidence of black spot was increased by applications of large amounts of nitrogen fertilizers. Koblet (1947, 1948) found an increase in black spot of 12 and 24% as the nitrogen rate per acre increased from 27 to 81 lb, respectively. Jacob et al. (1950) reported an increase in black spot as nitrogen increased from 50 to 100 lb/acre. de Bruyn (1929) found that high amounts of nitrogen increased the susceptibility of tubers to stem-end darkening.

The tendency of potatoes to enzymatic discoloration has been related to their lipid content (Mondy et al., 1965). These workers found that two varieties of potatoes, Pontiac and Ontario, which differed widely in their lipid content also differed in their susceptibility to discoloration. The variety most resistant to darkening had the highest lipid content. Mondy and Mueller (1977), studying potato discoloration in relation to anatomy, found that enzymatic darkening was always greater and lipid content lower in the stem than in the bud regions of the tuber. Chippewa potatoes had a greater crude lipid and phospholipid content than Katahdin potatoes and were less susceptible to enzymatic darkening. A decrease in tuber lipid content and increase in susceptibility to enzymatic darkening have been observed following the use of some chemical sprout inhibitors (Mondy and Mueller, 1977).

Potassium fertilization also exerts a significant influence on black spot. Oortwijn Botjes and Verhoeven (1927), Van der Waal (1929), and Verhoeven (1929) were among the first to show that potash reduced the amount of black spot in potatoes. Mulder (1949) observed that potassium-deficient tubers were susceptible to discoloration and that the amount of black spot could be estimated from the severity of potassium deficiency of the leaves. Scudder (1951) reported that the percentage of tubers exhibiting black spot was reduced from 63 to 40% as potassium fertilizer applications were increased from 100 to 400 lb/acre. Kunkel et al. (1965) and Mondy et al. (1967) also observed that the discoloration of potatoes decreased as potash applications were increased. Vertregt (1968) found tubers of different black spot susceptibility also differed in potassium content. Black spot incidence in Bintje and Eigenheimer potatoes was under 20% if potassium content in the tubers was over 580 mequiv/kg of dry matter (DM). Black spot was over 50% at potassium content under 500 mequiv/kg of DM.

Potassium content has been correlated with lipid levels in several types of plant tissues. Experiments with Katahdin potatoes revealed that potassium significantly increased the crude lipid and phospholipid content in both pith and cortex tissues and potassium-fertilized tubers discolored less than control tubers (Mueller, 1976). Fabian (1969) reported a similar phenomenon in sunflower plants, where he observed that phospholipid content in leaves and roots was decreased by potassium deficiency. Potassium

Division of Nutritional Sciences, Cornell University, Ithaca, New York 14853.

0021-8561/78/1426-0666$01.00/0

may also alter black spot susceptibility through its influence on tuber hydration. It is well established that potassium fertilization reduces the dry matter content of potatoes (Smith and Nash, 1940; Terman et al., 1949; Sheard and Johnston, 1958; Teich and Menzies, 1964; Kunkel et al., 1965; Chapman et al., 1970). Massey (1952) indicated that the effect of potash on black spot was indirect with potash reducing specific gravity and thus reducing black spot. A reduction in specific gravity renders the tissues less susceptible to damage by bruising due to increased hydration which increased cell turgidity.

This study was undertaken in order to determine the effect of different levels of nitrogen fertilization on tuber discoloration and to study further the interrelationships of lipid, potassium, and dry matter content on black spot susceptibility.

MATERIALS AND METHODS

Katahdin potatoes grown at the Cornell Vegetable Research Farm in Riverhead, Long Island during the 1974 and 1976 growing seasons were used in the studies. Inorganic nitrogen in the form of ammonium nitrate was banded at planting at rates of 0, 100, and 150 lb/acre in the first year and at rates of 0, 100, 150, 200, and 250 lb/acre in the second year of the study. The randomized block design contained two replicated plots per treatment. Tubers were harvested 24 weeks after planting and stored at 5 °C until analyzed. The tubers were divided into cortex (including the peel) and pith sections, and unless stated otherwise the cortex section was used since this area is the one most susceptible to discoloration.

Determination of Discoloration. Two methods were used to compare the discoloration of control tubers with tubers receiving different levels of nitrogen fertilization. (1) Color measurements were made on potato tissue using the Hunter Color Difference Meter as previously described by Mondy et al. (1967). (2) Color comparisons were made using the chloroform-disc method described previously by Mondy and Mueller (1977).

These methods correlate well with each other and compare favorably with the black spot index method of Schippers (1971).

Determination of Lipid Content. The method used for the extraction of the crude lipid from potato powder had been described earlier by Mondy et al. (1963). Duplicate analyses were made for each of the treatments. This procedure minimizes the possibility for oxidation since the fresh tissue is frozen immediately following separation into pith and cortex sections, lyophilized, and stored under nitrogen. Similar results were obtained with tissue frozen in liquid nitrogen and tissue frozen by the conventional method, so it can be assumed that relatively little oxidation occurred in the process. Crude lipid was fractionated using the method previously described by Mondy et al. (1965). Fatty acid compositon of the phospholipid portion of each sample was determined by gas chromatography in the manner described previously by Mondy and Mueller (1977). Duplicate determinations were made on each sample.

Determination of Potassium Content. The potassium content was analyzed using the photoelectric spectrometer technique described by Kenworth (1960).

Determination of Dry Matter Content. Dry matter was based on the amount of water removed from three 250-g samples of cortex tissue during 30 h of lyophilization (product shelf, +21 °C, condenser plate, −45 °C).

Statistical Analysis. The statistical significance of the lipid and dry weight data were determined using one-factor analysis of variance and the Dunnet test which compares every treatment with the control (Steel and Torrie, 1960).

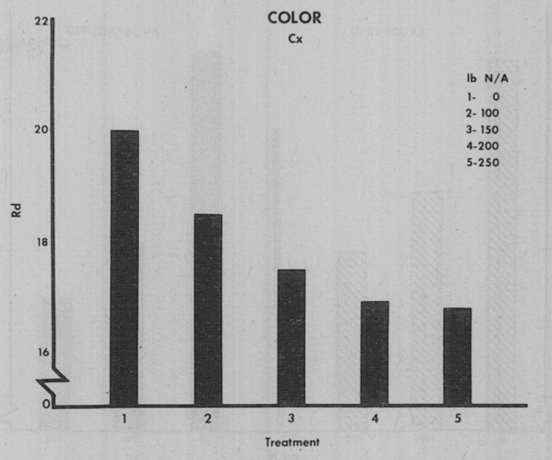

Figure 1. Effect of nitrogen fertilization on potato discoloration. R_d values decrease as blackening increases; (lb N/A) = pounds of nitrogen/acre.

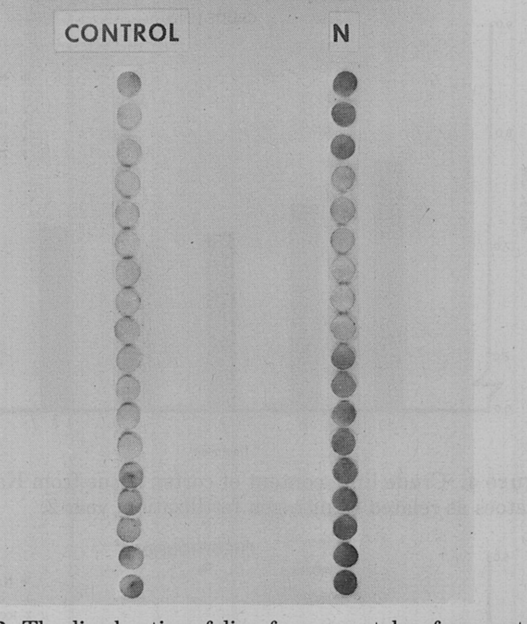

Figure 2. The discoloration of discs from cores taken from control and nitrogen-fertilized Katahdin potatoes. The discs were from tubers that had been fertilized with 200 lb of nitrogen/acre.

RESULTS AND DISCUSSION

Discoloration. Tubers from plants receiving high levels of nitrogen fertilizer discolored significantly more ($p < 0.05$) than control tubers (Figures 1 and 2). Discoloration increased with increasing levels of nitrogen. These findings are in agreement with those of Koblet (1947, 1948) and Jacob et al. (1950) who used the black spot index as a measure of discoloration.

Lipid Composition. In both years of the study, the crude lipid and phospholipid content was highest in the cortex tissue of the control tubers and was decreased significantly ($p < 0.01$) by nitrogen fertilization (Figures 3, 4, 5). In both years an inverse relationship between nitrogen level and lipid content was observed. An exception to this trend occurred in the second year with the highest level of fertilization, namely 250 lb/acre. The decrease in lipid at this level may be due to delayed tuber maturity which interfered with cellular multiplication and growth. Callihan et al. (1973) observed that heavy (600 lb/acre) nitrogen applications increased cork cell thickness in Russet Burbank potatoes. Reeve et al. (1971) reported that high (300 lb/acre) nitrogen rates reduced cell size in

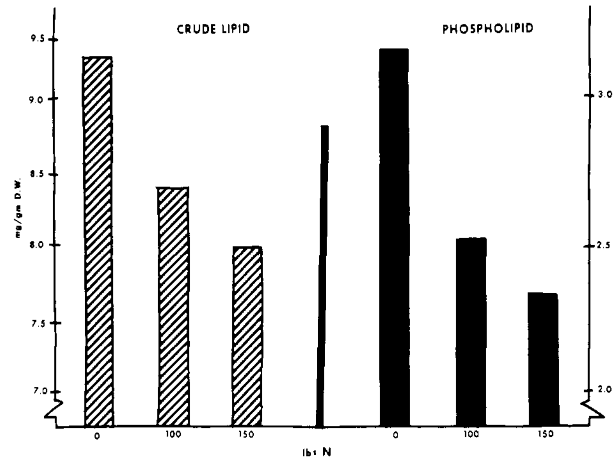

Figure 3. Crude lipid and phospholipid content of cortex tissue from Katahdin potatoes as related to nitrogen treatment; year 1.

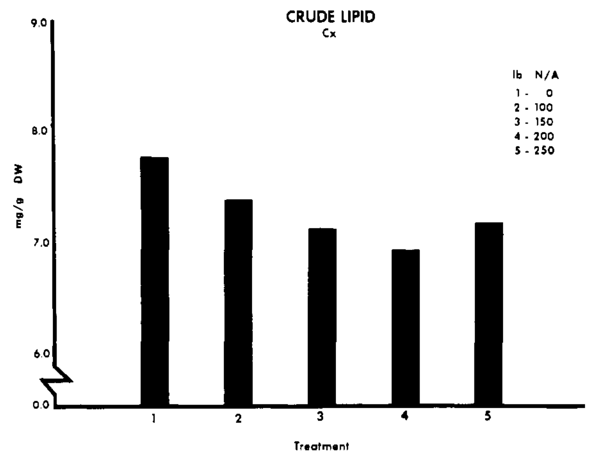

Figure 4. Crude lipid content of cortex tissue from Katahdin potatoes as related to nitrogen fertilization; year 2.

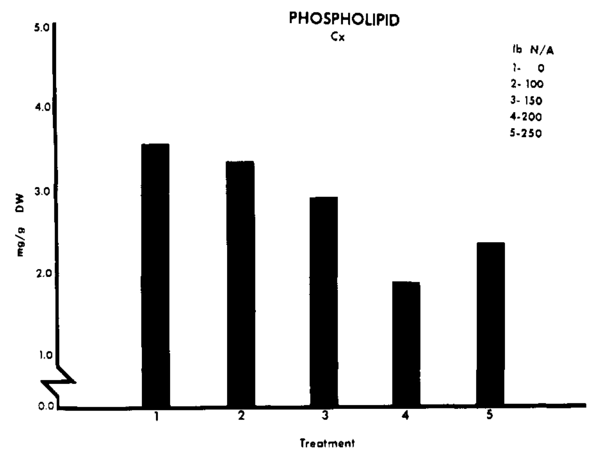

Figure 5. Phospholipid content of cortex tissue from Katahdin potatoes as related to nitrogen fertilization.

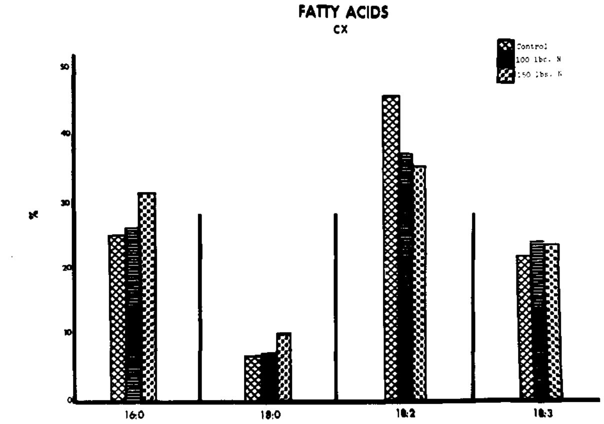

Figure 6. Major fatty acid composition of the phospholipid fraction of cortex tissue from Katahdin potatoes. The control had 0 lb of nitrogen fertilizer added; year 1.

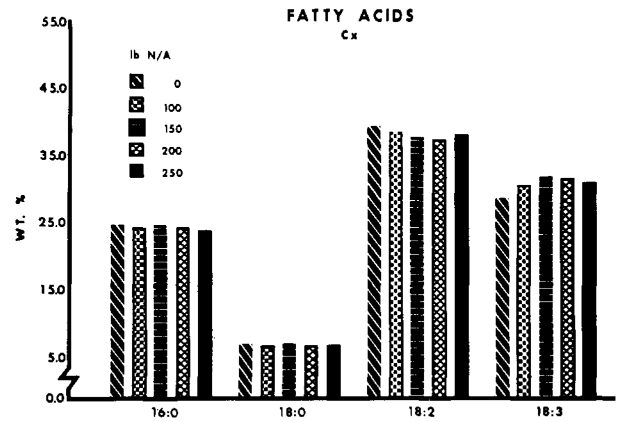

Figure 7. Major fatty acid composition of the phospholipid fraction of cortex tissue from Katahdin potatoes treated with different levels of nitrogen fertilization; year 2.

cortex and pith tissues of Russet Burbank potatoes. A reduction in cell size coupled with an increase in cell thickness would increase membrane area per unit volume. Since tuber lipids are associated with membranes, the lipid content of tubers receiving high nitrogen fertilization would be increased. The effect of nitrogen on the fatty acid composition was not consistent for the 2 years (Figures 6, 7). In the first year of the study the levels of the major saturated acids, palmitic and stearic, were significantly decreased ($p < 0.01$) and linoleic acid significantly decreased ($p < 0.01$) with nitrogen fertilization at the rate of 150 lb/acre. In the second year of the study the same trends were observed for the unsaturated fatty acids but no significant differences were found in the saturated fatty acids. Differences in climatic conditions may account for the differences observed in the 2 years.

A significant ($p < 0.05$) negative correlation ($r = -0.95$) between the lipid content and enzymatic darkening was observed in tubers receiving nitrogen fertilization. The lipid content decreased and discoloration increased as the level of nitrogen increased. These results are in agreement with those reported earlier (Mondy and Mueller, 1977; Mueller and Mondy, 1977). Although lipid accounts for a small percentage of tuber dry weight, it is an important determinant of tuber quality. Galliard (1973) found that the phospholipid fractions of the tuber were associated with the lipoprotein membrane structures of the cells. In potato tubers the cellular membranes separate phenolase substrates which are located in the vacuoles. The lipid content of potatoes is associated with the biophysical properties of cellular membranes and thereby determines cellular integrity. A reduction in lipid content could render the tuber more susceptible to enzymatic darkening since interactions between phenolic substrates and phenolase enzymes would be facilitated.

Potassium Content. The potassium content of cortex tissues decreased as nitrogen applications increased (Figure 8) except at the highest level of nitrogen application. Enzymatic darkening of cortex tissues also increased with nitrogen fertilization. These findings are in agreement with Cowie (1942) who observed that potash deficiency symptoms of potato plants were intensified by increasing

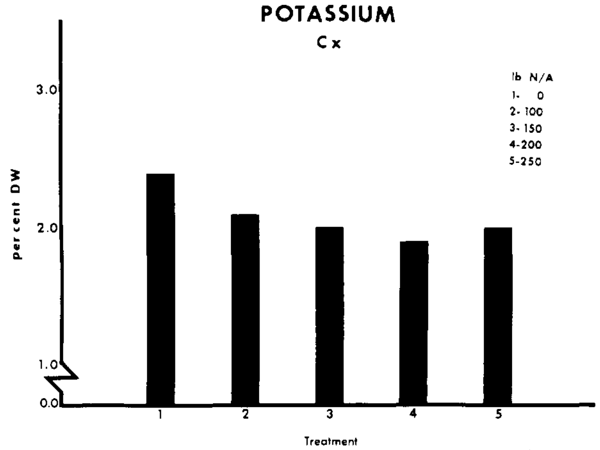

Figure 8. Potassium content of cortex tissue from Katahdin potatoes treated with different levels of nitrogen fertilizer.

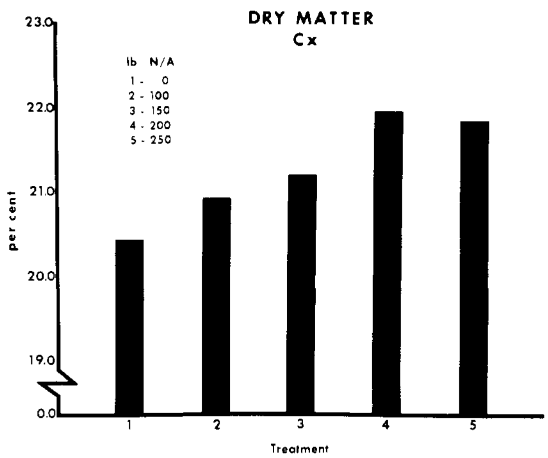

Figure 9. Dry matter content of cortex tissue from Katahdin potatoes which had been treated with different levels of nitrogen fertilizer.

nitrogen applications and Scudder (1951), Boyd and Dermott (1964), and Loginow et al. (1964) observed that as nitrogen levels increased potassium content in dry matter decreased. Potassium deficiency may have decreased tuber lipid content (Mueller 1977; Fabian 1969) which would increase enzymatic discoloration. A significant ($p < 0.01$) positive correlation ($r = 0.99$) existed between lipid and potassium contents, and the increase in enzymatic discoloration may have been due to the decrease in both of these constituents.

Dry Matter. A significant ($p < 0.01$) positive correlation ($r = 0.97$) existed between the level of nitrogen and dry matter content (Figure 9). As the dry matter content increased the potassium content decreased and a significant ($p < 0.05$) negative correlation ($r = -0.88$) was observed between these two variables. Both of these factors may have contributed to the greater enzymatic darkening observed.

Tuber hydration, as reflected by specific gravity, determines cell turgor and resulting susceptibility to bruising. Factors such as potassium deficiency which lower the water content of cells and increase the specific gravity result in greater susceptibility to black spot. Sawyer and Collins (1960) demonstrated that enzymatic discoloration in discs of tuber tissue was increased by bathing in plasmolyzing solutions which reduced cell turgor. Cotter (1956) observed a similar phenomenon in whole tubers which had been injected with water to restore turgidity. Tubers of high specific gravity were more susceptible to bruising. Kunkel and Gardner (1959) reduced the susceptibility of potatoes to black spot by allowing tubers to absorb water under vacuum and become turgid. In this experiment, nitrogen-induced potassium deficiency increased specific gravity and black spot susceptibility of cortex tissues.

From this study it appears that high levels of nitrogen fertilization are unnecessary. High levels of nitrogen fertilization for potatoes not only increases the cost of production and increases nitrate–nitrite pollution in run-off water but also decreases the quality of potatoes.

ACKNOWLEDGMENT

The authors acknowledge the assistance of G. W. Selleck and P. A. Schippers, Department of Vegetable Crops, and Robert Plaisted, Department of Plant Breeding, for arrangements made in the growing, harvesting, and transporting of the potatoes.

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Received for review September 20, 1977. Received January 11, 1978.