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Received for review November 5, 1981. Accepted April 16, 1982. The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned. This work was performed in fulfillment of the requirements for a Special Problems Class at Illinois State University, Normal, IL 61761. Presented at the Biomass Energy Symposium at the 16th Great Lakes Regional American Chemical Society, Illinois State University, Normal, IL, June 7–9, 1982.

Effect of Magnesium Fertilization on the Quality of Potatoes: Total Nitrogen, Nonprotein Nitrogen, Protein, Amino Acids, Minerals, and Firmness

Lisa B. Klein, Subhash Chandra, and Nell I. Mondy*

The effect of magnesium fertilization on total nitrogen, nonprotein nitrogen, protein content, and amino acid composition as well as firmness and mineral content of Katahdin potatoes was examined. Magnesium sulfate was applied at rates of 0, 40, and 100 lb/acre. At all levels of fertilization, total nitrogen, protein, and the summation of both free and total amino acids of tubers were increased. Nonprotein nitrogen and mineral content varied with the year of cultivation. Tubers from plants receiving magnesium fertilization were significantly firmer than controls.

Magnesium is an essential nutrient for plant growth and metabolism and is required for the translocation of sugars in potato plants (Lewin and Lewin, 1956). Magnesium sulfate fertilization has been shown to increase anaerobic respiration, decrease oxygen consumption, and increase carbon dioxide evolution (Vermes et al., 1974). The magnesium content of potato tubers was shown to increase following $MgSO_4$ application (Vermes et al., 1974). Although the phosphorus content of tubers was depressed by $MgSO_4$ fertilization, there was no observed effect on the contents of nitrogen, potassium, calcium, or magnesium (Laughlin, 1966); however, levels of fertilization were very high (250 and 500 lb/acre). The addition of magnesium to a nitrogen–phosphorus–potassium fertilizer treatment reduced the potassium and manganese contents and increased the magnesium content of snap bean leaves in two experiments, while leaf nitrogen was also reduced and leaf phosphorus increased during one of the two experiments. The magnesium content of the total plant was increased during both experiments, while total plant potassium and manganese contents were reduced during only one (Polaniyandi and Smith, 1978).

Since previous work from our laboratory has shown that the fertilization with $MgSO_4$ increased yield, reduced discoloration and phenolic content, and increased crude lipid and phospholipid content of potato tubers (Klein et al., 1981), this study was conducted in order to determine the effect of $MgSO_4$ fertilization on the contents of total nitrogen, nonprotein nitrogen, protein, amino acids, minerals, and firmness of Katahdin potato tubers.

Institute of Food Science (L.B.K.), Department of Chemistry (S.C.), and Division of Nutritional Sciences and Institute of Food Science (N.I.M.), Cornell University, Ithaca, New York 14853.

MATERIALS AND METHODS

Katahdin potatoes grown at the Cornell Vegetable Research Farm at Riverhead, Long Island, NY, during the 1978 (year 1), 1979 (year 2), and 1980 (year 3) growing seasons were used in the study. Soil type was Riverhead fine sandy loam. Magnesium sulfate was banded at planting at rates of 0, 40, and 100 lb/acre. The randomized block design contained two replicated plots per treatment. The pounds per acre of available minerals on these plots averaged as follows: magnesium, 70; phosphorus, 43.4; potassium, 219; calcium, 2240; manganese, 12.6; zinc, 2.4. The soil was not deficient in any of these minerals for potato crop (Kelly, 1981). Soil organic matter averaged 2.91%, and soil pH was 6.1. All plots were irrigated in the same manner.

Tubers were harvested 24 weeks after planting and stored at 5 °C for 5 months prior to analysis. Uniform tubers of medium size were sliced longitudinally from bud to stem and then divided into cortex (including the periderm) and pith sections, frozen, lyophilized in a Stokes freeze-dryer, ground in a Wiley mill through a 40-mesh screen, and stored under nitrogen until analyzed. Cortex tissue was used for all determinations because of its high metabolic activity.

Determination of Total Nitrogen Content. The method described in AOAC (1975) was used for total nitrogen determination. Duplicate determinations using 100 mg of freeze-dried powder were made on each treatment.

Determination of Nonprotein Nitrogen Content. Nonprotein nitrogen was determined using a modified version of the method of Desborough and Weiser (1974) as previously described by Klein et al. (1980). Duplicate determinations were made on each treatment.

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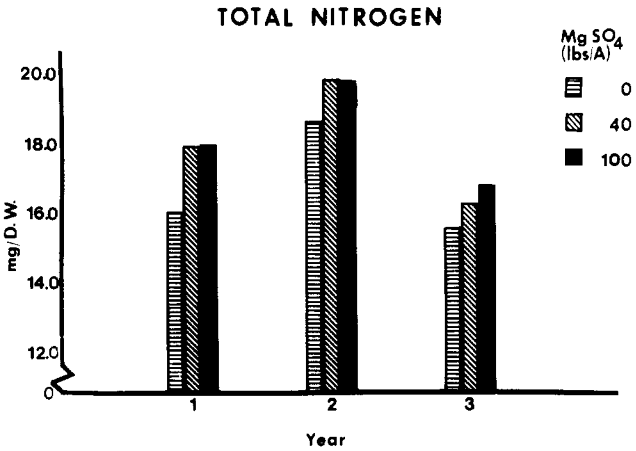

Figure 1. Effect of $MgSO_4$ application on the total nitrogen content of Katahdin potato tubers.

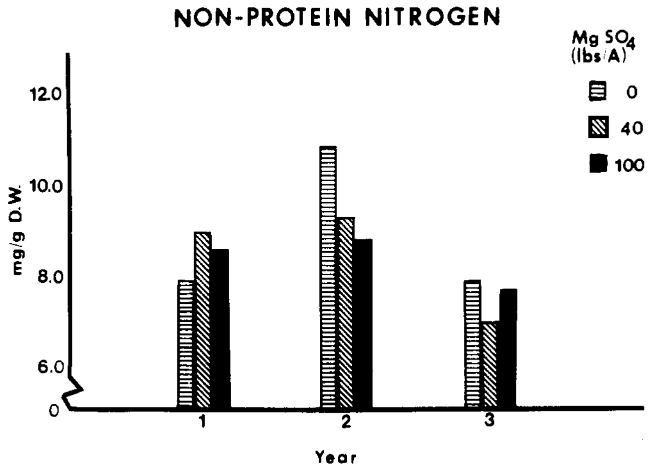

Figure 2. Effect of $MgSO_4$ application on the nonprotein nitrogen content of Katahdin potato tubers.

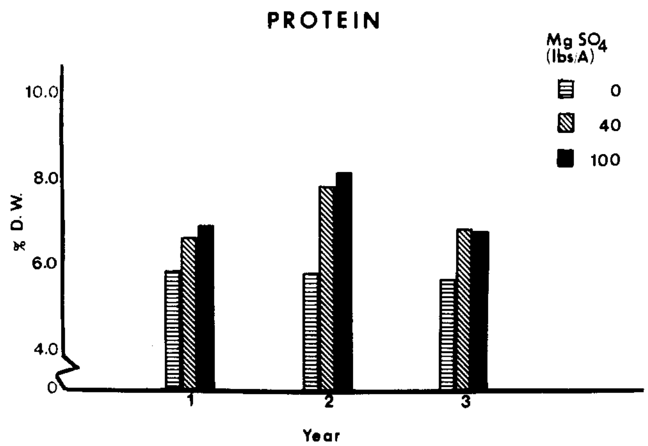

Figure 3. Effect of $MgSO_4$ application on the protein content of Katahdin potato tubers.

Determination of Protein Content. Protein nitrogen was determined by subtracting nonprotein nitrogen from total nitrogen. Percent protein was calculated by utilizing the 7.5 Kjeldahl conversion factor as indicated by Desborough and Weiser (1974).

Determination of Free Amino Acids. Free amino acids were extracted from 100 mg of freeze-dried potato powder by using 70% ethanol as described by Weaver et al. (1978). Sulfosalicylic acid (50 mg) was added to a 1-mL portion of the extract prior to centrifuging. A 50-μL aliquot was introduced into a Technicon TSM amino acid analyzer with physiological fluid columns and analyzed according to Speckman et al. (1958). Norleucine served as the internal standard.

Determination of Total Amino Acids. Total amino acids were hydrolyzed from 50 mg of freeze-dried potato powder by using 6 N HCl and an 18-h digestion in a 110 °C oil bath. The digestion mixture was evaporated to dryness, made up to 5 mL with dilute HCl buffer (0.01 M), and centrifuged. A 100-μL aliquot was analyzed as above. Because of initial results found for total nitrogen and protein content, amino acid content was determined during year 1 of the study.

Mineral Analysis. Mineral content was determined by atomic emission spectroscopy using an inductively coupled plasma system, as described by Fassel and Kniseley (1974). Duplicate determinations were made on each treatment.

Determination of Firmness. The method of Bourne and Mondy (1967) was used to determine firmness of the whole fresh potatoes by using an Instron Universal Testing machine. Ten potatoes of medium size were tested for each treatment. Because of results found for calcium and magnesium content, firmness was determined during year 3 of the study.

Statistical Analysis. Data were analyzed by using analysis of variance and the L.S.D multiple test which compares all treatments with each other (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Total Nitrogen. All levels of magnesium sulfate increased significantly ($p < 0.01$) the total nitrogen content of tubers (Figure 1). Laughlin (1966) found no effect of $MgSO_4$ fertilization on the nitrogen content of potato tubers, but levels of application were excessively high (250 and 500 lb/acre). Palaniyandi and Smith (1978) found that the addition of magnesium to an N–P–K fertilizer reduced the content of nitrogen in snap bean leaves although no effect was found for the total plants, which suggests that magnesium may have increased the total nitrogen content of the beans.

Nonprotein Nitrogen and Protein. The nonprotein nitrogen content of tubers (Figure 2) was inconsistently affected by magnesium fertilization. The inconsistency between years may be due to the variety of nitrogen-containing compounds other than free amino acids present in tubers, which may change in response to seasonal growing conditions. The protein content of tubers was increased at all levels of fertilization (Figure 3). Magnesium is required during the activation, initiation, and elongation steps of protein synthesis.

Although the protein content of the potato is only about 2% on a wet weight basis (8–10% dry weight), the nutritive value of potato protein is equal to or better than that of soybean, and on the basis of protein quality and crop and protein yields per acre, potato satisfies the protein needs of more people per acre than corn, beans, peas, or wheat (Kaldy, 1972). The potato can be regarded as a source of high-quality protein, especially in comparison with other vegetable crops, and an increase in protein content as a result of magnesium fertilization is nutritionally beneficial.

Amino Acids. The summation of free amino acids was increased by approximately 9% and 5% at the 40 and 100 lb/acre rates of application; however, individual amino acids demonstrated different trends (Table I). General increases in free amino acid content were observed for aspartic acid, asparagine, leucine, phenylalanine, and lysine. General decreases were observed for serine and methionine, while threonine, glutamic acid, glutamine, proline, glycine, alanine, valine, isoleucine, tyrosine, his-

Table I. Effect of $MgSO_4$ Fertilization on the Free Amino Acid Content (Milligrams per Gram Dry Weight) of Katahdin Potato Tubers Grown during Year 1

	$MgSO_4$, lb/acre		
amino acids	0	40	100
aspartic acid	1.92	2.20	2.40
threonine	0.32	0.34	0.32
serine	0.56	0.48	0.48
asparagine	7.21	9.41	8.31
glutamic acid	3.11	2.45	3.11
glutamine	3.27	4.00	3.01
proline	0.40	0.52	0.53
glycine	0.07	0.07	0.07
alanine	0.18	0.19	0.18
valine	1.51	1.54	1.35
methionine	0.42	0.31	0.30
isoleucine	0.56	0.56	0.55
leucine	0.31	0.36	0.34
tyrosine	0.61	0.56	0.63
phenylalanine	0.47	0.50	0.51
lysine	0.26	0.31	0.32
histidine	0.30	0.37	0.29
arginine	1.00	0.59	0.91
γ-aminobutyric acid	1.12	0.98	1.22
total	23.60	25.74	24.83
% increase		9.1	5.2

Table II. Effect of $MgSO_4$ Fertilization on the Total (Hydrolyzed) Amino Acid Content (Milligrams per Gram Dry Weight) of Katahdin Potato Tubers Grown during Year 1

	$MgSO_4$, lb/acre		
amino acids	0	40	100
aspartic acid	19.10	21.47	21.02
threonine	2.82	3.17	3.43
serine	3.53	3.97	3.82
glutamic acid	13.68	14.15	13.82
proline	2.68	3.41	3.32
glycine	2.55	2.97	3.12
alanine	2.72	3.20	3.32
valine	4.53	5.12	5.09
methionine	1.58	1.52	1.65
isoleucine	2.77	3.22	3.33
leucine	4.86	5.65	5.75
tyrosine	2.25	2.53	2.73
phenylalanine	3.11	3.79	3.51
lysine	4.54	5.43	5.46
histidine	1.65	1.91	1.97
arginine	3.79	4.49	4.35
γ-aminobutyric acid	1.90	1.65	1.67
total	78.06	87.65	87.36
% increase		12.3	11.9

tidine, arginine, and γ-aminobutyric acid showed little or no inconsistent trends.

The summation of total (hydrolyzed) amino acids of tubers was increased by approximately 12% at 40 and 100 lb/acre magnesium fertilization (Table II). General increases were observed for all amino acids except glutamic acid, methionine, and γ-aminobutyric acid, which were consistent. An increase in total amino acids is in agreement with the increases found for total nitrogen and protein following magnesium fertilization.

Minerals. There was no significant effect of magnesium fertilization on the tuber contents of potassium or phosphorus during the 3 years of study. Calcium content was significantly increased during years 1 and 3 and magnesium content during all 3 years (Table III). An increase in the magnesium content of potato tubers following $MgSO_4$ application is in agreement with the results of Vermes et al. (1974). Palaniyandi and Smith (1978) found an increase in the magnesium content of total snap bean plants during two experiments, yet the total plant potassium content was reduced in only one experiment. Laughlin (1966) found no effect of $MgSO_4$ on the potassium, calcium, or magnesium content of potato tubers, while the phosphorus content was inconsistently depressed. However, levels of fertilization were very high (250 and 500 lb/acre).

There was no significant effect of magnesium application on the tuber contents of boron or zinc during the 3 years of study, and manganese content was inconsistently affected. Cobalt and copper contents were significantly increased during years 1 and 2, and iron content was significantly increased during all 3 years (Table IV). An increase in the iron content of tubers is nutritionally im-

Table III. Effect of $MgSO_4$ Fertilization on the Macromineral Content (Percent Dry Weight) of Katahdin Potato Tubers

macro-mineral	year	$MgSO_4$, lb/acre		
		0	40	100
potassium	1	1.82	1.98 (NS)[a]	1.74 (NS)
	2	1.62	1.76 (NS)	1.68 (NS)
	3	2.43	2.30 (NS)	2.38 (NS)
phosphorus	1	0.321	0.396 (NS)	0.308 (NS)
	2	0.322	0.312 (NS)	0.332 (NS)
	3	0.301	0.293 (NS)	0.301 (NS)
calcium	1	0.025	0.045 ($p < 0.05$)	0.052 ($p < 0.05$)
	2	0.044	0.045 (NS)	0.036 (NS)
	3	0.033	0.028 (NS)	0.038 ($p < 0.05$)
magnesium	1	0.079	0.100 ($p < 0.01$)	0.077 (NS)
	2	0.106	0.118 ($p < 0.01$)	0.111 ($p < 0.01$)
	3	0.098	0.095 (NS)	0.104 ($p < 0.05$)

[a] NS = not significant.

Table IV. Effect of $MgSO_4$ Fertilization on the Micromineral Content (ppm Dry Weight) of Katahdin Potato Tubers

micro-mineral	year	$MgSO_4$, lb/acre		
		0	40	100
manganese	1	9.76	17.95 ($p < 0.01$)	13.65 ($p < 0.01$)
	2	12.70	12.45 (NS)[a]	9.67 ($p < 0.01$)
	3	14.30	11.35 (NS)	16.70 (NS)
iron	1	57.85	75.70 ($p < 0.05$)	65.90 (NS)
	2	60.95	86.65 ($p < 0.05$)	85.30 ($p < 0.05$)
	3	38.60	37.20 (NS)	64.75 ($p < 0.01$)
copper	1	10.11	14.65 ($p < 0.05$)	10.85 (NS)
	2	8.49	12.40 ($p < 0.01$)	13.05 ($p < 0.01$)
	3	13.56	14.40 (NS)	16.00 (NS)
boron	1	7.06	8.94 ($p < 0.05$)	6.79 (NS)
	2	7.96	7.59 (NS)	7.71 (NS)
	3	7.49	6.94 (NS)	7.38 (NS)
zinc	1	17.70	19.50 (NS)	13.70 (NS)
	2	13.60	38.90 ($p < 0.05$)	36.10 (NS)
	3	51.70	51.20 (NS)	52.00 (NS)
cobalt	1	0.945	1.25 ($p < 0.05$)	1.15 ($p < 0.05$)
	2	1.30	1.58 ($p < 0.05$)	1.49 ($p < 0.05$)
	3	0.648	0.537 (NS)	0.754 (NS)

[a] NS = not significant.

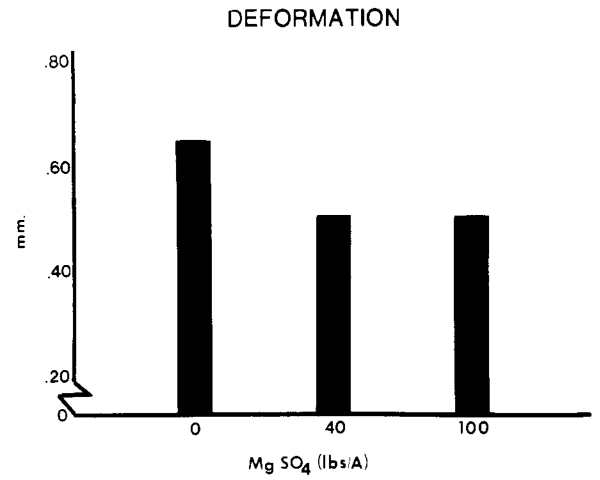

Figure 4. Effect of $MgSO_4$ application on the actual deformation (mm) of Katahdin potato tubers (year 3).

portant since iron deficiency is probably the most prevelant deficiency state affecting human populations, and it is generally higher in developing countries where the population relies heavily on vegetable foods and where infections and excessive sweating are common (Underwood, 1977).

Firmness. Magnesium fertilization resulted in tubers which exhibited significantly ($p < 0.01$) less deformation than controls in response to pressure testing (Figure 4). Firmness of fresh potatoes is important since baking and chipping quality are dependent upon it. A mealy texture of the cooked tuber is associated with the specific gravity and dry matter content of the raw potato (Smith, 1977). Since resistance of raw tuber tissue to a pressure force is significantly correlated with specific gravity and texture (Lujan and Smith, 1964), a firmer potato suggests a mealier texture and is associated with better baking and processing qualities. A firmer potato is also less susceptible to bruising and enzymatic darkening.

An elevation in the calcium and magnesium content of fertilized tubers (Table III) may be related to the firmer texture since the presence of both elements in cell walls has been associated with metal bridges between pectin molecules and a firmer texture in cooked tubers (Bartolome and Hoff, 1972).

Since fertilization with magnesium sulfate results in altered chemical composition of potato tubers, levels of fertilization should be controlled in order to produce tubers of desirable quality.

ACKNOWLEDGMENT

We acknowledge the assistance of Drs. G. W. Selleck, P. A. Schippers, and J. E. Sieczka, Department of Vegetable Crops, and Dr. Robert Plaisted, Department of Plant Breeding, for arrangements made in the growing, harvesting, and transporting of the potatoes. We acknowledge the assistance of Dr. M. C. Bourne, Department of Food Science and Technology, at Cornell University at Geneva, NY, for assistance with the determination of tuber firmness.

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Received for review October 26, 1981. Accepted April 19, 1982.

Isolation and Identification of *N*-Nitrosothiazolidine in Fried Bacon

Walter I. Kimoto,* John W. Pensabene, and Walter Fiddler

An unidentified possible nitrosamine observed in extracts from fried bacon obtained by the mineral oil distillation procedure, which elutes after *N*-nitrosopyrrolidine when analyzed by gas chromatography–thermal energy analyzer, was shown to be *N*-nitrosothiazolidine (NTHZ). This substance had the same gas chromatographic retention time and low-resolution mass spectrum as standard NTHZ. Preliminary investigations indicate that most, but not all, of it is produced artifactually as a result of analysis when residual nitrite is present prior to analysis.

During the analysis of fried bacon for volatile nitrosamines, primarily *N*-nitrosodimethylamine (NDMA) and -pyrrolidine (NPYR), by the mineral oil distillation procedure (Fine et al., 1975), an unknown peak was occasionally observed on the gas chromatography–thermal energy analyzer (GC–TEA) chromatogram. This possible new nitrosamine was brought to our attention by the Food Safety Inspection Service (FSIS). The component re-

Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Philadelphia, Pennsylvania 19118.