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ORIGINAL PAPER

EFFECT OF POTATO TUBER BIOFORTIFICATION WITH MAGNESIUM AND THE STORAGE TIME ON THE CONTENT OF NUTRIENTS*

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Abstract

The aim of this study has been to determine the relationship between the supply of potato with mineral magnesium during potato growth and the content of selected nutrients: magnesium, ascorbic acid and total protein in tubers after harvest and after storage. The vitamin C content was assayed with the Tillmans method, in line with standard PN-90/A-75101/11. The content of total protein was calculated from the content of nitrogen multiplied by 6.25, assayed with the Kjeldahl method on a Büchi Labortechnik B-324 apparatus, after mineralization in concentrated sulphuric acid (VI). The magnesium content was determined in the dry weight in potato tubers after mineralization and using atomic absorption spectrophotometry. An attempt has been made to present model determination of daily consumption of total protein, vitamin C and magnesium, assuming that the daily consumption of potato tubers equalled 300 g per capita. The data were compared with the RDA (Recommended Dietary Allowance). We have found that the content of magnesium after harvest ranged from 1.61 g kg^{-1} to 1.80 g kg^{-1} with an average of 1.69 g kg^{-1}. The content of ascorbic acid ranged from 210 to 224 mg kg^{-1} with an average of 218 mg kg^{-1} and total protein – from 9.13 to 9.91 g kg^{-1} with an average of 9.51 g kg^{-1} in fresh weight of the tubers, and they were similar to data found in the literature. The following findings can be reported: 1) the magnesium fertilisation applied during potato growth increased the content of the nutrients in tubers; 2) after 3 and 6 months of tuber storage, the content of ascorbic acid became considerably decreased, but the magnesium applied reduce the loss; 3) potato tubers had the highest nutritive value when magnesium sulphate was applied at a dose of 80 kg MgO ha^{-1}.

Keywords: fertilisation, Mg, storage, vitamin C, protein.

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INTRODUCTION

The officially accepted international definition of food provided in FAO/ WHO Codex Alimentarius is as follows: "Food means any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance which has been used in the manufacture, preparation or treatment of food, but does not include cosmetics or tobacco or substances used only as drugs" (European Food Safety Authority 2014). Food biofortification can be achieved in different ways; e.g. through the application of artificial additives to ready foodstuffs, for example preservatives. However, what seems to be a more rational approach is the implementation of agrotechnical practices in the cultivation of plants which result in an dditional supply of nutrients to enhance the quality of plant raw material for food production (Veerman et al. 2002, Martindale 2010, Bouis et al. 2011). At present, quality control of ready food product is losing its key importance, while methods which prevent the production of poor quality raw materials, from breeding to technological processes, are gaining importance (Pawelzik, Möller 2014). Potato remains to be a popular crop grown in our climate. Although the role of mineral fertilisers (N, P, K) in producing high quality table and processing potato is well known, the knowledge of the effect of Mg fertilisation is still insufficient (Rogozińska et al. 2005, Mona et al. 2012, Huber, Jones 2013, Volpe 2013, Yourtchi et al. 2013). Since magnesium as a bioelement plays an essential role in the functioning of living organisms, research has been launched into the effect of potato biofortification with this macroelement. Another justification for the research was that potato as foodstuff is easy to prepare, in addition to which it seems universal since it combines the nutritive value of cereal crops with the delicacy and chemical composition of vegetables (Hanif et al. 2006). It is also worth noting that consumer awareness of sound nutrition has increased.

The aim of the experiment has been to determine the relationship between the supply of potato with mineral magnesium during potato growth and the content of selected nutrients (total protein, ascorbic acid, magnesium in tubers after harvest and after storage). Potato tubers are consumed all year round and are therefore stored through autumn and winter (even up to 9 months). Hence, their quality after 3 and 6 months of storage has been also investigated.

MATERIAL AND METHODS

A field experiment in which cereals were the preceding crop was carried out at the Experimental Station of the Faculty of Agriculture and Biotechnology (53°13′ N, 17°52′ E) in the Kuyavia-Pomerania region of north-central

Poland, in the growing seasons of 2009, 2010 and 2011. According to the IUSS Working Group WRB (2007), the soil used in the experiment was predominantly a Luvisol (LV), with a fine sandy loam texture. The textural composition of the soil was as follows: sand fraction (74.5%), silt fraction (22.9%) and clay fraction (2.7%). The topsoil had a high content of available phosphorus (190-210 mg kg^{-1}), a medium content of potassium (105-150 mg kg^{-1}) (both determined with the Egner-Riehm method), a low content of magnesium (21.5-25.0 mg kg^{-1}) (determined with the Schatschabel method), and was slightly acidic (pH in 1M KCl 5.7). The total sulphur content (0.32 g kg^{-1}) and S-SO_4 (15.7 mg kg^{-1}) in the LV were moderate, both measured with the nephelometric method. The organic carbon content (7.55-7.80 g kg^{-1}) and total nitrogen (0.69-0.75 g kg^{-1}) in the soil were rather low. The mid-early cultivar Bila was planted mechanically at the row spacing of 0.75 × 0.35 m and the size of a single plot of 35 m^2. The potato was planted in the last ten days of April. The experiment, including three replications, was set up in a completely randomized block design, where fertiliser doses were taken as a treatment and the date of determination was considered as a block.

The experiment involved five magnesium doses: 0, 20, 40, 60, 80 and 100 kg MgO ha^{-1}, using kieserite, i.e. magnesium sulphate ($MgSO_4$, 15.7% Mg). Other mineral fertilisers were also added to the soil before planting at the following doses: nitrogen – 100 kg N ha^{-1} as ammonium nitrate (34%), phosphorus – 43.6 kg P ha^{-1} using triple superphosphate (46%) and potassium – 132,8 kg K ha^{-1} as potassium sulphate (50%).

The weather conditions (Figure 1) in 2009 and 2011 were unfavourable to the potato growth in the initial and final growth stages, whereas in 2010 the unfavourable conditions for potato growth and development ocurred during tuberization. In that year, semi-drought and drought occurred from the third week of April to mid-June, with the average total rainfall at that time being much lower than the multi-year mean. Furthermore, in 2010, the air temperature in July was much higher than the multi-year mean.

Potatoes were collected at the potato full physiological maturity, and samples (10 kg) were taken for storage from each plot. The tubers were then stored in two chambers (Thermolux Chłodnictwo Klimatyzacja, Raszyn, Polska) in the Institute of Microbiology of Food Technology of the UTP University of Science and Technology in Bydgoszcz. Each experimental storage chamber was 2 m high, 2 m wide and 3.8 m long, with milky white translucent polypropylene plates as the tank's shell material, with such advantages as being flame retardant, moisture proof and lightfast as well as providing thermal insulation. Moreover, to simulate the temperature environment and reduce heat loss, the experimental storage chamber was covered with 20 mm thick foam insulation material. The chambers are equipped with an automatic system for maintaining humidity in the storage chambers. When it dropped below 95%, the system turned on and fogged the air through the nozzles. Constant temperature and relative air humidity were then maintained for three and six months of storage, according to the requirements defined

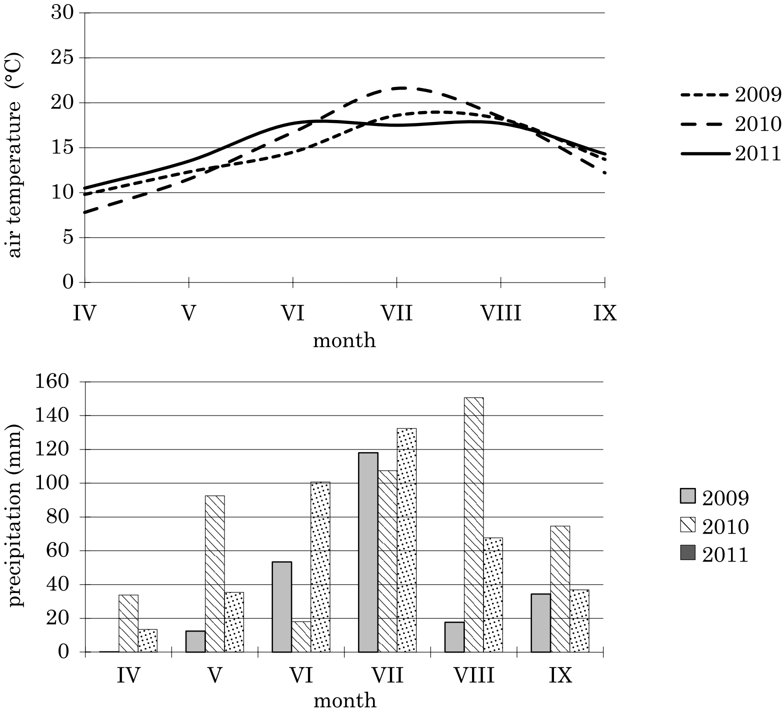

Fig. 1. Weather conditions during vegetation seasons, 2009-2011

for edible potatoes. Tubers were stored at +4°C with relative air humidity (Rh) of 95%.

The plant material was washed with distilled water and foreign substances (which included soil and dust particles) removed before tuber samples were sliced to 0.5-1.0 cm to ensure uniformity. The samples of potato tubers were freeze-dried (CHRIST ALPHA 1-4 LSC, Germany) in order to achieve constant weight. Freeze-dried samples were then ground into powder in an electric grinder (CHEMLAND, Type FW 177, Poland), and stored in sealed plastic bags at -20°C until analysis.

The vitamin C content was assayed with the Tillmans method, by titration of an adequately prepared sample with the titrant of 2.6-dichlorophenoloindophenol, in line with standard PN-90/A-75101/11; the content of total protein was calculated from the content of nitrogen multiplied by 6.25, assayed with the Kjeldahl method on a BüchiLabortechnik B-324 apparatus, after mineralization in concentrated sulphuric acid (VI). The magnesium content was determined in the dry weight in potato tubers after mineralization and using atomic absorption spectrophotometry on a VARIAN AA240FS Fast Sequential Atomic Absorption Spectrometer system USA (Ostrowska et al. 1991). Wet mineralization was carried out with sulfuric acid.

In this paper, an attempt has been made to present model determination of daily consumption of total protein, vitamin C and magnesium, assuming that the daily consumption of potato tubers equalled 300 g per capita. The data were compared with the RDA – Recommended Dietary Allowance (Institute of Medicine 2006).

The three-year research results were statistically verified by analysis of variance. The significance of differences was evaluated using the Tukey multiple confidence intervals for the significance level of $\alpha = 0.05$. The analysis of data variance was calculated using Statistica® software, and the main effects were tested by ANOVA. To determine relationships between doses of Mg and nutrients as well as between chemical compounds in tubers, Pearson's linear correlation coefficients and regression analysis equations were calculated.

RESULTS AND DISCUSSION

Considering the effect of the supply of potato with basic minerals on quality of potato tubers, special attention should be paid to magnesium (Veerman et al. 2002, Wadas et al. 2012). Magnesium takes part in plant metabolism, it is the main component of chlorophyll and the activator of most enzymes, it also plays an important role in the structure of pectin compounds, carbohydrates, the synthesis of proteins and pH stabilization (Rogozińska et al. 2005, Volpe 2013). Potato tubers contain more than 1% of mineral compounds (Rytel 2010, Wadas et al. 2012). According to Wroniak (2006), the content of magnesium in the dry weight of potato is 2 g kg^{-1}. In the present research, the content of magnesium after harvest ranged from 1.61 g kg^{-1} to 1.80 g kg^{-1} with an average of 1.69 g kg^{-1} (Table 1). Wadas et al. (2012) report on the magnesium content in the tubers of three cultivars being lower than noted in the present research, namely 1.08 g kg^{-1} for the

Table 1

The magnesium content in potato tubers (mg kg^{-1} DM) depending on magnesium fertilisation and date of study – means from 3 years of the research

Fertilisation, dose MgO (kg ha^{-1}) (B)	Date of determination (A)			Mean
	after harvest (control)	after storage		
		3 months	6 months	
0	1.62±0.001*	1.59±0.006	1.60±0.004	1.60±0.004
20	1.61±0.001	1.60±0.002	1.67±0.006	1.62±0.004
40	1.66±0.011	1.68±0.011	1.66±0.006	1.68±0.008
60	1.69±0.004	1.73±0.007	1.75±0.002	1.72±0.005
80	1.80±0.003	1.76±0.003	1.80±0.002	1.78±0.003
100	1.79±0.002	1.77±0.006	1.79±0.004	1.78±0.004
Mean	1.69±0.004	1.69±0.006	1.71±0.003	1.70±0.004
$LSD_{0.05}$ A – n.s.** B – 0.006 A×B – n.s.				

* SD (standard deviation), ** no significant

cultivar Aster and 1.07 g kg^{-1} for the cultivars Fresco and Gloria. Interestingly, the authors recorded its highest content following the application of Hydro-Complex fertiliser, which contains magnesium. In the present research into the effect of the MgO doses applied as fertiliser, the magnesium content in tubers after harvest was increasing steadily, while its significant increase, in comparison with the non-fertilised object, was recorded starting from the dose of 60 kg MgO ha^{-1}, and the highest Mg content was noted in the tubers from the plot fertilised with 80 kg MgO ha^{-1}, which is confirmed by a significant positive value of the coefficient of correlation between the dose applied and the content of total magnesium in tubers (r = 0.77) – Figure 2.

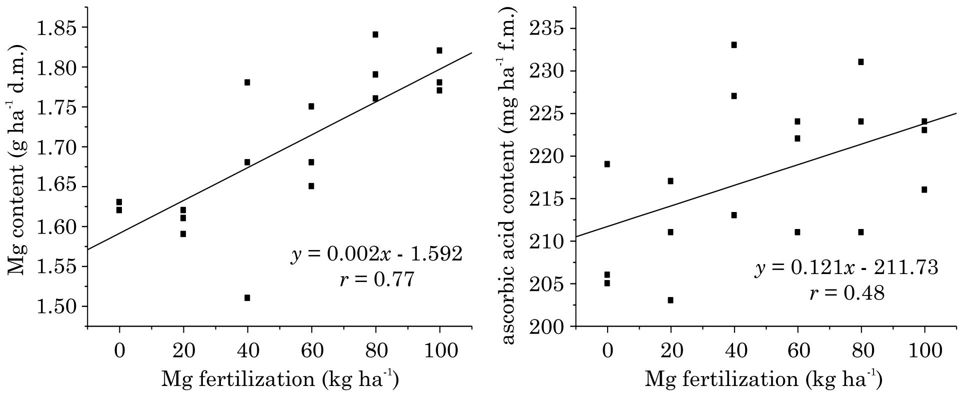

Fig. 2. Relationship between the dose of magnesium fertilization and magnesium content, ascorbic acid content in the potato tuber after harvest:
r – indicates that the correlation is significant at the 0.05 probability level

The results were verified with the linear regression analysis. The dependencies for which the value of the coefficient of determination was higher than 20% are presented in Figures 2-4. The results coincide with the data from other research, for instance by MICA, VOKAL (1993) and ROGOZIŃSKA et al. (2005), who used other potato cultivars and other MgO doses, while CIEĆKO et al. (2000) report on magnesium fertilisation against various N, P, K combinations not modifying the Mg content in potato tubers significantly. RUDZIŃSKA-MĘKAL, MIKOS-BIELAK (2001), on the other hand, claim that Mg concentration in tubers mostly depend on the length of the plant growing season; the longer the plant growing period, the higher the amount of the nutrient in tubers.

The magnesium requirements in humans are covered mostly by the consumption of plant products. Potato, due to its high share in the diet of an average consumer, is considered to be its major source (YUSUPH et al. 2003). The presence of magnesium in human diet neutralizes the acidifying effect of meat, fish and cereal products (WRONIAK 2006). Drawing on the present research results, it was calculated that the consumption of 300 g of potato introduces 114 mg of magnesium into the body, which meets 32-33% of the daily magnesium requirements (applying the dose of 80 kg MgO ha^{-1}).

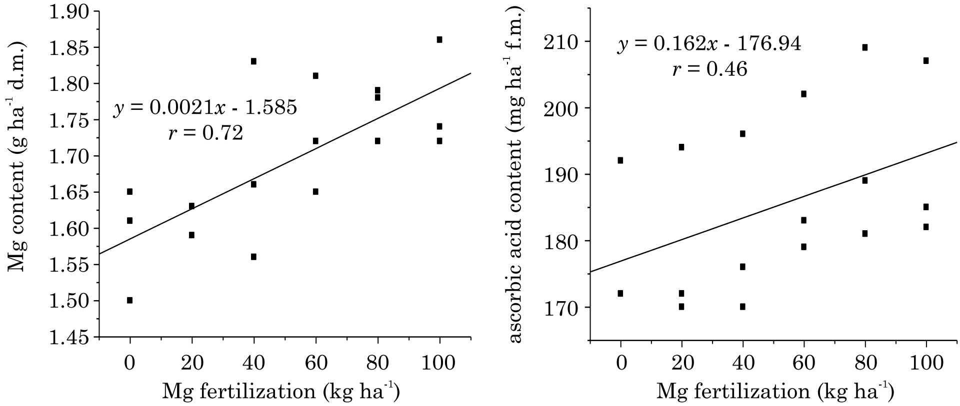

Fig. 3. Relationship between the dose of magnesium fertilization and magnesium content, ascorbic acid content in the potato tuber after 3 months storage: r – indicates that the correlation is significant at the 0.05 probability level

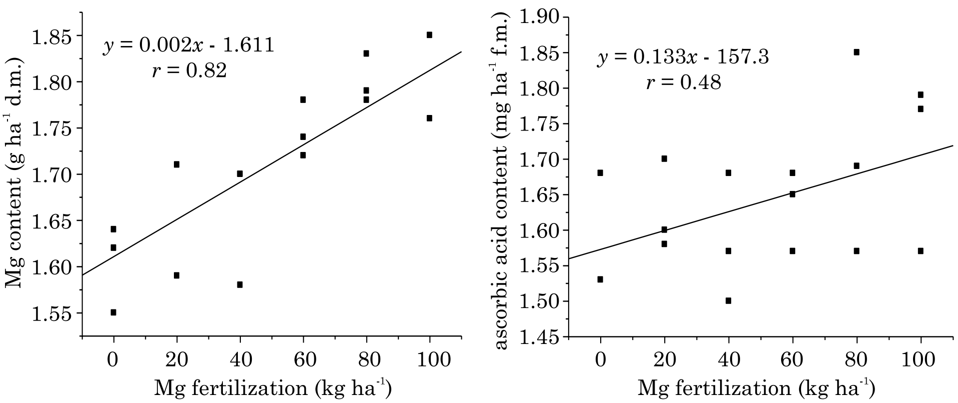

Fig. 4. Relationship between the dose of magnesium fertilization and magnesium content, ascorbic acid content in the potato tuber after 6 months storage: r – indicates that the correlation is significant at the 0.05 probability level

WIERZBICKA (2012) reports on the consumption of 300 g of potato meeting 18-21% of the daily magnesium requirements. The difference can be due to the fact that the author analysed potatoes from organic farming withou application of magnesium nutrition, hence its lower content in tubers.

The nutritive value of potato is also owed to the presence of vitamins and protein in potato flesh. It is an essential source of ascorbic acid, and provides protein of a very high biological value, slightly less good than animal protein (TIAN et al. 2016). An average concentration of ascorbic acid in potato tubers is about 200 mg kg^{-1} of fresh weight, although it changes in a wide range (from 30 to 300 mg) depending on a cultivar and the year of growing (HAN et al. 2004, TEDONE et al. 2004, PAULAUSKIENE et al. 2006, HAMOUZ et al. 2009). The content of total protein, on the other hand, is about 20 g kg^{-1} of fresh weight on average, although the amount of complete, the-so-called 'pure' protein, equivalent to animal protein, is about 1% (LACHMAN et al. 2005, WIERZBICKA 2012). In the present research, concentrations of ascorbic acid and total protein were similar to the literature data. The content of ascorbic acid ranged from 210 to 224 mg kg^{-1} with an average of 218 mg kg^{-1} and total protein varied from 9.13 to 9.91 g kg^{-1} with an average of 9.51 g kg^{-1} in fresh weight of the tubers (Tables 2-3). As a result of each of the magnesium doses applied, the content of ascorbic acid and total protein increased, although a significant increase was found from 40 kg MgO ha for ascorbic acid and from 60 kg MgO ha for total protein (Tables 2-3, Figure 2). A significantly positive effect of magnesium fertilisation on the potato tuber nutrients discussed here was confirmed by the results reported by other authors (WSZELACZYŃSKA 2001, 2004, ROGOZIŃSKA et al. 2005). Different results were recorded by CIEĆKO et al. (2010); when using magnesium fertilisation in a form of foliar application (7.5 kg Mg ha^{-1}) and when being introduced into soil (15.0 kg Mg ha^{-1}), magnesium nutrition did not have a considerable effect on the content of protein nitrogen in the potato tubers of the medium-early cultivar Zebra. WADAS et al. (2012), on the other hand, noted neither compound fertilisers containing magnesium nor magnesium sulphate itself affected the content of L-ascorbic acid in potato tubers of the cultivars Aster, Fresco and Gloria. Noteworthy is the positive correlation between the content of ascorbic acid and the content of total protein in tubers after 6 months of storage (r = 0.48) – Figure 5. The increase in the content of stable ascorbic acid offers very important enrichment of potato, popular foodstuff, with the nutrient essential for consumer health. The application of increasing magnesium doses raised the content of ascorbic acid in tubers, and this effect is confirmed by a significantly positive value (r = 0.48) of the coefficient of correlation (Figures 2, 4).

Table 2

The ascorbic acid content in potato tubers (mg kg^{-1} FM) depending on magnesium fertilisation and date of study – means from 3 years of the research

Fertilisation, dose MgO (kg ha^{-1}) (B)	Date of determination (A)			Mean
	after harvest (control)	after storage		
		3 months	6 months	
0	210.0±1.62*	178.7±1.93	158.0±1.76	182.2±2.29
20	210.3±1.64	178.7±2.11	162.7±1.51	183.9±2.81
40	224.3±1.85	180.7±2.14	158.3±1.78	187.8±2.96
60	219.0±1.67	188.0±2.04	163.3±1.54	190.1±2.45
80	222.0±1.88	193.0±2.26	170.3±1.19	195.1±2.73
100	221.0±1.45	191.3±2.17	171.0±1.08	194.4±2.82
Mean	217.8±1.61	185.2±2.19	163.9±2.07	189.0±2.93
$LSD_{0.05}$ A – 17.7 B – 5.8 A×B – 17.1				

* SD (standard deviation)

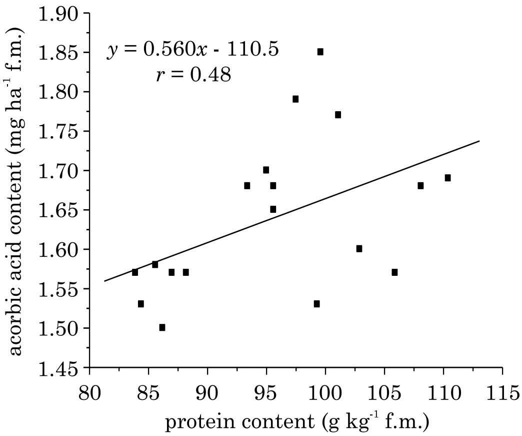

Fig. 5. Relationship between protein content and ascorbic acid content in the potato tuber after 6 months storage:
r – indicates that the correlation is significant at the 0.05 probability level

Table 3

The total protein content in potato tubers (g kg^{-1} FM) depending on magnesium fertilisation and date of study – means from 3 years of the research

Fertilisation, dose MgO (kg ha^{-1}) (B)	Date of determination (A)			Mean
	after harvest (control)	after storage		
		3 months	6 months	
0	9.13±0.52*	9.43±0.56	9.24±0.62	9.26±1.05
20	9.21±0.64	9.39±0.77	9.45±0.75	9.35±1.16
40	9.48±0.76	9.50±0.85	9.59±0.84	9.52±1.01
60	9.78±0.73	9.62±0.74	9.69±0.96	9.69±1.09
80	9.91±0.75	9.81±0.86	9.94±0.93	9.88±1.15
100	9.54±0.69	9.87±0.81	9.42±0.78	9.61±1.12
Mean	9.51±0.94	9.60±1.07	9.55±1.08	9.55±1.14
$LSD_{0.05}$ A – n.s.** B – 0.25 A×B – n.s.				

* SD (standard deviation), ** no significant

Han et al. (2004) and Hamouz et al. (2009) claim that a high content of the nutrient in the product does not mean that the product has a high share in supplying it in a food ration, as this depends on the amount of the product consumed. Since potatoes are consumed almost every day, one can assume that they have a major share in supplying the consumers with ascorbic acid and total protein. Having applied 80 kg MgO ha^{-1} (which is the dose at which tubers contained most ascorbic acid and total protein), the consumption of 300 g of potatoes meets 70% of ascorbic acid and 12% of total protein daily requirements. As provided by the OECD (2002), the share of potato in the diet meets 40% of the daily ascorbic acid require-

Table 4

The results ascorbate-nitrate* index (I_{AN}) studied in potato tubers depending on magnesium fertilisation and date of study

Fertilisation, dose MgO (kg ha^{-1})	Date of determination			Mean
	after harvest (control)	after storage		
		3 months	6 months	
0	0.59 ± 1.34	0.61 ± 0.57	0.57 ± 1.44	0.58 ± 1.60
20	0.58 ± 1.42	0.55 ± 1.39	0.59 ± 1.35	0.57 ± 1.65
40	0.65 ± 0.72	0.61 ± 0.58	0.60 ± 1.45	0.62 ± 1.75
60	0.64 ± 1.43	0.63 ± 1.49	0.65 ± 1.48	0.64 ± 1.40
80	0.70 ± 1.39	0.69 ± 1.44	0.71 ± 1.27	0.70 ± 1.36
100	0.73 ± 1.28	0.73 ± 1.23	0.74 ± 1.30	0.73 ± 1.18
Mean	0.65 ± 1.20	0.64 ± 1.34	0.64 ± 1.38	0.64 ± 1.48

* nitrate content results are included in the manuscript by Wszelaczyńska et al. (2020)

ments. According to Wroniak (2006), the consumption of 200 g of potatoes satisfies 30-50% of the daily vitamin C requirements. This author also claims that the consumption of potato tubers at the amount of 130 kg a year covers 50% of the annual requirements.

Potato tubers can be consumed at a time considerably distant from the time of harvest. During storage there are changes in potato tubers resulting from their physiological activity. Mineral substances, including magnesium and nitrogen, show high stability during storage and so they do not undergo major changes (Rogozińska et al. 2005). The present research confirms it since the magnesium and total protein content was not significantly affected by the storage time (3 and 6 months), which coincides with other reports (Wszelaczyńska 2001).

Ascorbic acid is the least stable among the nutrients investigated here. It becomes destroyed due to the effect of UV rays, high temperature, the presence of oxygen, oxidative enzymes, metal ions as well as long-term storage, which therefore causes very high losses (Wszelaczyńska 2004, Rogozińska et al. 2005, Żołnowski 2013). A high content of ascorbic acid as a natural antioxidant in potato tubers considerably eliminates the carcinogenic effect of nitrosamines, formed from nitrates (V) (Karadeniz et al. 2005, Reyes et al. 2005, Nara et al. 2006). In the present research irrespective of the experimental factors, the ascorbic acid losses after 3 months and after 6 months of storage were 13% and 24%, respectively. The longer the storage time, the greater the loss of ascorbic acid (Burgos et al. 2009, Abong et al. 2011). After 6 months of storage, Wszelaczyńska (2001, 2004) evaluated the ascorbic acid loss at 34%, and Wojdyła et al. (2007) noted as much as 41.7% of ascorbic acid lost in potato tubers. What is noteworthy is the positive correlation between increasing magnesium doses and the content of ascorbic acid in tubers after storage, both after 3 (r = 0.46) and 6 (r = 0.48) months of storage (Figures 3-4), which is due to the fact that magnesium fertilisation significantly increases the content of this element in tubers in each research period (after harvest r = 0.77, after 3 months of storage r = 0.72, and after 6 months of storage r = 0.82). Such a result is confirmed by all the authors who claim that after storage, irrespective of the storage time, the greatest amounts of magnesium and ascorbic acid were found in the tubers which accumulated the highest amounts of Mg during the growth period under the influence of applied fertilisation (Rogozińska et al. 2005). Consumption of potato tubers stored for 3 and 6 months, assuming the model-based ration, satisfies the needs of the human body relative to the dietary requirements in the following shares: about 14% of total protein, about 60% of ascorbic acid and about 32% of magnesium requirements, respectively (Table 4).

The nutritive value can also be evaluated using the ascorbate-nitrate index (IAN) (Pokluda 2006, Wadas et al. 2012). According to Lachman et al. (1997), vegetables with the index value up to 0.5 show a low nutritive value, ranging from 0.5 to 1 are neutral, and above 1 they havea high nutritive value. The less nitrates (V) and the more ascorbic acid the potato tubers contain, the higher their IAN value. In the present research. the IAN value ranged from 0.5 to 1 (Table 4). Interestingly, the magnesium fertilisation applied increased the index value. This dependence is also demonstrated after 3 and after 6 months of storage. According to Pokluda (2006) and Wadas et al. (2012), the ascorbate-nitrate index value depends significantly on a vegetable species, its cultivar and on the year of growing. The magnesium fertilisation applied, by decreasing the content of nitrates (V), nitrate content results are included in the manuscript by Wszelaczyńska et al. (2020) increased the IAN value. Opposite results were reported by Wadas et al. (2012) in an experiment where the index value was decreasing following the application of a compound fertiliser containing magnesium. The nitrate content was positively correlated with nitrogen fertilisation, while the effect on l-ascorbic acid content was relatively small. It was only at the highest N level, which led to drastic yield depressions (3.8 g N pot^{-1}), that l-ascorbic acid content was significantly reduced (Lin et al. 2005). According to Hajslová et al. (2005), the results indicated lower nitrate content and higher vitamin C content to be the parameters most consistently differentiating organically from conventionally produced potatoes.

CONCLUSIONS

1. The magnesium fertilisation applied during potato growing increased the content of the magnesium, vitamin C and total protein in tubers.

2. As a result of tuber storage for 3 and 6 months, the content of ascorbic

acid became considerably decreased but the application of magnesium as a fertiliser limited this loss.

3. Potato tubers showed the highest nutritive value when magnesium sulphate was applied at the dose of 80 kg MgO ha^{-1}.

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