THE CONTENT OF IRON AND MANGANESE IN POTATO TUBERS TREATED WITH BIOSTIMULATORS AND THEIR NUTRITIONAL VALUE

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Abstract. The aim of the study was to evaluate the content and nutritional value of iron and manganese in edible potato tubers. Field experiments were carried out in 2015-2017 with the use of biostimulators on the individual farm in Międzyrzec Podlaski, Poland. The experiment was based on the random split-plot method. The influence of two factors was examined. The first row factor included three varieties of edible potato: Honorata, Jelly, Tajfun, and the second row – five methods of using biostimulators: Kelpak SL, Titanit, GreenOk, BrunatneBio Złoto Cytokininy, potato plants sprayed with distilled water were the control object. Potato plants were treated three times with biostimulators (at the beginning of flowering, at full flowering and after plant flowering). The high amount of rainfall in 2017 contributed to the increase of iron and manganese content in potato tubers. Plant tubers treated with the BrunatneBio Złoto Cytokiny preparation were characterized by the highest content of iron and manganese in comparison to plants from the control object. Titanite reduced the content of manganese and iron in tubers. The content of micronutrients in tubers was significantly differentiated by the genotype of the variety. The highest Mn concentration was found in the Jelly tubers, Fe in the Honorata variety. The average content of manganese was 4.4 $mg{\cdot}kg^{-1}$, and iron 43.5 $mg{\cdot}kg^{-1}$, which covers the demands in 1.7 and 5.5% per day, respectively.
Keywords: *edible potato, minerals, nutritional value, bioregulators*

Introduction

Nutritionists encourage an increase in the consumption of potato (*Solanum tuberosum* L.) tubers due to low caloric value and high nutritional and dietary values. The calories cooked potato (50-90 kcal per 100 g) slightly exceeds the energy value of apples (54 kcal per 100 g) or milk (62 kcal per 100 g), it is also three times smaller than wheat bread's (275 kcal per 100 g) and seven times smaller than chcolate's (540 kcal per 100 g) (Kunachowicz et al., 2010). This plant also provides a number of valuable nutrients, such as: carbohydrates, proteins, vitamins (C, B_1, B_2, PP, B_6), minerals (K, Mg, Fe, Cu, Mn, J), dietary fibre (Lutaladio and Castaidi, 2009).

The nutritional value of potato tubers, in addition to protein, carbohydrates and vitamins, is also determined by the content of minerals that after digestion and absorption into the blood are used by the body as a building block or a factor regulating life processes (Żechałko-Czajkowska, 1992; Spiak, 2000; LAW ON food and Nutrition Safety, 2009). Potato tubers contain 1-1.2% of minerals. Minerals are those components which remain in the form of ash after burning. In order for the human body to function properly, it must receive all necessary nutrients from outside, including minerals. Microelements control enzymatic processes, the largest amount (73-79%) comes from manure (Kaniuczak et al., 2009). In modern agriculture, more and more attention is paid not only to the amount of harvested crop, but also to its quality. According to Czuba (2000), the content of micronutrients in the crop yields is

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an important agrotechnical issue, as well as an important quality feature assessed according to consumption and feed criteria. For this purpose, in addition to pesticides, a number of preparations are used as plant development regulators or biostimulators (Maciejewski et al., 2007). Biostimulators control mineral metabolism, increase the plant's resistance to stressful environmental conditions (Sawicka and Mikos-Bielak, 2002; Wierzbowska et al., 2015; Papenfus et al., 2013; Panda el al., 2012), as well as increase resistance to attacks of diseases and pests (Grzyś, 2012). Several authors have demonstrated the effect of acid pH < 5.5 on increasing the availability of manganese and iron in it (Prośba-Białczyk and Mydlarski, 2000; Rogóż, 2009). Iron participates in the process of photosynthesis and nucleic acid metabolism, stimulates the formation of chlorophyll, participates in the reduction of nitrates and the binding of free nitrogen, and regulates oxidation-reduction reactions. Manganese is involved in oxidation-reduction processes, photosynthesis, decarboxylation and binding of free nitrogen (Kabata-Pendias and Pendias, 1993; Zarzecka, 2004). The aim of the article is to examine the effect of biostimulators on the content of manganese and iron in potato tubers and to assess the nutritional value of the selected minerals.

Materials and methods

The experimental site

Potato tubers from a field experiment carried out in 2015–2017 in an individual farm in Międzyrzec Podlaski, Poland were the material for testing. The experiment was established in triplicate using the random split-plot method, on the soil included in the very good rye complex, class IVA. In individual years of research, soils differed in the content of organic matter and absorbable macro-elements. In 2015 and 2016, the soil was characterized by slightly acidic reaction, and in the last year of research, alkaline. The content of organic matter ranged from 15.0 to 18.7 g/kg. The content of absorbable phosphorus (P) was from high to very high, potassium (K) from medium to very high, and magnesium (Mg) was high. The first factor was three moderately early varieties of edible potato: Honorata, Jelly and Tajfun, and the second one, four types of biostimulators used in three dates (beginning of flowering, fully flowering and after flowering of plants):

1. Control object – without the use of biostimulators spraying with distilled water
2. Biostimulator Kelpak®SL (active substance – *Ecklonia maxima* algae extract) containing plant hormones: auxin – 11 mg/l and cytokinin – 0.031 mg·l, at a dose of 0.20 $L \cdot ha^{-1}$
3. Biostimulator Tytanit® (active substance – titanium) at a dose of 0.20 $L \cdot ha^{-1}$,
4. Biostimulator GreenOk® (active substance – humus substances 20 g/l) at a dose of 0.20 $L \cdot ha^{-1}$
5. Biostimulator BrunatneBio Złoto (active substances – plant hormones: auxin – 0.06 mg·l and cytokinin – 12 mg·l,) at a dose of 0.20 $L \cdot ha^{-1}$

The forecrop for potato in particular years of research was winter wheat. After harvesting the forecrop, a team of post-harvest crops was made. In autumn, each year preceding planting, natural fertilization in the form of manure in the amount of 25.0 $t \cdot ha^{-1}$ and mineral fertilization with phosphorus-potassium in the amount of P – 44.0 (100 $P_2O_5 \cdot 0.44$) kg/ha (lubofos for potatoes 7%) and K – 124.5 (150 $K_2O \cdot 0.83$)

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kg·ha^{-1} (lubofos for potatoes 25%) was applied. These fertilizers were plowed pre-season plowing. Nitrogen fertilizers were sown in the spring in an amount of N 100 kg/ha (nitro-chalk 27%) and mixed with the soil using a cultivator. Potatoes were planted manually under the marker at a spacing of 67.5 × 37 cm, in the third decade of April (2015, 2016, 2017). Each plot consisted of five ridges. Cultivation and care treatments were carried out in accordance with the requirements of correct agrotechnics and methodological assumptions of the experiment. Prior to harvest, random samples of tubers were collected from each plot and used for chemical analysis and assessment of consumption-related characteristics of the tubers.

Chemical analysis methods

Weight of about 0.2–0.3 g of sample was transferred to the PTFE vessel and HNO_3 and HCL was added, 3:1 respectively. The vessels were placed in the rotor and loaded to the microwave. The following digestion program has been used:

Step 1 – 10’ at 350 W

Step 2 – 35’ at 650 W

Step 3 – cooling and ventilation

Mineralized samples were transferred to the 50 ml flasks through filtering paper and diluted with ultra-pure water.

Samples were examined with SpectroBlue ICP OES spectrometer at the Regional Research Center for Environment, Agricultural and Innovative Technologies, Pope John II State School of Higher Education in Biała Podlaska. Analytical curves were built by diluting Bernd Kraft Der Standard Spectro Genesis ICAL Solutions and VHG SM68-1-500 Element Multi Standard 1 in 5% HNO_3. Operating parameters for ICP OES instrument: coolant flow: 12 l/min; auxiliary flow: 0.90 l/min; nebulizer flow: 0.78 l/min; pump speed: 30 Rpm; number of measurements: 3.

Meteorological conditions

The weather conditions in the potato growing years were shown by precipitation sums and average air temperatures in *Table 1*.

***Table 1**. Weather conditions during of potato vegetation*

Years	**Months**						**April-September**
	April	**May**	**June**	**July**	**August**	**September**	
Air temperature (°C)							
2015	8.2	12.3	16.5	18.7	21.0	14.5	15.2
2016	9.1	15.1	18.4	19.1	18.0	14.9	15.8
2017	6.9	13.9	17.8	16.9	18.4	13.9	14.6
Multiyear mean 1996-2010	8.0	13.5	17.0	19.7	18.5	13.5	15.0
Rainfall (mm)							
2015	30.0	100.2	43.3	62.6	11.9	47.1	295.1
2016	28.7	54.8	36.9	35.2	31.7	13.6	200.9
2017	59.6	49.5	57.9	23.6	54.7	80.1	325.4
Multiyear sum (1996-2010)	33.6	58.3	59.6	57.5	59.9	42.3	335.4

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The growing season of 2015 proved to be an average air temperature of 15.2 °C, 0.2 °C higher than the long-term average and precipitation at 295.1 mm. The highest average air temperature was recorded in 2016 and amounted to 15.8 °C, it was higher than the long-term average by 0.8 °C, while this year was characterized by the lowest amount of precipitation – 200.9 mm, lower by 134.5 mm from the long-term sum. The highest number of rainfall was recorded in the growing season of 2017 – 325.4 mm and the lowest average air temperature -14.6 °C (*Table 1*).

Statistical analysis

Results of the study were analysed by ANOVA. Significance of sources of variation was checked with the Fisher-Snedecor test and the significance of differences between means was tested using the multiple comparison Tukey's test at the significance level of P = 0.05. Statistical calculations were performed in Excel using the authors' own algorithm based on the split-plot mathematical model.

Results and discussion

The average iron content in tubers was 43.5 $mg \cdot kg^{-1}$ d.m., ranging from 41.5 to 46.4 $mg \cdot kg^{-1}$ (*Table 2*). The research shows that the genetic factor had a significant effect on the iron content in potato tubers. The variety that contained the most of this ingredient was the Honorata variety, followed by Tajfun and Jelly. The influence of varietal properties on iron content is emphasized by Leszczyński and Lisińska (1986), Mikos-Bielak and Sawicka (1992), Gąsior (1996), as well as Sawicka (1996). Among the biostimulators used in the experiment, only the BrunatneBio Złoto biostimulator significantly increased the iron content in the tubers of the tested varieties. The factor that also significantly modified the content of the analysed component were the hydrothermal conditions prevailing during the years of research. High content of iron was found in tubers harvested in 2017 in which the sum of rainfall was 124 and 30 mm than in 2016 and 2015, respectively (*Table 1*). The problems of biostimulators on mineral content in potato tubers were investigated by Wierzbowska et al. (2015). When analysing the effect of Asahi SL, Bio-Algeen S90 and Kelpak SL biostimulators, the authors showed that the iron content in tubers was significantly modified only by the Kelpak SL biostimulator. The opposite direction of changes in iron content was observed by the authors in relation to the Bio-Algeen S90 biostimulator. In the light of the presented research, it should be stated that the iron content in tubers depends on the type of biostimulator and the mechanism of its impact on plants and on hydrothermal conditions. The large amount of rainfall caused that the potato tubers accumulated twice as much iron as in the remaining years. Lombardo et al. (2014) and Griffiths et al. (2012) found that the "mineral profile" can be influenced by the cultivation system. Lipiński et al. (2006) in their research proved that higher soil pH and higher humus content causes iron reduction. Iron affects the proper functioning of the circulatory system, participates in the synthesis of haemoglobin and in the oxidation and delivery of oxygen to tissues (Błoniarz et al., 2005). It is part of cytochrome oxidase, peroxidase and catalase enzymes (Jędrzejczak, 2004). The iron content in potato tubers treated with biostimulators was on average 43.5 $mg \cdot kg^{-1}$ d.m., and the daily norm of this element is 8 mg according to the recommendations of the Academy of Food Science and Nutrition in the USA (Wierzbicka, 2012). Consumption of 100 grams of potatoes covers the daily demand

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for iron in approx. 5.5% of the daily requirement (*Table 3*). The established iron content in potato tubers corresponds to the research of: Prośba-Białczyk and Mydlarski (2000), Rogóż and Trąbczyńska (2009), Sawicka and Mikos-Bielak (2008), Różyło and Pałys (2006), Wierzbicka (2012), Wierzbicka and Trawczyński (2011) and Wierzbowska et al. (2015), who fund iron content in potato tubers from 26.9 mg·kg^{-1} - 91.85 mg·kg^{-1} d.m., while Kabata-Pendias and Pendias (1993) considered 21-58 mg·kg^{-1} of dry matter as the optimal content, while Ostrowska et al. (1991) estimate that the content of this element in potato is 93-188 mg·kg^{-1} of dry matter. The correct ratio of iron to manganese in feeds is assumed to be 2.5:1 (Rogóż, 2009). If it is larger, manganese deficiency is likely (Wierzbicka, 2012; Wierzbowska et al., 2015). In the tests carried out, the ratio was 10:1, which indicates a deficiency of manganese. The content of manganese in tubers treated with biostimulators was on average 4.4 mg·kg^{-1} d.m., which with demand of 1.8-2.3 (Wierzbicka, 2012) per 100 g of tubers realizes the demand for this component in the range of about 1.7% (*Table 3*). The studies carried out show that varietal features were the dominant factor that influenced the formation of manganese content in potato tubers (*Table 4*). The variety that contained the most of this ingredient was the Jelly variety. The observed interaction between the varieties and the years proves the individual reaction of the varieties to the weather conditions in the research years. The highest average manganese content was obtained in the Jelly and Tajfun varieties in 2017 (with the highest rainfall total). Tubers originating from objects treated with biostimulators in relation to the control object were characterized by a significantly higher content of manganese. The content of manganese in tubers was significantly modified by the BrunatneBio Złoto biostimulator. The applied biostimulator reacted to the atmospheric conditions in the years of research as indicated by the object x years interaction. The BrunatneBio Złoto biostimulator caused a significant increase in manganese content in 2017, which turned out to be wet and cold. The level of manganese content in potato tubers in the conducted experiment coincides with that given by other authors – 3.6-15 mg·kg^{-1} of dry mass (Kabata-Pendias and Pendias 1993; Sawicka, 1996; Sykut et al., 1998). In the studies by Mikos-Bielak (1999), the upper limit of the range was exceeded twice, and in Kucharzewski et al. (2002) almost ten times. The Mn concentration of approx. 500 mg·kg^{-1} of dry mass is toxic for most plants (Kucharzewski and Dębowski, 2001). It should be emphasized that Fe and Mn accumulate mainly in the outer layer of the potato tuber, so their excess can be removed by peeling (Mikos-Bielak, 1999). In the research conducted by Wierzbicka and Trawczyński (2011), the average contents of micro-elemenys in the tubers of organic potatoes were equal to: Fe-46.9; Mn-7.3 mg·kg^{-1} d.m. The spatial distribution of minerals in potato tubers is not even (Subramanian et al., 2011; Petryk and Bedla, 2010; Srek et al., 2012). According to Zarzecka (2004), some herbicides cause an increase in manganese in potato tubers. Kaniuczak et al. (2009) found in their research that liming reduces the content of manganese, and mineral fertilization increases the content of Mn in potato tubers. Manganese performs important functions in the plant. It takes part in the process of photosynthesis, the transformation of nitrogen compounds in the plant and in the biosynthesis of vitamin C (Jędrzejczak, 2004). It influences the uptake of phosphorus and iron from the soil. Manganese deficiency in potato delays plant development. In humans, it is responsible for the absorption of vitamins, the formation of connective tissue and bones, metabolism of carbohydrates, lipids and normal brain function (Wierzbicka, 2012).

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Table 2. *Content of iron in tubers of potatoes depending on the biostimulator used*

Objects	Cultivars			Years			Mean
	Honorata	Jelly	Tajfun	2015	2016	2017	
1. Control object	44.6	42.9	44.1	42.5	43.5	45.6	43.9
2. Kelpak SL	43.2	42.0	43.5	41.9	43.5	43.5	43.0
3. Tytanit	42.8	42.1	43.1	41.5	43.1	43.1	42.6
4. GreenOk	44.8	42.4	43.7	42.1	43.5	45.3	43.6
5. BrunatneBio Złoto	45.6	43.5	43.7	43.1	44.3	46.4	44.6
Mean	44.2	42.6	43.6	42.2	43.6	44.8	43.5

$LSD_{0.05}$ for: cultivars – 0.63; objects – 0.31; years – 0.63; interaction: objects x years – 0.54; cultivars x years – 1.1; cultivars x objects – 0.46; cultivars x objects x years – 0.8

Table 3. *Mean daily intake of iron and manganese with diet*

Component	Range in dry matter mean ($mg \cdot kg^{-1}$)	Mean ($mg \cdot kg^{-1}$)	Dietary reference intake/day[1]	Percent of realization	
				Women	Men
Iron (Fe)	41.5-46.4	43.5	8 (mg)	5.5	5.5
Manganese (Mn)	3.5-5.0	4.4	1.8-2.3 (mg)	1.7	2.2

[1]By National Academy of Sciences Food and Nutrition Board USA (Jarosz, 2012)

Table 4. *Content of manganese in tubers of potatoes depending on the biostimulator used*

Objects	Cultivars			Years			Mean
	Honorata	Jelly	Tajfun	2015	2016	2017	
1. Control object	4.4	4.7	4.5	4.2	4.5	4.9	4.5
2. Kelpak SL	4.2	4.4	3.5	3.6	3.8	4.7	4.0
3. Tytanit	4.2	4.5	4.5	4.1	4.2	4.9	4.4
4. GreenOk	4.1	4.5	4.4	4.0	4.2	4.7	4.3
5. BrunatneBio Złoto	4.6	4.8	4.8	4.5	4.7	5.0	4.7
Mean	4.3	4.6	4.3	4.1	4.3	4.8	4.4

$LSD_{0.05}$ for: cultivars – 0.33; objects – 0.43; years – 0.33; interaction: objects x years – 0.75; cultivars x years – 0.58; cultivars x objects – 0.64; cultivars x objects x years – 1.11

Conclusions

The content of iron and manganese in potato tubers was significantly differentiated by the genotype of the variety. The highest concentration of Mn was found in the Jelly variety tubers, and of iron in the Honorata variety tubers. Tubers of plants treated with the BrunatneBio Złoto Cytokiny preparation were characterized by the highest content of iron and manganese. Weather conditions, particularly the high amount of rainfall in 2017, contributed to the increase of iron and manganese in potato tubers.

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