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ORIGINAL PAPER

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THE INFLUENCE OF BIOSTIMULANTS ON THE MICROELEMENT CONTENT OF TUBERS IN SELECTED POTATO CULTIVARS

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ABSTRACT

The aim of this study was to determine the influence of biostimulants on the content of selected microelements in the skin and flesh of potato tubers. Five potato cultivars were grown: Irga, Satina (with cream- and yellow-colored flesh), Valfi, Blaue St. Galler (with purple-colored flesh) and Highland Burgundy Red - HB Red (with red-colored flesh). Potatoes were treated with the following biostimulants: Asahi SL, Bio-Algeen S 90, Kelpak SL and Trifender WP. Control plants were not treated with biostimulants. Samples of potato tubers were analyzed immediately after the harvest and after 5 months of storage (4°C). The highest content of micronutrients in the skin and flesh of potato tubers was determined at harvest in the driest 2015 year. In all years of the experiment, micronutrient concentrations were lower in the flesh than in the skin of potato tubers, and the greatest differences were noted in the content of Fe. The concentrations of Zn, Mn and Fe in the skin and flesh of potato tubers increased as a response to the Bio-Algeen S 90 biostimulant, and the content of Fe was also higher in the skin of potatoes treated with Kelpak SL. In general, the skin and flesh of potatoes cvs. Valfi, Blaue St. Galler and HB Red were more abundant in microelements than cvs. Irga and Satina potatoes. Content of Zn and Mn increased and the content of Cu and Fe decreased (excluding the first year of the study) in the skin and flesh of stored potatoes. The skin and flesh of stored potato tubers treated with biostimulants were characterized by Mn concentrations that were higher or similar to those recorded in the control treatment (excluding the skin of potatoes treated with Bio-Algeen S 90) and a smaller decrease in Cu content.

Key words: potato cultivars, growth regulators, skin and flesh, micronutrients

INTRODUCTION

Growing demand for food will require an increase in crop production. Potato is a staple crop in many countries around the world [Ezekiel et al. 2013]. In Poland, annual potato consumption is estimated at 100 kg per capita [GUS 2016], and the demand for potato products continues to increase [Luis et al. 2011, Dzwonkowski et al. 2014]. A total of 103 potato cultivars have been registered in Poland, including 77 edible cultivars (38 local and 39 foreign) and 26 cultivars for industrial processing (23 local and 3 foreign) [Polish National List of Agricultural Plant Varieties 2017]. Cultivars with red- or purple-colored flesh contain two to three times more antioxidants (phenolic compounds and anthocyanins) than cream-

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colored cultivars, and their popularity continues to increase [Friedman and Levin 2009, Hamouz et al. 2010]. Antioxidants play an important role in the prevention of cancer and other chronic diseases [Love and Pavek 2008, Stushnoff et al. 2008].

The health status [Sławiak et al. 2009, Gachango et al. 2012] and chemical composition of potato tubers determine the quality of the final product. Potatoes are an abundant source of protein, carbohydrates, fiber, antioxidants (vitamins, phenolic compounds) and minerals. Potatoes contain 0.5−2% minerals, including iron, copper, manganese, zinc, boron and others [Leszczyński 2012, Żołnowski 2013]. Two hundred grams of potatoes provide 100% of the recommended daily intake of molybdenum, 20% of iodine, 50% of chromium, 20% of selenium, 15% of fluoride, 15% of magnesium, 15% of iron, 12% of copper and 12% of phosphorus [Bethke and Jansky 2008]. Micronutrients promote the maintenance of the acid-base balance, electrolyte balance and fluid balance in the body; they control carbohydrate, protein and lipid metabolism; they participate in cholesterol metabolism, synthesis of hemoglobin and erythrocytes, and in other processes [Soetan et al. 2010].

Micronutrients play vital roles in physiological and biochemical processes in plants. Copper regulates photosynthesis and respiration; Zn is responsible for the metabolism of carbohydrates, proteins and phosphorus compounds; Mn is involved in oxidation and reduction processes, and photosynthesis [Leszczyński 2012]. Microelements also participate in the induction of defense responses against pathogens. Magnesium is involved in the synthesis of lignin and suberin [Hammerschmidt and Nicholson 2000]; Zn protects cell membranes against oxidative stress [Cakmak 2000]; Cu is responsible for the lignification of cell walls and the accumulation of phenolic compounds [Evans et al. 2007, Stangoulis and Graham 2007]. The micronutrient content of potato tubers is influenced by weather conditions [Medyńska et al. 2009], genetic factors [Gugała et al. 2016], cultivation system and crop protection agents [Kaniuczak et al. 2009, Griffiths et al. 2012, Lombardo et al. 2014, Gugała et al. 2016]. In modern potato production systems, both artificial and natural substances, such as algae, are used to promote the growth and development of potato plants. Natural growth promoters have a varied composition (polysaccharides, microelements and plant growth hormones), and they can exert different effects on plants. They can induce resistance to stress [Khan et al. 2009, Craigie 2011, González et al. 2013] and improve crop performance by enhancing the root development and the uptake and transfer of nutrients [Abdel-Raouf et al. 2012, Sharma et al. 2014].

The aim of this study was to determine the influence of biostimulants on the microelement content of the skin and flesh of tubers in selected potato cultivars.

MATERIALS AND METHODS

The micro-plot field experiment was performed in the Agricultural Experiment Station in Tomaszkowo near Olsztyn (53°41'N, 20°24'E) in 2013−2015. The station is operated by the University of Warmia and Mazury in Olsztyn. The experiment was conducted on podzolic soil with the granulometric composition of light loam (suitability complex 4 and quality class IIIb /WRB 2014/). Soil parameters were determined before the experiment: pH 4.04−4.54 in 1 M KCl; available minerals: (mg·kg^{-1} soil): P – 85.6–111.8 (PN-R-04023:1996), K – 104.2–204.2 (PN-R-04022:1996/Az1:2002), Mg – 38.0–42.0 (PN-R-04020:1994/Az1:2004), Cu – 0.90–1.05 (PN-R-04017:1992), Zn – 4.50–5.59 (PN-R--04016:1992), Mn – 110–139 (PN-R-04019:1993), Fe – 1400, C$_{org.}$ – 10.4–10.8 (g kg^{-1}, PB 24 ed. 3 03.12.2012), N$_{total}$ – 0.71–0.76 (g kg^{-1}, PB 29 ed. 4 27.11.2014). The experiment had a randomized sub-block design with three replications.

Five cultivars of edible potatoes were grown: Irga (cream-colored flesh) and Satina (yellow-colored flesh), which are registered on the Polish National List of Agricultural Plant Varieties, and Valfi, Blaue St. Galler (purple-colored flesh) and Highland Burgundy Red (HB Red, red-colored flesh), which are listed in the European Common Catalogue of Varieties of Agricultural Plant Species.

Each year of the study, potatoes were planted 40 cm apart, with inter-row spacing of 67.5 cm (20 plants per micro-plot), in the last ten days of April (30 April 2013, 28 April 2014 and 23 April 2015). The preceding crops were winter rye (2013), winter triticale (2014) and oats (2015). Potatoes were fertilized with 25 t·ha^{-1} manure in fall. Mineral fertilizers were applied in spring before planting: 40 kg·N ha^{-1} (urea, 46% N), 26.2 kg P·ha^{-1} (enriched superphosphate, 17.45% P) and 100 kg K·ha^{-1} (potash salt, 50% K), in addition 40 kg N·ha^{-1} (urea, 46% N) was applied in stage BBCH 51 (the first flower buds of the first inflorescense are visible main shoot).

The following biostimulants were applied according to the manufacturers' recommendations:

– Asahi SL – 0.1% solution (natural nitrophenols: 0.3% para-nitrophenol sodium salt, 0.2% ortho-nitrophenol sodium salt, 0.1% 5-nitroguaiacol sodium salt) – 4 foliar applications beginning in stage BBCH 39;

– Bio-Algeen S 90 (1% solution; extract of *Ascophyllum nodosum* brown algae, amino acids, vitamins, alginic acid, macronutrients (N, P, K, Ca, Mg) and micronutrients (B, Fe, Cu, Mn, Zn, Mo, Se, Co) – 4 foliar applications beginning in stage BBCH 39;

– Kelpak SL (0.2% solution; extract of *Ecklonia maxima* brown algae, 11 mg·dm^{-3} auxins, 0.031 mg dm^{-3} cytokinins) – seed potato dressing and 2 foliar applications beginning in stage BBCH 39;

– Trifender WP (*Trichoderma asperellum* fungal spores at a concentration of $5 \times 10^8 \cdot g^{-1}$ of the product, T1 isolate) – soil application and 4 foliar applications beginning in stage BBCH 39.

Control plants were not treated with growth regulators.

Agricultural practices were identical in all microplots. Weeds were controlled mechanically. Pests were controlled using 0.1 dm^3·ha^{-1} of thiacloprid (Calypso 480 SC), 0.08 kg·ha^{-1} of acetamiprid (Mospilan 20 SP) and 0.16 dm^3·ha^{-1} of lambda-cyhalothrin (Karate Zeon 050 CS). Pathogens were controlled with 1.6 dm^3·ha^{-1} of propamocarb hydrochloride and fluopicolide (Infinito 687.5 SC), 1.7 dm^3·ha^{-1} of propamocarb hydrochloride and fenamidone (Pyton Consento 450 SC), 2 kg·ha^{-1} of dimethomorph and mancozeb (Acrobat MZ 69 WG), 2 kg·ha^{-1} of mancozeb and cymoxanil (Inter Opium 72.5 WP), and 2.5 kg·ha^{-1} of metalaxyl-M and mancozeb (Ridomil Gold MZ Pepite 67.8 WG). Potato tubers were harvested on 26 August 2013, 26 August 2014 and 28 August 2015.

Ten tubers with a cross-section of 35–50 mm were sampled for chemical analysis at the harvest and after 5 months of storage (4°C). The tubers were rinsed in water, peeled with a peeling knife (skin thickness – 3 mm) and cubed. The prepared skins and flesh were freeze-dried in the Alpha 1–4 LDplus freeze dryer (Doncerv®) and ground in a laboratory mill (A 11 basic).

The ground material was divided into three representative samples (1 g each) and mineralized in the CEM Mars 5 Xpress microwave mineralization system (CEM Corp., Matthews, NC, USA) in a closed system (55 cm^3 vessels) using 6 cm^3 of 65% HNO_3 and 1 cm^3 of 30% H_2O_2. Plant material was digested in a microwave oven in three stages: I – 600 W, 100°C, 3 min; II – 600 W, 120°C, 3 min; III – 1200 W, 200°C, 8 min. Digested material was filtered and made up to a final volume of 100 cm^3 with distilled water. The micronutrient content of plant material (Cu, Fe, Mn, Zn) was analyzed by flame atomic absorption spectrometry using the AA Duo-AA280FS/AA280Z spectrometer (Agilent Technologies, Mulgrave, Victoria, Australia) equipped only with single-element hollow-cathode lamps (Varian) [Subramanian et al. 2012].

Achieved results were processed statistically by ANOVA in the Statistica 12.5 software. Mean values were compared in Tukey's test at a significance level of 0.05. Cluster analysis was carried out by single-linkage clustering, and the Euclidean distance was a measure of dissimilarity.

RESULTS AND DISCUSSION

The average temperatures in the growing seasons of 2013–2015 were similar to the long-term average (1981–2010) (Tab. 1). However, the distribution of temperatures in each year of the study differed from the long-term average. In April 2013, the average temperature was 1.8°C lower, and in May and June 2013, it was around 1.3°C higher than the long-term average. In 2014, a warm April was followed by a cool May and June (with temperatures 0.5°C and 1.7°C below the long-term average, respectively) and a hot July (1.7°C higher than the long-term average). In 2013 and 2014, temperatures at the end of the growing season (August) were below the long-term average. In 2015, the average temperatures between April and July were below the long-term average, in particular in May and July. August temperatures exceeded the long-term average by 1.9°C. In the analyzed growing seasons, precipitation levels were similar to the long-term average only in 2013. In 2014 and 2015, precipitation levels were 24% and 36.7% lower than the long-term average, respectively. Rainfall distribution was irregular in different months of the growing season, and the highest precipitation was recorded in July 2013, July 2015 and August 2014 (64%, 10% and 45% higher than the long-term average, respectively). The driest months in the analyzed period were May, June and, in particular, August of 2015 (49%, 63% and 76% below the long-term average).

In this study, the concentrations of Zn, Mn, Cu and Fe differed across years (weather conditions), biostimulant treatments and potato cultivars (Tab. 2). In potato samples analyzed at the harvest, the highest contents of Zn, Mn, Cu and Fe in the skin and the highest concentrations of Zn, Mn and Fe in the flesh were noted in the driest year 2015. The Zn, Mn and

Table 1. Mean air temperature and precipitation sums registered by the meteorological station in Tomaszkowo (NE Poland)

Year	April	May	June	July	August	x/∑
Temperature (°C)						
2013	5.9	14.8	17.5	18.0	17.4	14.7
2014	8.8	13.0	14.4	20.4	17.1	14.7
2015	6.7	11.8	15.5	17.5	19.8	14.3
1981–2010	7.7	13.5	16.1	18.7	17.9	14.8
Rainfall (mm)						
2013	28.5	54.5	61.2	121.9	37.6	303.7
2014	26.0	32.7	50.8	37.3	86.1	232.9
2015	38.2	29.7	29.5	81.9	14.3	193.6
1981–2010	33.3	58.5	80.4	74.2	59.4	305.8

Table 2. Micronutrient content of potato skins and flesh at harvest (mg kg^{-1} DM)

Specification	Skin				Flesh			
	Zn	Mn	Cu	Fe	Zn	Mn	Cu	Fe
Years								
2013	24.65b	9.73b	9.78b	126.0c	23.77b	7.82b	7.26a	16.28c
2014	21.81c	4.63c	6.31c	159.0b	20.89c	4.51c	3.81c	39.38b
2015	26.84a	17.70a	13.29a	203.3a	25.27a	11.93a	4.06b	46.53a
Biostimulants								
Control object	24.30a	10.51a	9.80a	142.8c	23.58a	8.37a	5.30a	31.56b
Asahi SL	24.31a	10.75a	9.62a	160.7bc	22.84a	7.76a	4.86a	33.53b
Bio-Algeen S 90	25.07a	11.57a	9.93a	181.7a	23.59a	8.55a	5.02a	37.03a
Kelpak SL	23.84a	10.03a	9.61a	167.1b	23.23a	7.75a	4.91a	34.86b
Trifender WP	24.64a	10.55a	10.00a	161.6bc	23.29a	8.02a	5.13a	33.34b
Cultivar								
Irga	21.76b	10.04b	10.12ab	147.9ab	21.76ac	6.40d	4.99bc	36.86b
Satina	21.50b	9.04b	7.85c	167.6ab	20.57c	7.24cd	4.78bc	27.97c
Valfi	26.69a	10.50ab	10.78ab	183.8a	24.67b	8.93b	5.46ab	36.54b
Blaue St. Galler	27.10a	10.67ab	9.01bc	185.5a	27.21a	8.30bc	4.22c	44.91a
HB Red	25.11a	13.16a	11.21a	129.2b	22.34c	9.58a	5.77a	24.04c
Mean	24.43	10.69	9.79	162.77	23.31	8.09	5.04	34.06

Cu content of potatoes (skin and flesh) was lowest in 2014, and the content of Fe was lowest in 2013. The mineral content of potato tubers is determined by weather conditions such as temperature, precipitation and rainfall distribution [Zarzecka et al. 2016, Baranowska et al. 2017], soil type and the mineral content of soil [Luis et al. 2011, Sawicka et al. 2016]. Gugała et al. [2016] reported the highest Cu content of potatoes in a growing season characterized by abundant precipitation and high temperatures, and the highest Zn content in a warm and dry growing season. The content of plant-available micronutrients is determined by soil properties, mainly pH, and the chemical form in which these metals occur [Wiśniowska-Kielian and Klima 2007]. The bioavailability of Fe, Mn, Zn and Cu is higher in acidic soils because these metals are more soluble in an acidic environment [Millaleo et al. 2010, Filipek and Skowrońska 2013, Garcia-Banuelos et al. 2014]. In contrast, Petryk and Bedla [2010] did not observe significant correlations between Zn and Fe concentrations in soil and potato tubers. According to Zarzecka [2016], the Zn content of soil influences Zn levels in potatoes.

The results presented in Table 2 indicate that the Zn content of potato skins and flesh was similar, whereas Mn, Cu and Fe concentrations were higher in the skin (1.3- , 1.9- and 4.8-fold on average, respectively). In a study performed by Subramanian et al. [2011], potato skins contained 17% of total Zn and 55% of total Fe. In fresh potato flesh, Mn, Zn and Fe concentrations were higher in the stolon, and Cu content decreased towards the inner part of potato tubers. In the work of Petryk and Bedla [2010], the Zn content of potato skins was determined at 30.8–68.9 $mg \cdot kg^{-1}$, Fe content at 79.8–211.3 $mg \cdot kg^{-1}$ DM, and potato flesh contained 18.8–48.3 $mg\ Zn \cdot kg^{-1}$ and 20.0–44.7 $mg\ Fe \cdot kg^{-1}$ DM. Šrek et. al. [2012] also reported higher concentrations of Cu, Mn and Zn in the skin than in peeled tubers, but the observed differences were not significant. Differences in the mineral content of potato skins and flesh could also be attributed to the size and shape of tubers [Andre et al. 2007].

In this study, biostimulants did not exert a significant effect on Zn, Mn and Cu content of potato skins and flesh, but they increased Fe concentration (in particular Bio-Algeen S 90) (Tab. 2). Biostimulants increased the Fe content of skins by 12.5–27.2% and the Fe content of potato flesh by 5.6–17.3% relative to the control. In other studies, biostimulants had also varied influence on the mineral content of plants. In the work of Majkowska-Gadomska and Wierzbicka [2013], Asahi SL exerted a minor effect on the mineral content of eggplant fruit. According to Wierzbowska et al. [2015], the Cu content of potato tubers increased under the influence of Kelpak SL. In a later study by Wierzbowska et al. [2016], the macronutrient content (P, K, Na, Ca and Mg) of potato tubers increased under exposure to Asahi SL, but decreased under the influence of Bio-Algeen S 90 and Kelpak SL.

Genetic factors influence the micronutrient concentrations in tubers, in particular Cu, Fe, Mn and Zn levels [Haynes et al. 2012, Sawicka et al. 2016]. Significant varietal differences were observed in Cu levels, but not in the Zn content of tubers [Arvin et al. 2005, Wierzbicka and Trawczyński 2011]. Gugała et al. [2016] demonstrated that the Zn content of potato tubers was influenced by genotype. In a study by Wierzbowska et al. [2015], potato tubers cv. Satina were characterized by the lowest concentrations of Zn and Mn, whereas the lowest Fe and Cu levels were noted in potato tubers cv. Irga. In a study by Tamasi et al. [2015], potato tubers of the four analyzed cultivars harvested in 2012, had Zn content of 10.7–25.4, Mn content of 3.6–5.3, Cu content of 4.2–8.1, and Fe content of 7.0–11.5.

Table 2 data show that potato cultivars with light-colored flesh (Irga and Satina) were characterized by the lowest Zn and Mn concentrations in skin and flesh. The skin and flesh of potatoes cvs. Satina and Blaue St. Galler were least abundant in Cu. The lowest Fe concentration was noted in the skin and flesh of potato tubers cv. HB Red. The highest Zn and Fe content was recorded in the skin and flesh of potatoes cv. Blaue St. Galler, while the skin and flesh of potatoes cv. HB Red were most abundant in Mn and Cu.

Asahi SL, Bio-Algeen S 90, Kelpak SL and Trifender WP modified the microelement content of the skin and flesh of the analyzed potato cultivars, but not all differences were statistically significant. Biostimulants decreased the Zn content of skin in potatoes cv. Valfi, Mn content of skin in potatoes cv. HB Red, Zn content of flesh in potatoes cvs. Irga and Valfi, Mn content of flesh in potatoes cvs. Irga and HB Red, and the Cu content of flesh in potatoes cvs. Irga and Satina (Tab. 3). The above growth regulators increased Fe concentration in the skin and flesh of potatoes cvs. Satina, Valfi and Blaue St. Galler, and Zn concentration in the flesh of potatoes cvs. Blaue St. Galler and HB Red.

Table 3. Influence of biostimulants on the micronutrient content of the skin and flesh of tubers in selected potato cultivars (mg kg^{-1} DM)

Cultivar	Biostimulant	Skin				Flesh			
		Zn	Mn	Cu	Fe	Zn	Mn	Cu	Fe
Irga	Control object	21.71c-f	9.93b-e	10.10a-d	132.5def	22.67b-g	6.74bcd	5.38abc	35.27a-f
	Asahi SL	24.93a-f	11.21a-e	10.30a-d	157.9a-f	21.75c-g	5.76d	4.79abc	36.37a-f
	Bio-Algeen S 90	19.77ef	10.04a-e	9.31a-d	161.0a-f	21.86c-g	6.51bcd	4.81abc	41.79a-d
	Kelpak SL	20.17ef	8.43cde	10.62a-d	163.2a-f	20.63efg	6.31cd	4.91abc	37.60a-f
	Trifender WP	22.23b-f	10.60a-e	10.26a-d	124.8ef	21.86c-g	6.66bcd	5.07abc	33.27b-f
Satina	Control object	21.22def	8.28de	8.06bcd	149.2b-f	20.95d-g	7.62bcd	5.60abc	26.25def
	Asahi SL	20.28ef	9.22b-e	8.18bcd	170.2a-f	19.43g	6.96bcd	4.19abc	29.44c-f
	Bio-Algeen S 90	25.62a-e	11.14a-e	8.57bcd	212.7a	22.06c-g	7.72a-d	4.33abc	29.62c-f
	Kelpak SL	21.30def	8.77cde	6.99d	156.8a-f	21.00d-g	7.03bcd	4.60abc	28.14c-f
	Trifender WP	19.11f	7.82e	7.42cd	149.4b-f	19.42g	6.87bcd	5.18abc	26.43def
Valfi	Control object	28.55a	9.56b-e	11.10ab	160.4a-f	28.48b	8.48a-d	5.25abc	34.07b-f
	Asahi SL	24.02a-f	10.25a-e	9.23a-d	162.6a-f	23.79a-g	8.71a-d	5.70abc	36.33a-f
	Bio-Algeen S 90	27.27abc	11.88a-e	10.54a-d	209.4ab	23.91a-g	9.83ab	6.03a	40.96a-e
	Kelpak SL	26.34a-d	9.64b-e	11.28ab	193.2a-d	21.83c-g	8.30a-d	4.93abc	34.51b-f
	Trifender WP	27.26abc	11.15a-e	11.75ab	193.1a-d	25.33a-f	9.34abc	5.38abc	36.83a-f
Blaue St. Galler	Control object	25.14a-e	10.05a-e	9.08a-d	154.4a-f	25.76a-e	8.26a-d	4.46abc	38.24a-f
	Asahi SL	27.64ab	10.04a-e	9.32a-d	178.9a-e	26.31a-d	8.06a-d	3.94c	42.79abc
	Bio-Algeen S 90	28.88a	11.96a-e	8.96a-d	191.4a-d	27.21abc	9.07a-d	4.05bc	47.09ab
	Kelpak SL	26.30a-d	11.89a-e	8.62a-d	210.1a	28.58ab	8.74a-d	4.14bc	50.42a
	Trifender WP	27.55abc	9.43b-e	9.08a-d	192.7a-d	28.21ab	7.39bcd	4.52abc	46.02ab
HB Red	Control object	24.89a-f	14.76a	10.68abc	117.6ef	20.06fg	10.75a	5.84abc	23.99f
	Asahi SL	24.68a-f	13.05abc	11.07ab	134.0def	22.94a-g	9.33abc	5.70abc	22.70f
	Bio-Algeen S 90	23.83a-f	12.85a-d	12.27a	134.0def	22.93a-g	9.64abc	5.87ab	25.68ef
	Kelpak SL	25.12a-e	11.41a-e	10.53a-d	112.2f	24.13a-g	8.37a-d	5.96a	23.66f
	Trifender WP	27.05a-d	13.74ab	11.50ab	148.0c-f	21.63c-g	9.82ab	5.50abc	24.15f

Values denoted by the same letters do not differ significantly at 5% error (Duncan test)

Bio-Algen S 90 contributed to the highest increase in the Zn (20.7%), Mn (34.5%) and Fe (42.6%) content of the skin in potatoes cv. Satina, and in the Mn (15.9%) and Cu (14.9%) content of the flesh in potatoes cv. Valfi. Kelpak SL led to the highest increase in Zn (20.3%) concentration in the flesh of potatoes cv. HB Red and in Fe (31.9%) concentration in the flesh of potatoes cv. Blaue St. Galler.

In comparison with the control treatment, the application of Asahi SL resulted in the highest decrease in the Zn (18.9%) and Cu (20.3%) content of the skin in potatoes cv. Valfi, and in Cu (33.7%) content of the flesh in potatoes cv. Satina. The concentration of Mn (approx. 29%) in the skin and flesh of potatoes cv. HB Red, and the concentration of Zn (30.5%) in the flesh of potatoes cv. Valfi decreased most under the influence of Kelpak SL.

In a study by Zarzecka et al. [2016], potato tubers cv. Satina contained 6.27 mg Cu·kg^{-1} (similar Cu levels were reported by Arvin et al. [2005] and

Manzelli et al. [2010]), 19.22 mg Zn·kg^{-1} and 20.91 mg Mn·kg^{-1}. According to the cited authors, herbicides and herbicide mixtures decreased the Cu concentration, but did not modify the Zn and Mn contents of potato tubers [Zarzecka et al. 2016]. Herbicides applied alone and in combination with Kelpak SL or Asahi SL biostimulants increased the Zn content of potato tubers [Gugała et al. 2016]. In a study by Wierzbowska et al. [2015], Kelpak SL increased and Bio-Algeen S 90 decreased the concentrations of Zn, Mn, Fe and Cu in potato tubers relative to the control treatment.

Stored potato tubers undergo physiological, chemical and biological changes, which lead to quantitative and qualitative losses in yield [Zgórska and Grudzińska 2012]. According to Murnice et al. [2011], changes in chemical composition of stored tubers are influenced by cultivar, weather conditions during the growing season and storage conditions.

The Zn and Mn contents of potato skin and flesh increased, whereas the Cu and Fe contents decreased in storage potato tubers (Fig. 1). The greatest increase in Zn and Mn concentrations was observed in the last year of the study (28% and 40% in the skin and 30% and 60% in the flesh, respectively). Particularly high decrease in Fe (–28% in the skin and –55% in the flesh) and Cu (–15% in the skin and –7% in the flesh) levels was noted in 2014.

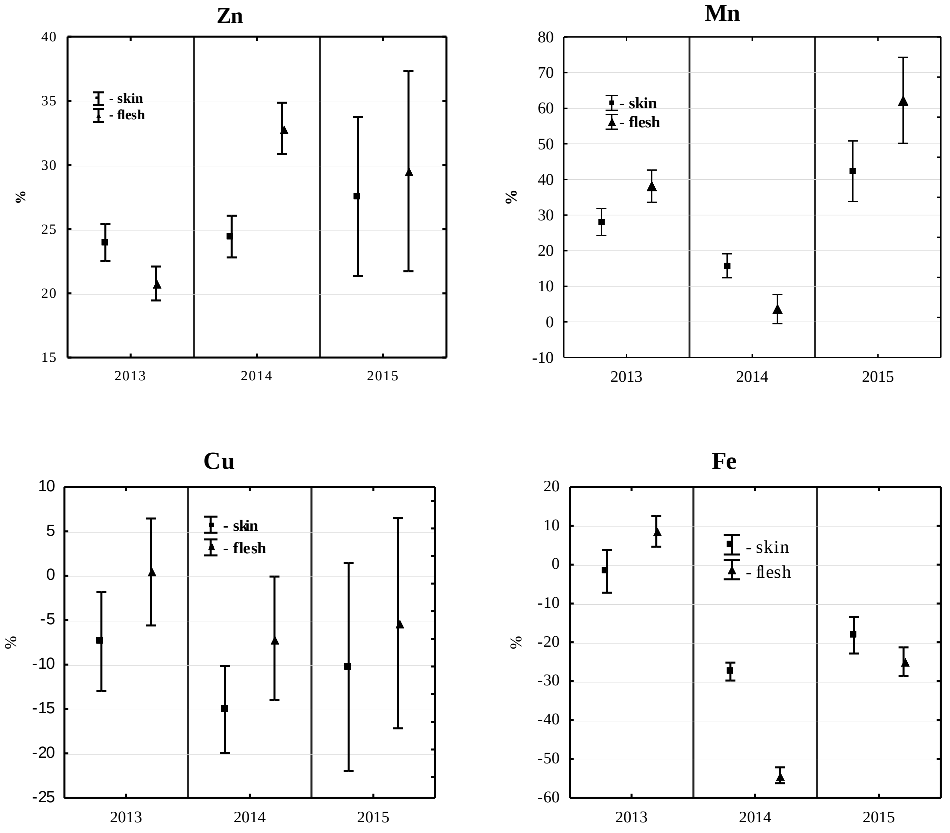
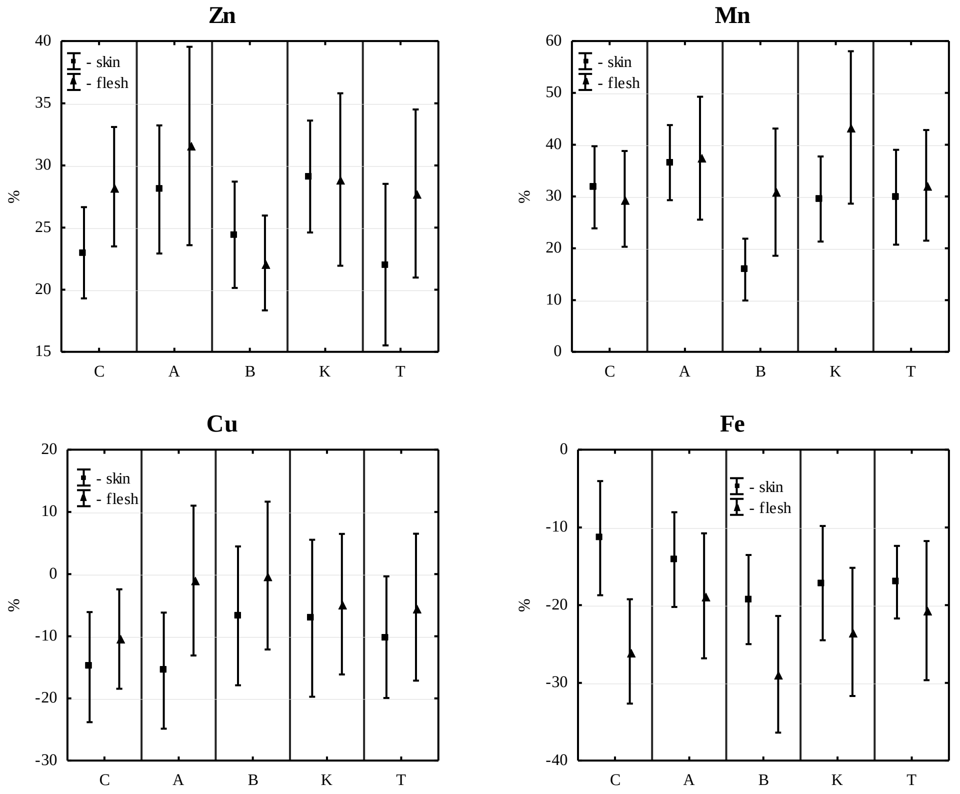


Fig. 1. Changes in the micronutrient content of the skin and flesh of potato tubers across the study years (mean ± 0.95 confidence interval)

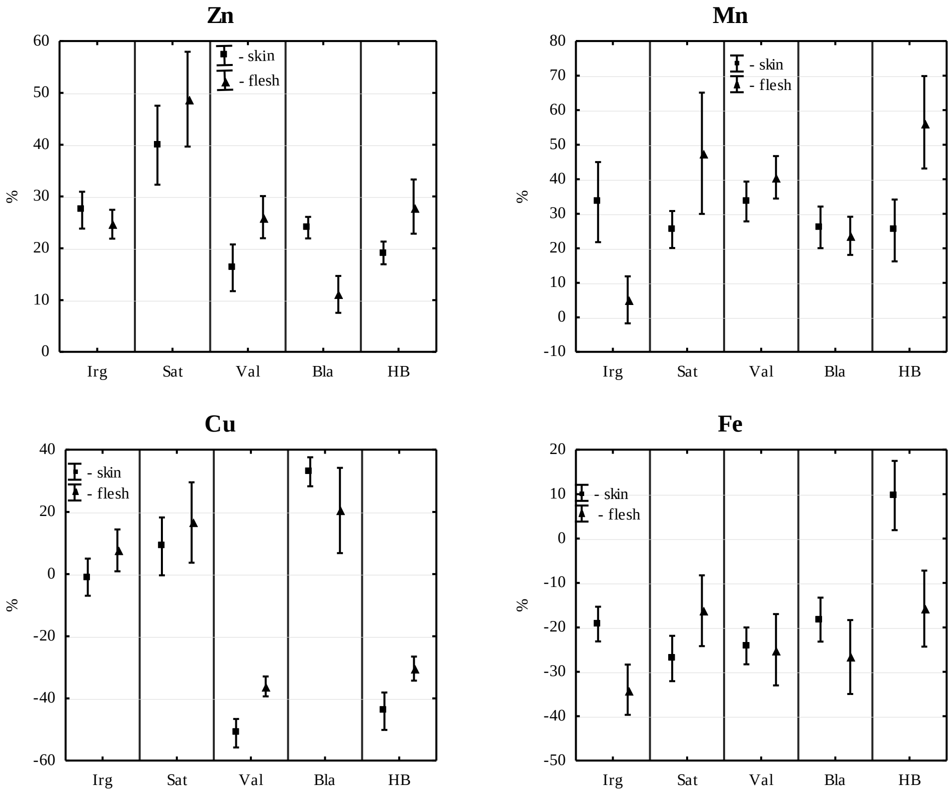


Explanation: C – control object; A – Asahi SL; B – Bio-Algeen S 90; K – Kelpak SL; T – Trifender WP

Fig. 2. Influence of biostimulants on the micronutrient content of stored potato tubers (mean ± 0.95 confidence interval)

In potato tubers treated with Asahi SL and Kelpak SL, a greater increase in Zn and Mn concentrations in the skin (Zn – 28% and 29%; Mn – 37%, only treated with Asahi SL) and flesh (Zn – 32% and 28%; Mn – 38% and 43%) was observed relative to the control treatment (Fig. 2). In potatoes treated with Bio-Algeen S 90, the relevant increase was smaller than in the control treatment. All biostimulants limited the loss of Cu (in skin and flesh) during the storage. A greater decrease in the Fe content of skin was recorded in potatoes treated with the evaluated biostimulants than in the control treatment. In the flesh of stored potatoes, the loss of Fe was minimized by all biostimulants except from Bio-Algeen S 90.

During storage, the highest increase in Zn concentration was observed in potatoes cv. Satina (40% in the skin and nearly 50% in the flesh) (Fig. 3). In the remaining potato cultivars, Zn concentration increased by 17–27% in the skin and by 12–28% in the flesh. The Mn content of stored potatoes increased by 25–33% in the skin and by about 3% (cv. Irga) to about 57% (cv. HB Red) in the flesh. Changes in the Cu and Fe content of potato skin and flesh were influenced by genotype. In potatoes cv. Irga, Cu concentration in the skin remained nearly constant and increased by less than 10% in the flesh during storage. Higher Cu concentration was noted in the skin and flesh of potatoes cvs. Valfi and Blaue St. Galler. Potatoes cvs. Valfi and HB Red were characterized by a significant decrease in the Cu content of the skin (around –50% and –40%, respectively) and flesh (about –35% and –30%, respectively). In stored potatoes cvs. Irga, Satina,



Explanation: Irg – Irga; Sat – Satina; Val – Valfi; Bla – Blaue St. Galler; HB – HB Red

Fig. 3. Changes in the micronutrient content of potato skins and flesh across the studied cultivars (mean ± 0.95 confidence interval)

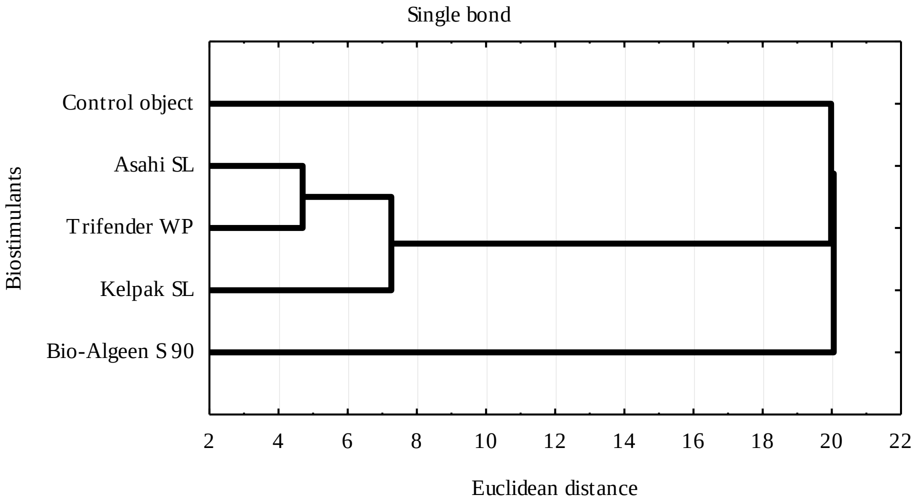


Fig. 4. Dendrogram of changes in the micronutrient content of potato tubers treated with biostimulants

Valfi and Blaue St. Galler, Fe concentration decreased by 18–25% in the skin and by 17–35% in the flesh. In potatoes cv. HB Red, the concentration of Fe increased by about 10% in the skin and decreased by approx. 15% in the flesh.

A cluster analysis revealed that Asahi SL and Trifender WP biostimulants had similar influence on the micronutrient content of potato tubers, and their effects did not differ significantly from that exerted by Kelpak SL (Fig. 4). The micronutrient content of potato tubers treated with Bio-Algeen S 90 was highly similar to that recorded for the control, but it differed significantly from that observed in the remaining biostimulant treatments.

CONCLUSIONS

Weather conditions, applied biostimulants and potato cultivars influenced the Zn, Mn, Cu and Fe content of potatoes at the harvest and after 5 months of storage. In potato samples analyzed at harvest, the highest content of Zn, Mn, Cu and Fe in the skin and flesh (excluding Cu) were noted in the driest year 2015. In all years of the study, micronutrient concentrations were higher in the skin than in the flesh at harvest, and the greatest variations were observed in the content of Fe. The concentrations of Zn, Mn and Fe increased in the skin and flesh of potatoes at harvest under the influence of Bio-Algeen S 90, and the Fe content of skin also increased in potatoes treated with Kelpak SL. The skin and flesh of potatoes were generally more abundant in micronutrients in potatoes cvs. Valfi, Blaue St. Galler (with purple-colored flesh) and HB Red (with red-colored flesh) than in potatoes cvs. Irga and Satina (with cream- and yellow-colored flesh). In all years of the study, Zn and Mn concentrations increased, and Cu and Fe concentrations decreased (excluding 2013) in the skin and flesh of stored potatoes. The content of Zn, Mn and Cu increased (excluding potatoes cvs. Valfi and HB Red) and the content of Fe decreased (excluding the skin of potatoes cv. HB Red) in the skin and flesh of the analyzed potato cultivars. In comparison with the control treatment, the skin and flesh of stored potatoes treated with the analyzed biostimulants were characterized by varied concentration of Zn, higher or similar content of Mn, smaller decrease in Cu concentration, greater loss of Fe in the skin and smaller loss of Fe in the flesh of potato tubers.

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