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Original Research

The Influence of Biostimulants on the Content of P, K, Ca, Mg, and Na in the Skin and Flesh of Potato Tubers

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Abstract

Potato cultivars Blaue St. Galler, Valfi, HB Red (with purple- and red-colored flesh), Irga, and Satina (with cream- and yellow-colored flesh) were treated with Trifender WP, Asahi SL, Bio-Algeen S90, and Kelpak SL. The influence of biostimulants on the P, K, Ca, Mg, and Na contents of potato skin and flesh was determined immediately after harvest and after storage. The highest content of Ca in the flesh and skin and the highest content of K in the skin were noted in potatoes treated with Kelpak SL. Potassium content was highest in the flesh of potatoes treated with Trifender WP. Phosphorus content was highest in the skin, whereas Mg content was highest in the flesh of potatoes treated with Bio-Algeen S90. The flesh and skin of cvs. Blaue St. Galler, Valfi, and HB Red were more abundant in macroelements. An increase in the contents of Na and P, and a decrease in the contents of K, Ca, and Mg were observed in the tubers of stored potatoes. The greatest increase in the content of P and Na and the smallest decrease in the concentration of Ca were noted in the flesh and skin of cv. Satina.

Keywords: *Solanum tuberosum* L., cultivar, growth regulators, storage, macroelements

Introduction

The nutritional value of agricultural crops has to be closely monitored due to the continued decrease in the concentrations of minerals in fruit and vegetables in recent decades [1]. Potato tubers are a rich source of nutrients in the human diet, including protein, carbohydrates, fiber, antioxidants (vitamin C, phenols, anthocyanins), and minerals (1-2%) [2-3]. Ratios between minerals are of particular importance to human health [4]. The growing demand for potatoes with high nutritional value necessitates research into new varieties and production technologies. Potato cultivars with colored skin and flesh are becoming increasingly popular due to their superior nutritional value relative to

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cultivars with yellow- and cream-colored flesh. Colored potatoes contain 60% more phenolic compounds (mainly chlorogenic acid) and anthocyanins [5]. They have antibacterial and free-radical scavenging properties [2] that are used in medicine [6]. Most studies conducted to date have focused on the effects of weather conditions and agronomic factors (crop rotation, crop species, organic and mineral fertilization, including the use of foliar fertilizers) on the macronutrient content of potato tubers [7-9]. Only a few studies have investigated the influence of biostimulants containing extracts from sea algae or chemically synthesized compounds on the chemical composition of tubers. Natural growth promoters contain polysaccharides, microelements, and plant growth hormones [10]. These treatments improve productivity by increasing plant resistance to environmental stressors [11-12], promoting root growth and the uptake of minerals by roots [13]. According to Leonel et al. [14], P availability in soil has a significant effect on the chemical composition of potato tubers. Kelpak SL and Asahi SL biostimulants (regardless of their dose and frequency of application) increased N concentration in carrot roots [15], and Asahi SL increased the K content of eggplant fruit [16]. Herbicides combined with biostimulants exerted varied effects on the concentrations of P and Ca in potato tubers [17], but they increased Zn and Cu content [18]. Biostimulants containing microorganisms improve soil fertility by converting nutrients into forms that are readily available for plants. Fungi of the genus *Trichoderma* (including *T. asperellum*, which is found in the Trifender WP biostimulant) compete for nutrients with phytopathogens [19], induce plant resistance to biotic stress [20], and increase tuber yield in treatments with cover crops [21]. Wierzbicka and Trawczyński [22] and Zarzecka et al. [3] demonstrated that the UGmax biofertilizer (containing macroelements, microelements, and microorganisms) exerted varied effects on the concentrations of N, P, and Mg in potato tubers.

The aim of this study was to determine the influence of biostimulants on the macronutrient content of the skin and flesh of potato tubers.

Materials and Methods

A field experiment (53°41'N, 20°24'E, 2013-2015, a randomized sub-block design, three replications) was performed on podzolic soil with the granulometric composition of light loam (suitability complex 4 and quality class IIIb). Soil parameters were determined before the experiment at: pH 4.04-4.54 in 1 M KCl; available minerals (mg/kg soil): P–85.6-111.8, K–104.2-204.2, Mg–38.0-42.0, $C_{org.}$–10.4-10.8 g/kg, and N_{total}–0.71-0.76 g/kg. Five cultivars of edible potatoes – Blaue St. Galler, Valfi (with purple-colored flesh), Highland Burgundy Red - HB Red (with red-colored flesh), Irga, and Satina (with cream- and yellow-colored flesh) – were treated with biostimulants (Table 1). The preceding crops were winter rye (2013), triticale (2014), and oats (2015). Potatoes were fertilized with 25 t/ha manure in fall. Mineral fertilizers were applied in spring before planting: 40 kg N/ha (urea, 46% N), 26.2 kg P/ha (superphosphate, 17.45% P), and 100 kg K/ha (potash salt, 50% K). The crops were top-dressed with 40 kg N/ha (urea, 46% N) in stage BBCH 51. Potatoes were planted by 23 to 30 April, and were harvested by 26 to 28 August. Pathogens and pests were controlled chemically, and weeds mechanically [23]. The tubers (35-50 mm, after harvest and 5 months of storage) were peeled (skin thickness 3-4 mm) and cubed. The prepared skins and flesh were freeze-dried and ground in a laboratory mill.

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, 100ºC, 3 min; II - 600 W, 120ºC, 3 min; and III - 1200 W, 200ºC, 8 min. Digested material was filtered and made up to a final volume of 100 mL with distilled water. The macroelement content of plant material (K, Ca, Mg, Na) was analyzed by flame atomic absorption spectrometry using an Agilent Technologies AA Duo-AA280FS/AA280Z spectrometer (Agilent Technologies, Mulgrave, Victoria,

Table 1. Experimental design.

Treatment	Composition	Usage
Control	Plants not treated with biostimulants	
Trifender WP	T1 isolate of *Trichoderma asperellum*, 5x10^8 fungal spores /g of the product	Soil application and 4 foliar use (from BBCH 39)
Asahi SL	0.3% para-nitrophenol sodium salt, 0.2% ortho-nitrophenol sodium salt, 0.1% 5-nitroguaiacol sodium salt	4 foliar use (as above)
Kelpak SL	Extract of *Ecklonia maxima*, 11 mg/dm auxins, 0.031 mg/dm cytokinins	Seed potato dressing and 2 foliar use (as above)
Bio-Algeen S90	Extract of *Ascophyllum nodosum*, amino acids, vitamins, alginic acid, N–0.2, P_2O_5–0.06, K_2O–0.96, cao–3.1, mgo–2.1 g/kg, B–16.0, Fe–6.3, Cu–0.2, Mn–0.6, Zn–1.0 mg/kg, Mo, Se, Co	4 foliar use (as above)

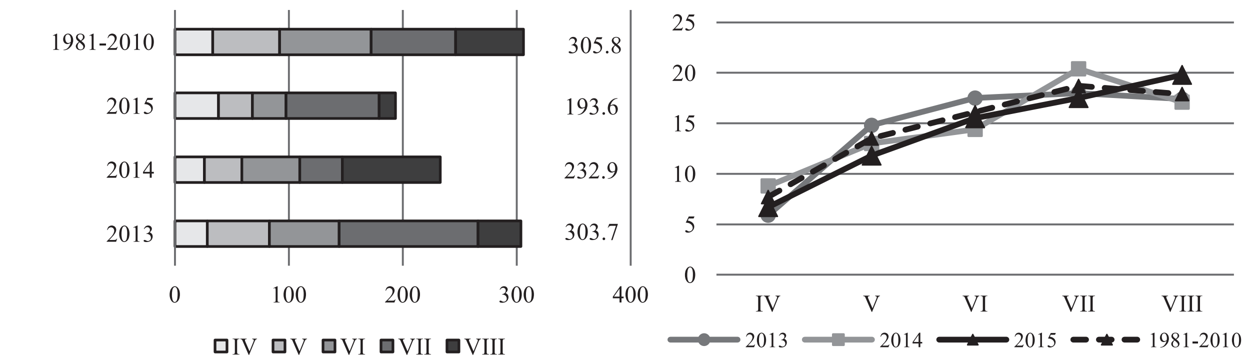

Fig. 1. Weather conditions.

Australia) equipped only with single-element hollow-cathode lamps (Varian) [24]. The phosphorus content of plant material was determined by atomic-absorption spectrophotometry of vanadium and molybdenum with a Shimadzu UV-1201V spectrophotometer [25].

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

Results and Discussion

Total precipitation during the growing season approximated the long-term average only in 2013. The growing seasons of 2014 and 2015 were

Table 2. Macroelement content of potato tubers.

Specification	P		K		Ca		Mg		Na	
	g/kg DM									
	Flesh	Skin	Flesh	Skin	Flesh	Skin	Flesh	Skin	Flesh	Skin
Year of research										
2013	3.57	3.64	11.59	17.29	2.70	5.11	1.67	1.80	0.66	1.19
2014	3.28	3.36	16.99	24.34	3.06	5.41	1.46	1.56	0.83	1.61
2015	2.39	2.65	18.98	20.76	3.51	5.85	1.77	1.84	0.73	1.21
$HSD_{0.05}$	0.08	0.08	0.10	0.09	0.03	0.04	0.01	0.01	0.01	0.01
Biostimulant										
C*	3.14	3.17	15.68	20.68	2.68	5.61	1.60	1.78	0.82	1.41
T	3.07	3.22	16.56	20.74	2.80	4.99	1.56	1.77	0.69	1.32
A	3.10	3.09	15.74	20.61	3.15	4.75	1.67	1.66	0.72	1.29
K	3.12	3.28	15.65	21.00	3.57	6.32	1.63	1.72	0.79	1.32
B	2.96	3.31	15.63	20.95	3.25	5.62	1.71	1.73	0.69	1.34
$HSD_{0.05}$	0.14	0.14	0.16	0.16	0.04	0.06	0.01	0.02	0.01	0.02
Cultivar										
Blaue St.Galler	2.97	3.09	17.33	19.59	2.88	6.44	1.75	1.98	0.85	1.52
Valfi	2.79	2.97	14.52	17.34	5.25	8.75	1.76	1.78	0.72	1.21
HB Red	3.36	3.36	16.31	22.08	3.32	4.54	1.28	1.43	0.81	1.53
Irga	3.07	3.25	14.98	22.17	2.00	4.34	1.71	1.61	0.64	1.25
Satina	3.20	3.40	16.11	22.80	1.99	3.23	1.65	1.87	0.68	1.18
$HSD_{0.05}$	0.14	0.14	0.16	0.16	0.04	0.06	0.01	0.02	0.01	0.02

*C–Control; T–Trifender WP; A–Asahi SL; K–Kepak SL; B–Bio-Algeen S90

Table 3. Effects of cultivars and biostimulants on macroelement content of potato tubers (means for 2013-2015)

Cultivar	Biostimulant	P		K		Ca		Mg		Na	
		g/kg DM									
		Flesh	Skin	Flesh	Skin	Flesh	Skin	Flesh	Skin	Flesh	Skin
Blaue St Galler	C*	3.00	2.98	17.42	19.88	2.78	9.78	1.71	2.21	0.84	1.60
	T	3.13	3.37	17.46	18.68	3.13	7.37	1.78	2.10	0.86	1.56
	A	2.99	2.86	17.38	19.92	3.01	4.35	1.83	1.83	0.83	1.36
	K	2.79	3.12	17.44	19.74	3.21	6.62	1.72	1.96	0.82	1.43
	B	2.94	3.12	16.97	19.73	2.28	4.05	1.71	1.80	0.90	1.64
Valfi	C	2.79	2.76	14.79	16.70	3.54	6.97	1.54	1.71	0.69	1.26
	T	2.69	3.11	14.65	17.71	4.21	6.28	1.54	1.64	0.53	1.17
	A	2.93	2.89	14.26	16.54	5.44	7.56	1.89	1.71	0.77	1.10
	K	2.82	3.24	14.10	17.86	7.22	10.30	1.89	2.03	0.78	1.23
	B	2.75	2.87	14.79	17.89	5.85	12.63	1.96	1.83	0.85	1.27
HB Red	C	3.42	3.45	15.25	22.95	2.97	4.18	1.28	1.49	0.93	1.45
	T	3.33	3.75	19.06	22.62	3.24	3.91	1.18	1.45	0.84	1.57
	A	3.35	3.18	15.79	21.18	2.66	3.86	1.11	1.32	0.78	1.56
	K	3.48	3.13	15.74	21.76	3.36	5.56	1.42	1.25	0.84	1.51
	B	3.21	3.29	15.73	21.89	4.36	5.17	1.43	1.63	0.64	1.55
Irga	C	3.25	3.36	14.34	22.43	2.27	4.46	1.85	1.38	0.85	1.51
	T	2.82	2.33	15.42	22.05	1.91	4.90	1.66	1.81	0.68	1.37
	A	3.14	3.16	15.58	22.57	1.73	4.00	1.69	1.56	0.47	1.30
	K	3.17	3.72	14.78	21.61	1.88	4.37	1.61	1.68	0.66	1.05
	B	2.98	3.67	14.76	22.16	2.20	3.98	1.75	1.63	0.54	1.00
Satina	C	3.26	3.29	16.60	21.43	1.84	2.64	1.65	2.12	0.77	1.22
	T	3.37	3.51	16.19	22.65	1.48	2.51	1.63	1.85	0.55	0.95
	A	3.11	3.37	15.71	22.83	2.92	3.98	1.82	1.91	0.73	1.11
	K	3.33	3.21	16.18	24.01	2.18	4.73	1.50	1.70	0.84	1.40
	B	2.90	3.61	15.87	23.06	1.54	2.27	1.67	1.79	0.54	1.22
$HSD_{0.05}$		0.41	0.42	0.49	0.48	0.13	0.18	0.03	0.05	0.04	0.05

*Explanations as per Table 2

characterized by low precipitation levels, which were 24% and 36.7% below the long-term average, respectively. Rainfall was unevenly distributed across months. Dry spells were noted in May, June, and, in particular, August 2015. The average temperature in the growing seasons of 2013-2015 approximated the long-term average. In April 2013, temperature was lower and in May and June 2013 – higher in comparison with the long-term average. In 2014, a warm April was followed by a cool May and June and a hot July. The temperatures at the end of the growing season in 2013 and 2014 were below the long-term average. Between April and July 2015, the average temperatures were below the 1981-2010 average, whereas the average temperature in August exceeded the long-term average by 1.9ºC (Fig. 1).

Weather and soil conditions, the applied agricultural treatments (type of crops, cultivation, fertilization, use of biostimulants), storage conditions, and plant genotype influence the chemical composition of potatoes, including their K, P, and Mg contents [8, 26]. In our study, the flesh and skin of the evaluated potato cultivars were least abundant in P in the driest year of 2015 (Table 2). The concentrations of the remaining macroelements were lowest in 2013. The highest content of K (18.98 g/kg DM) in potato flesh was determined in 2015, and in the skin (24.34 g/kg DM) in 2014. The analyzed potatoes were most abundant in Ca and Mg in 2015, and in Na in 2014.

Biostimulants induced changes in macroelement concentrations in the flesh and skin of potatoes (Table 2). The application of Bio-Algeen S90 significantly increased the P content of skin relative to the control treatment. The highest concentration of K in the flesh was noted in potatoes treated with Trifender WP, and the highest concentration of K in the skin was observed in potatoes treated with Kelpak SL and Bio-Algeen S90. In comparison with the control treatment, the flesh of potatoes treated with Kelpak SL contained 33.2% more Ca. The concentration of Ca in the skin increased by 12.7% under the influence of Kelpak SL. The biostimulants (excl. Trifender WP) increased the concentration of Mg in the flesh, but decreased the Mg content of potato skin. The flesh and skin of potatoes treated with biostimulants were characterized by a lower concentration of Na than control tubers. In the study by Subramanian et al. [27], macroelement concentrations were higher in the skin than in the flesh of potato tubers. The average content of P and Mg was only somewhat higher in the skin than in the flesh (by 4.5% and 6.1%, respectively; Table 2). The evaluated biostimulants induced greater differences in the concentrations of the remaining macroelements: K content was more than 31% higher, and the concentrations of Ca and Na were 76.7% and 81% higher, respectively, in the skin than in the flesh. In a study by Subramanian et al. [27], potato skins were particularly abundant in Ca (34% of total content). In comparison with the content of P, the concentration of Ca was more likely to decrease toward the center of potato tubers. Šrek et al. [28] also reported higher macroelement concentrations (N, P, K, Ca, Mg) in the skin than in the flesh of peeled potatoes. Subramanian et al. [27] reported higher concentrations of Mg, S, and Cl in the stem end than in the bud end of potato tubers. The content of K decreased gradually toward the stem end. Andre et al. [29] observed that the content of minerals in the surface layers of potato tubers can be influenced by the shape and size of tubers (skin-to-flesh ratio).

Cultivars with purple- and red-colored flesh were more abundant in macroelements than cultivars with yellow- and cream-colored flesh (Table 2). The highest concentrations of K and Na in the flesh and Mg in the skin were noted in cv. Blaue St. Galler, whereas the highest P content of the flesh and the highest Na content of the skin were in cv. HB Red. Potatoes cv. Valfi were characterized by the highest concentrations of Ca in the flesh and skin and Mg in the flesh, and the lowest concentrations of P and K. The skin of cv. Satina was most abundant in P and K. Potato tubers of this cultivar were least abundant in Ca. The significant interactions were observed between the applied biostimulants and potato cultivars (Table 3). Trifender WP induced a 25% increase in the K content of flesh in cv. HB Red and a 31% increase in the Mg content of skin in cv. Irga. The application of Asahi SL increased the Ca content of flesh in cv. Satina by 58% and decreased the concentrations of Ca and Na in the flesh of cv. Irga. Kelpak SL doubled the Ca content of flesh in cv. Valfi and increased the Ca content of skin in cvs. HB Red and Satina (by 33% and 80% respectively). Bio-Algeen S90 increased the concentration of Ca in the skin of cv. Valfi and in the flesh of cv. HB Red (by 80% and 47%, respectively). In a study by Wierzbowska et al. [26], the concentrations of P, K, Na, Ca, and Mg in potatoes increased in response to Asahi SL and decreased under the influence of Bio-Algeen S90 and Kelpak SL. Trawczyński and Bogdanowicz [30] and Wierzbicka and Trawczyński [22]

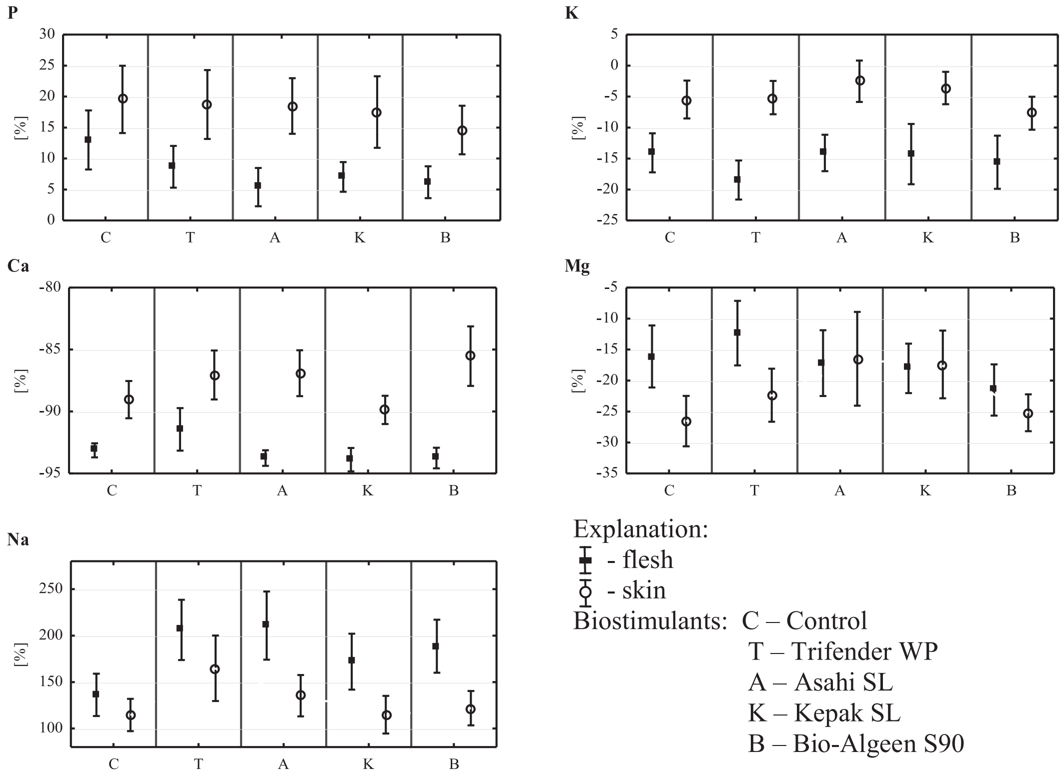

Fig. 2. Changes in the macroelements content of stored potatoes treated with different biostimulants .

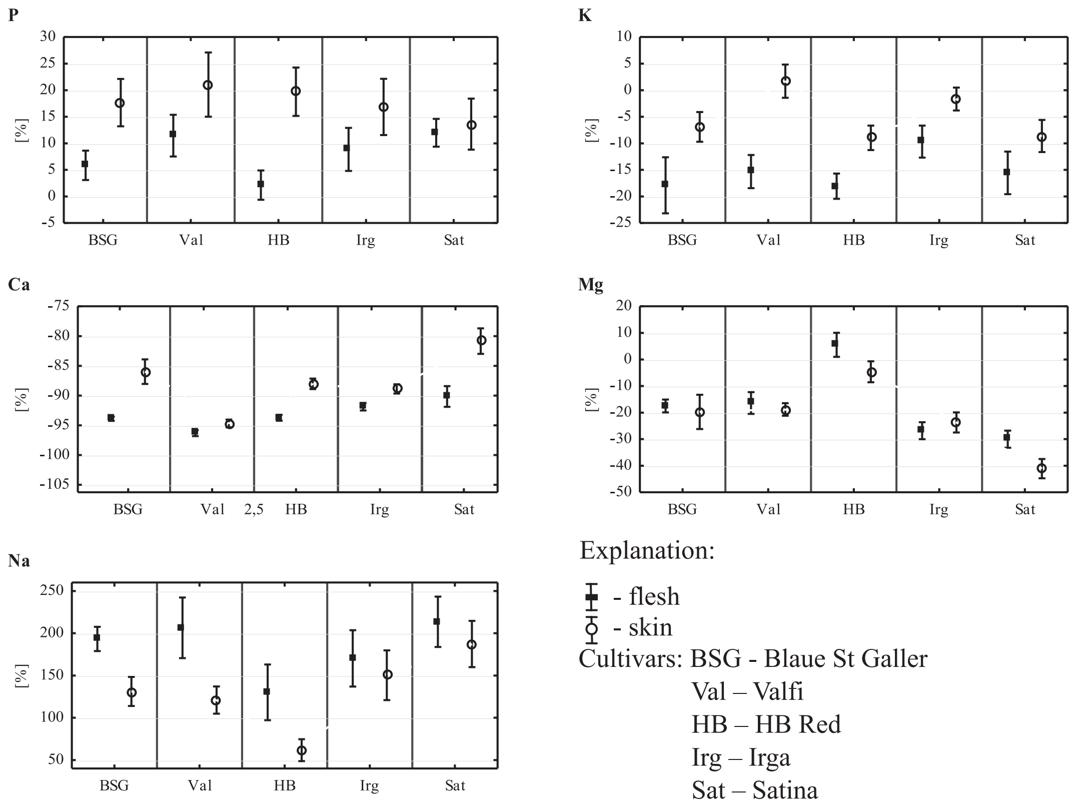

Fig. 3. Changes in the macroelements content of stored potatoes of different cultivars.

did not observe differences in the P content of potato tubers treated with the UGmax biofertilizer. In contrast, Wichrowska et al. [9] reported a significant increase in the concentrations of P and K in potatoes after the application of the UGmax biofertilizer. UGmax did not influence the Mg content of potato tubers [3, 22].

The concentrations of P and Na increased in stored potatoes, and the content of K, Ca, and Mg decreased (Fig. 2). The highest increase in the concentration of P was noted in control potatoes (by 13.0% in the flesh and 19.5% in the skin). The concentration of P increased by only 5% in the flesh of potatoes treated with Asahi PL, whereas the P content of skin increased by 14.5% in response to Bio-Algeen S90. The increase in Na content was greater in the flesh (136-210%) than in the skin (114-165%) of potatoes treated with biostimulants. The concentration of K decreased in the flesh and in the skin, and it was not highly modified by biostimulants. The Ca content of potato flesh and skin decreased by around 90% in all treatments. Trifender WP inhibited the loss of Mg in the flesh, and Asahi SL and Kelpak SL in the skin of stored potatoes.

A greater increase in the concentration of Na was observed in the flesh, and a greater increase in the content of P was noted in the skin of stored potatoes (Fig. 3). A smaller decrease in K and Ca content and a similar decrease in Mg content were noted in the skin than in the flesh. The highest increase in the P and Na

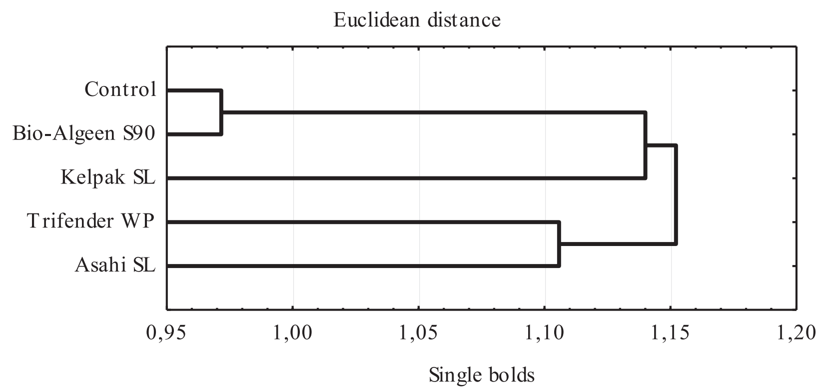

Fig. 4. Dendrogram of changes in the macroelements content of potato tubers.

content of flesh was observed in potatoes cvs. Valfi and Satina, and the highest increase in the content of P in the skin of potatoes with purple- and red-colored flesh. The smallest decrease in Mg content was noted in the skin, whereas a minor increase in Mg content was noted in the flesh of cv. HB Red. The flesh and skin of the above cultivar were also characterized by the greatest decrease in the concentration of K. The analyzed potato cultivars were least differentiated in terms of their Ca content.

The changes in the chemical composition of stored potatoes are determined by, e.g., cultivars and storage conditions [9]. In a study by Wichrowska et al. [31], the P and K contents of potatoes increased during storage. Wierzbowska et al. [26] reported an increase in the concentrations of P, K, Na, Ca, and Mg in stored potato tubers. The greatest increase in the concentrations of K and Na was observed in potatoes treated with Asahi SL, the greatest increase in the concentration of P was in potatoes treated with Kelpak SL, and the greatest increase in the concentration of Ca was in potatoes treated with Bio-Algeen S90. Biostimulants also inhibited the increase in the concentration of Mg.

Cluster analysis revealed similar macroelement concentrations in potatoes treated with Bio-Algeen S90 and in control plants (Fig. 4). The potatoes treated with Trifender WP and Asahi SL formed a more differentiated cluster. Kelpak SL exerted a significantly different influence on the macroelement content of potatoes than the remaining biostimulants.

Conclusions

New technologies that rely on biostimulants contribute to reduced use of agrochemicals in potato cultivation, which is an important consideration from both economic and environmental perspectives. The present study fills the existing gap regarding the effect of biostimulants on tuber quality, including an increase in nutrient content. It was found that the macronutrient content of potato flesh and skin was largely dependent on weather conditions and cultivar. In freshly harvested potatoes, the Ca and Mg contents of flesh and skin and the K content of flesh were highest in the driest year of 2015. The evaluated biostimulants exerted different effects on the macroelement content of potato tubers after harvest and storage. The highest concentration of Ca in the flesh and skin and of K in the skin analyzed after harvest were observed in potatoes treated with Kelpak SL. Trifender WP induced the greatest increase in the K content of potato flesh, whereas the concentrations of P in the skin and Mg in the flesh were highest in potatoes treated with Bio-Algeen S90. The concentration of Na increased 3-fold in the flesh and more than 2-fold in the skin of stored potatoes treated with Asahi SL and Trifender WP. A higher increase in the concentration of P was observed in the skin than in the flesh. The Mg content of potato flesh and skin decreased by around 90%, whereas a smaller decrease was noted in the concentrations of K and Ca in stored tubers. The flesh and skin of potato tubers of cultivars with purple- and red-colored flesh were generally more abundant in macroelements than cultivars with cream- and yellow-colored flesh.

Conflict of Interest

The authors declare no conflict of interest.

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