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Effects of bio-stimulants on the yield of cucumber fruits and on nutrient content

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The aim of the experiment was to assess the effect of bio-stimulants of different composition (Asahi SL - based on three nitrophenol compounds, naturally occurring in plants, as active ingredients; Optisil – mineral growth stimulant containing 24 g L^{-1} of Fe and 200 g L^{-1} of SiO_2; Kelpak SL – manufactured from *Ecklonia maxima* and containing auxins and cytokinins) on the content of macronutrients and micronutrients in cucumber fruits (*Cucumis sativus* L.) and on the fruit yield of the Akord F1 variety. With three replications, the field experiment was conducted in a completely randomised design on a private farm in Wólka Leśna in Poland (N 52°11'59", E 22°24'30"). The experiment was carried out in three growing seasons between 2015 and 2017. Three types of growth regulators and a cucumber variety were used as experimental factors. During the experiment, it was found that in response to bio-stimulants, fruit protein content and the yield significantly increased relative to control. The highest yield was noted after application of the bio-stimulant containing Fe and SiO_2. Additionally, the above products applied to cucumber plants significantly increased magnesium content in the fruits but decreased the amount of sodium. Similarly, higher amounts of iron, manganese, and boron in relation to control were recorded, and in the case of Optysil the content of Zn and Co also increased.

Key words: *Cucumis sativus* L., growth stimulators, macronutrients, micronutrients, protein.

INTRODUCTION

The highly competitive food market of the present times has forced farmers to find new crop growing methods that will allow them to obtain marketable yields of the highest quality. Increasingly, safety of the offered food and care for the natural environment are becoming a priority (Mikiciuk and Dobromilska, 2014; Wierzbowska et al., 2015). On the other hand, manufacturers and farmers must ensure that the technologies used in food production will make use of yield potential of plants in a maximum way. Therefore, due to the pressure exerted on food quality, farmers progressively apply new farming methods. Now, substances with bio-stimulating effects are used growingly around the world, which is an opportunity for the development of sustainable methods of agricultural production in the future (Calvo et al., 2014; López-Bucioa et al., 2015; Chagas Junior et al., 2019).

Increasingly, higher and better quality yields and reduced use of mineral fertilizers and chemical plant protection products are considered a primary issue (Owen et al., 2015; Filipczak et al., 2016). Biological

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Table 1. Soil chemical properties before the experiment (data provided by OSCHR).

Element	Concentration	Rating
Concentration of available macronutrients (g kg^{-1})		
P_2O_5	0.224	Very high
K_2O	0.165	High
Mg	0.056	High
Concentration of available micronutrients (mg kg^{-1})		
B	0.21	Low
Mn	147.0	Medium
Cu	1.3	Low
Zn	5.3	Medium
Fe	1030	Medium

products are extremely effective in plant protection as they are eco-friendly to plants, soil environment, and human health. Substances with bio-stimulating effects increase the resistance of plants to environmental stresses, provide nutrients to plants, and trigger physical changes in the soil (Babuška, 2004; Schwarz et al., 2010; Paradikovic et al., 2011; Zarzecka and Gugała, 2012). Moreover, the literature increasingly points out to an increase in nutrient content in crops after the use of bio-stimulants of different compositions (Wierzbowska et al., 2016; Carillo et al., 2019; Chagas Junior et al., 2019). With their higher demand for nutrients, new crop varieties require even greater intensification of alternative methods of crop growing and plant protection (Bulgari et al., 2015). Their use has beneficial effect on the quality and amount of crop yields, maintaining the full safety of food products at the same time. The literature usually deals with the effect of different types of stimulants on initial plant growth, biomass growth, and on the yield (Boehme et al., 2005; Azizi and Mahmoudabadi, 2013; Musale et al., 2018; Chagas Junior et al., 2019). On the other hand, studies on the effects of growth stimulants on the chemical composition of edible parts of plants can rarely be found, which is why the aim of the experiment was to determine the effect of three bio-stimulating products with various active ingredients on macronutrient and micronutrient content in cucumber fruits of the Akord F1 variety and on their yield.

MATERIALS AND METHODS

The field experiment was conducted in three growing seasons between 2015 and 2017. It was set up on a private farm in Wólka Leśna in Poland (N 52°11'59" E 22°24'30") at the beginning of May, 2015, with a random design, three replications, and a plot area of 40 m^2. The soil on which the experiment was conducted was moderately heavy and its chemical and physical properties were determined by the OSCHR (Regional Chemical and Agricultural Station**)** in Warsaw. It was slightly acidic with the pH in 1 N KCl of 6.49. The concentration of macronutrients and micronutrients in the soil before the start of the experiment is presented in Table 1.

Mineral N was applied in split doses at 120 kg ha^{-1} in the form of ammonium nitrate. Half the dose was added before sowing, mixing the fertilizer with the soil, while the rest was divided into two portions and used as top dressing. The first was applied when plants had 3-4 leaves and the other at the beginning of flowering. K and P were not added to the soil due to their high content there. In the first year, the crop preceding cucumber was sweet clover, which was ploughed into the soil in the previous autumn; in the second year it was soybean and spring wheat in the third. Meteorological conditions during the experiment are given in Table 2.

Experimental factors

1. Kelpak SL, Asahi SL, and Optysil bio-stimulants in doses recommended by the manufacturers;
2. Control (without bio-stimulants);
3. Akord F1, a cucumber variety.

Characteristics of bio-stimulants

Asahi SL is a bio-stimulant with three active substances of the nitrophenol group naturally occurring in plants. It contains sodium para-nitrophenolate (0.3%), sodium ortho-nitrophenolate (0.2%), and sodium 5-nitroguaiacolate (0.1%). Optysil is a mineral growth stimulant that contains 24 g L^{-1} of Fe and 200 g L^{-1} of silicon dioxide SiO_2. Kelpak SL is produced from *Ecklonia maxima* (a seaweed species growing in the southern oceans), and in its composition contains auxins and cytokinins (11 and 0.03 mg L^{-1}). The use of bio-stimulants during the growing season of the cucumber and its doses are given in Table 3.

Cucumber seeds were planted directly into the soil on 26/05 in the first year, on 23/05 in the second year, and on 23/05 in the third year. In 2015, cucumber were harvested on 21/07 for the first time and on 27/08 for the last time; in 2016 on 14/07 for the first time and on 15/08 for the last time; and in 2017 on 17/07 for the first time and on 18/08 for the last time.

The content of ash, dry matter, macronutrients, protein, and micronutrients in fresh cucumber fruits was determined. Chemical analyses of the content of the aforementioned components were performed in the OSCHR (the Regional Chemical and Agricultural Station) in Warsaw. In each growing season, individual bio-stimulants did not affect the content of dry matter, ash, protein,

Table 2. Meteorological conditions during the research (data provided by the Meteorological Station in Siedlce, Poland).

Year	2015	2016	2017	2015	2016	2017
Month	Temperature (°C)			Precipitation (mm)		
01	0.7	-4.2	-4.7	51.4	26.6	11.4
02	0.5	2.9	-1.7	0.7	56.2	34.2
03	4.8	3.3	5.6	53.1	46.4	36.4
04	8.2	8.9	7	30	50.2	81.6
05*	12.3	14.6	13.6	100.2	35.5	45.6
06*	16.5	18.1	17.6	43.3	55.6	59.9
07*	18.7	19	18.1	62.6	126.8	72.1
08*	21	17.9	18.8	11.9	58.2	52.6
09	14.5	14.4	13.7	77.1	15.4	112.3
10	6.5	6.8	9.2	39	161.2	90
11	4.7	2.4	4.2	42.2	39.4	46.4
12	3.7	0.4	1.9	16.5	46.5	27.6
Mean total	9.3	8.7	8.6	528	718	670

*Cucumber growing season.

Table 3. Doses and application times of bio-stimulants.

Bio-stimulant	Characteristics
Kelpak SL	The first treatment at the 2^{nd}-4^{th} leaf stage (BBCH* 12-14), the next two at intervals of 14 days, all treatments with a single dose of 2 L ha^{-1}).
Asahi SL	The first treatment at the stage of the second true leaf on the main stem (BBCH 12-14), with three treatments at intervals of 7 days, each treatment with a single dose of 0.6 L ha^{-1}.
Optysil	5 treatments: 1- the stage of 3-5 true leaves on the main stem (BBCH 13-15); 2 – the stage of 6-9 leaves on the main stem (BBCH16-19); 3 - the stage of 1-2 flower initials with elongated ovary visible on the main stem (BBCH 51-52), 4 - the stage of 6-7 flower initials with elongated ovary visible on the main stem (BBCH 51-52); 5 - after the first harvest (BBCH 71), all treatments with a single dose of 0.5 L ha^{-1}

* The *BBCH*-scale is used to identify development stages of plants.
Source: Adamczewski and Matysak (2005).

macronutrients and micronutrients in cucumber fruits in a statistically significant way. For this reason, the average values for the effect of Kelpak SL, Asahi SL, Optisil and for control for the whole period of 2015 to 2017 were provided. Single factor analysis of variance for multiple groups was used to analyse the results, and a detailed comparison of means was made using Tukey's test at $p \leq 0.05$. Calculations were carried out with the statistical software Statistica 12.

RESULTS AND DISCUSSION

Application of bio-stimulants to cucumber plants of the Akord F1 variety resulted in a large variation in protein content, with statistically significant differences between all kinds of treatment (Table 4).

The highest content, 25.2% higher than in control fruits, was noted on plots with the bio-stimulant produced from *E. maxima* and containing cytokinins and auxins (Kelpak SL) as well as the lowest on the control plot. A similar statistically significant effect of this stimulant on protein content in grass was reported by Ciepiela and Godlewska (2014). Additionally, Zodape et al. (2010) confirmed the effect of seaweed extract on the growth of protein content in bean plants. In the present experiment, dry matter content in plants treated with Kelpak SL, based on *E. maxima*, increased by 15.5% in relation to the control plot. However, cucumber fruits did not respond in a statistically significant way with a higher amount of dry matter to the other bio-stimulants. According to the studies of Gawlik-Wolska et al. (2010), the application of bio-stimulants based on sea algae enriched with P and K and a mineral bio-stimulant to tomato plants did not affect the increase of this parameter in relation to control. Similar results were obtained by Maciejewski et al. (2007)

Table 4. Effects of bio-stimulants on selected parameter content in cucumber fruits and on the yield.

Treatment	Dry matter [%]	Ash [%]	Protein [%]	Yield [kg ha^{-1}]
Asahi SL	3.30^{AB}*	0.636^{AB}	1.17^{B}	18350.0^{B}
Kelpak SL	3.50^{A}	0.630^{AB}	1.24^{A}	17850.0^{B}
Control	3.03^{B}	0.616^{B}	0.99^{D}	16000.0^{C}
Optysil	3.20^{AB}*	0.643^{A}	1.10^{C}	20250.0^{A}
Year	**Growing season effect****			
2015	3.20^{B}	0.63^{A}	1.13^{AB}	17950.0^{B}
2016	3.33^{A}	0.63^{A}	1.14^{A}	19275.0^{A}
2017	3.25^{AB}	0.63^{A}	1.09^{A}	16800.0^{C}

* - the means in columns marked with the same letters do not differ significantly at P = 0.05; **The above means represent results of the experiment carried out between 2015 and 2017.

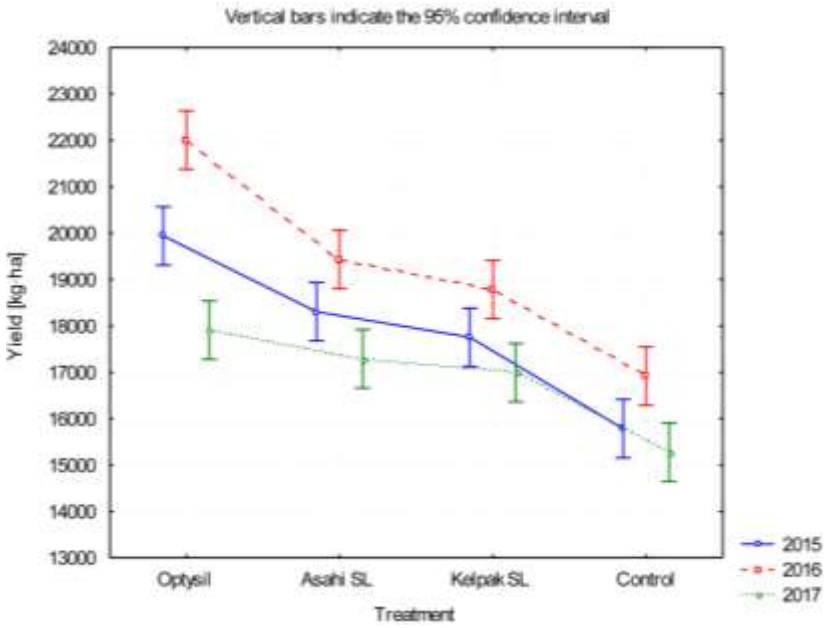

Figure 1. The yield of cucumber fruits throughout the experiment.

and Sawicka and Mikos-Bielak (2008), who after using Asahi SL did not record an increase in dry matter content in potato tubers. In this regard, Łyszkowska and Gajc-Wolska (2008) as well as Gawlik and Gołębiowska (2008) point out that this content is dependent not only on applied bio-stimulants but also on the species of plants.

The bio-stimulants significantly affected the yield of cucumber fruits. In all three growing periods, the lowest yields were obtained on the control plot. Plants treated with Asahi SL and Kelpak SL had their fruit yields at a similar level, significantly higher than from the control plot (Table 4). An increase in potato tuber yields by 14.2 and 24.7% was also recorded by Wierzbowska et al. (2015) after application of the Kielpak SL bio-stimulant. Compared with the effects of other bio-stimulants, Optysil significantly increased the yield of cucumber fruits in 2015 and 2016. In 2017, the fruit yield of plants treated with Optysil was significantly higher than from the control and higher than from plots treated with the other bio-stimulants. The increase in the fruit yield after applying the biostimulant based on Fe and SiO_2 (Optysil) was 26.6% higher than on the control plot. Cucumber fruits growing on the control and on plots where Asahi SL and SL Kelpak SL were applied had the highest yield in 2016, while in 2017 it was significantly the lowest. A similar trend occurred in the case of Optysil, except that the yield in different growing seasons varied significantly from each other (Figure 1).

A significant increase in the yield from individual plots in 2016 was related to the high amount of rainfall and its

Table 5. Effects of bio-stimulants on macronutrient concentration in cucumber fruits, average of three growing seasons (mg 100 g^{-1} DM).

Treatment	Ca	Mg	K	Na	P
Asahi SL	15.9^{AB}*	20.7^{AB}	298.0^{A}	0.85^{C}	39.6^{A}
Kelpak SL	15.9^{AB}*	21.3^{A}	291.2^{AB}	0.91^{B}	37.9^{BC}
Control	14.6^{B}	19.0^{C}	284.4^{AB}	1.15^{A}	36.9^{AB}
Optysil	16.3^{A}	20.0^{B}	294.6^{B}	0.68^{D}	38.6^{C}
Year	**Growing season effect**				
2015	15.2^{B}	19.6^{B}	280.4^{B}	0.84^{C}	38.1^{AB}
2016	16.5^{A}	20.6^{A}	302.2^{A}	0.97^{A}	39.1^{A}
2017	15.2^{B}	20.6^{A}	289.5^{B}	0.89^{B}	37.6^{B}

* - the means in columns marked with the same letters do not differ significantly at P = 0.05.

favourable distribution. In various growing seasons, the amount of rainfall varied (Table 2). In 2016, during the most critical time for the growth and yield of cucumber, from May to August, precipitation was 276.1 mm and was definitely higher than during the other growing seasons. According to Lipiński (2016), the demand of cucumber plants for water during a whole growing season ranges from 400 to 450 mm. Fruits of the Akord F1 cucumber variety were characterised by varying levels of macronutrients. Content of magnesium and sodium was significantly higher in plants treated with bio-stimulants (Table 5).

The highest amounts of magnesium were noted in the fruits treated with Kelpak SL, a bio-stimulant which in its composition contains auxins and cytokinins. It was higher by 12.1% in comparison with the fruits collected from the control plot (Table 5). In the case of Na, the applied products contributed to a reduction in the content of this element in the fruits, which was lower by 69.1% relative to control in plants treated with the mineral bio-stimulant containing Fe and SiO_2 in its composition. This bio-stimulant at the same time increased Ca content in the fruits by 11.6%, and the two others increased the content of this element by 8.9% relative to control. The highest content of K and P was noted in plants treated with the bio-stimulant based on substances from the group of nitrophenols. The content of the above elements increased in comparison with the control plot, respectively, by 4.8 and 7.3% (Table 5). Higher content of K (by 12%) and P (by 15%) in fruits of tomato after applying Asahi SL was noted by Ambroszczyk et al. (2016). An increase in macronutrient content in cucumber leaves after bio-stimulant application was also reported by El-Nemr et al. (2012).

There were significant differences in the content of trace elements between fruits collected from the control and those treated with Optysil, the bio-stimulant containing Fe and SiO_2 (Table 6). The highest increase in the content, by 21.6%, 20.0%, and 13.7%, respectively, was observed in the case of Fe, Cu, and B. The bio-stimulant containing substances from the nitrophenol group (Asahi SL) increased the content of Mn by 13.3% in comparison with cucumber fruits harvested from the control plot. Kelpak SL, the product based on marine algae, increased the content of Zn and Cu by 3.7 and 8.6%; however, it was not a significant difference compared with the control plot. The stimulating effect of Kelpak SL on the content of those elements was confirmed by Godlewska and Ciepiela (2016), who recorded a 10.3% increase in Zn content in grass, with a 9.1% increase in Cu content. Similarly, using an extract of red algae Zodape et al. (2009) obtained a 4.9% increase in Zn content in wheat grains.

An increase in Mn, Zn, Co, and Fe content in potato tubers after application of a substance based on brown algae was also reported by Głosek-Sobieraj et al. (2018). In the present experiment, there was a significant difference in the amounts of these trace elements in cucumber fruits between plants treated with Asahi SL and plants treated with Kelpak SL. Weather conditions, both the temperature and the quantity and distribution of rainfall, did not affect the content of Fe, Zn, Mn and B in cucumber fruits. However, Co content was not the same in different growing seasons, and the highest concentration of this element was reported in the year with the largest amount of rainfall (Tables 2 and 6). This was confirmed by research of Gugała et al. (2016), who recorded the highest content of Co in potatoes during a growing season with high precipitation.

Conclusion

The studies were designed to determine the effects of three bio-stimulants on ash, dry matter, protein, macronutrient, and micronutrient content in cucumber fruits of the Akord F1 variety. The products used in the experiment significantly increased protein content in

Table 6. Effects of bio-stimulants on micronutrient concentration in cucumber fruits (w mg kg^{-1} DM)

Treatment	Fe	Zn	Cu	Mn	B
Ashasi SL	1.98^{B}	2.53^{AB}	0.37^{AB}	0.68^{A}	0.76^{B}
Kelpak SL	1.94^{B}	2.52^{AB}	0.38^{AB}	0.66^{A}	0.78^{B}
Control	1.85^{C}	2.43^{B}	0.35^{B}	0.60^{C}	0.73^{C}
Optysil	2.25^{A}	2.54^{A}	0.42^{A}	0.63^{B}	0.83^{A}
Year	**Growing season effect**				
2015	1.99^{A}	2.50^{A}	0.37^{B}	0.65^{A}	0.77^{A}
2016	2.03^{A}	2.53^{A}	0.39^{A}	0.65^{A}	0.77^{A}
2017	1.99^{A}	2.48^{A}	0.38^{AB}	0.64^{A}	0.78^{A}

* - the means in columns marked with the same letters do not differ significantly at P = 0.05.

cucumber fruits. The highest content was observed after the use of the bio-stimulant produced from marine algae. In addition, all products used in the experiment significantly increased the yield. The highest yield was recorded after the use of the stimulator based on Fe and SiO_2, in the growing period with the highest precipitation. The bio-stimulants used in the experiment significantly lowered Na content in relation to control. In contrast, the highest Mg content was recorded after the use of the seaweed extract, with the increase significantly different from the effects of other treatments. In addition, the bio-stimulants significantly increased Fe, Mn, and B content in cucumber fruits in relation to control, and in the case of Optysila, the content of Zn and Cu as well.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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