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THE EFFECT OF FOLIAR PREPARATION WITH SILICON ON THE YIELD AND QUALITY OF POTATO TUBERS IN COMPARED TO SELECTED BIOSTIMULATORS

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Abstract. In field studies in light soil (loamy sand), the effect of biostimulatory foliar preparations on yield and selected elements of potato tuber quality was assessed. During the growing season, two foliar treatments (in development phases of BBCH 19 and 39) were applied using the Krzemian preparation, as well as Dynamic Plus, Nano Active Forte and Kelpak SL. The control was not subject to foliar fertilisation. Under the influence of foliar fertilisation with Krzemian, a significant increase in tuber yield was obtained, on average by 10.8% compared to the control. The tuber yield following Krzemian application did not differ significantly compared to that obtained under the influence of the preparations Dynamic Plus, Nano Active Forte and Kelpak SL. Significantly higher content of starch and vitamin C was found, as well as a reduction in the level of nitrates in tubers after application of the silicon preparation and other biostimulators in relation to the control. The impact of all preparations had no significant effect on tuber yield structure or the ratio of deformed and green tubers compared to the control.

Key words: biostimulation, foliar fertilisation, potato, quality, yield of tubers

INTRODUCTION

Variable weather conditions during the growing season, heavy precipitation alternating with drought, large fluctuations in air temperature, outbreaks of disease and pests are stressors. Preventive measures should include the activation of natural plant defence systems, stimulation of their growth and development, and tissue strengthening [Dixon 2001, Rykaczewska 2013, Sharma et al. 2014]. A way to improve the condition of plants and thus increase their yield and quality can be foliar fertilization with preparations of various origins containing bioactive compounds and quickly available forms of nutrients [Erlichowski and Pawińska 2003, Trawczyński 2013, Wierzbowska et al. 2015]. One way to improve the condition of plants is foliar fertilisation with silicon, which until now has been given less importance in plant development. As it turns out, this element used in the right form may play a beneficial role in their proper functioning [Mitani and Ma 2005, Raven 2003]. In the soil, silicon occurs in the form of silica, which is practically inaccessible to plants [Sommer et al. 2006]. Silicon applied in right foliar form impregnates the outer epidermis cells, strengthens cell walls, increased their stiffness and resistance to mechanical damage. Due to a thicker cuticle lined with silica, water losses are limited and plants may be less affected by fungal diseases and pests [Fauteux et al. 2005, Sacała 2009]. The beneficial effects of silicon on the ion balance in plants as well as the reduction of toxic effects of excess aluminium, manganese, lead, cadmium, zinc and mercury have also been proven

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[Hou et al. 2006]. In conditions of drought, silicon can reduce the effects of water stress by lower evaporation of water from plants and higher photosynthesis efficiency [Romero-Aranda et al. 2006]. The dry matter of plants such as field horsetail, rice or sugar cane contains 10–15% of silica, cereals and grasses accumulate up to 3% of silica, and dicotyledonous plants have less than 0.5% [Guntzer et al. 2012]. However, previous studies have confirmed the beneficial effect of foliar preparations on yield and its quality in relation to dicotyledons, including root plants [Artyszak et al. 2014] or vegetables [Górecki and Danielski-Busch 2009, Stamatakis et al. 2003, Ugrinović et al. 2011]. The lack of scientifically proven tests from the industry for ready-made silicon preparations prompted them to be carried out in relation to the potato.

The aim of the study was to assess the impact of silicon preparation on yield and selected quality characteristics in potato tubers as compared to technologically different products with nutritional and biostimulatory properties.

MATERIALS AND METHODS

Field experiments were carried out in 2016–2017 at the Plant Breeding and Acclimatisation Institute, Jadwisin division (52°45′ N, 21°63′ E) on light soil, with agranulometric composition of loamy sand. The soil was characterised as acidic, with high phosphorus content, an average potassium, magnesium, manganese, zinc and copper copper, while the level of iron and boron was low (Table 1). Weather conditions during the growing season were assessed on the basis of total rainfall and average air temperatures compared to average multiyear values. The years of research in the initial (April, May) and final (September) period of potato plant growth and development varied significantly in terms of rainfall and average air temperature. During the period of tuber weight increase, the months June, July and August were wet and warm both years. In general, total precipitation and average air temperatures for the entire growing season were higher than the multiyear average (Table 2).

Table 1. Soil conditions in the investigation years

Years	pH_{KCl}	Content in the soil ($mg \cdot kg^{-1}$)							
		P	K	Mg	Fe	Mn	Zn	Cu	B
2016	5.3	86	112	33	575	123	3.7	2.0	0.42
2017	5.0	80	122	32	580	120	3.8	2.4	0.43

Organic fertilisation in the study was fragmented and ploughed after harvesting straw from winter triticale in an amount of about 5 $t \cdot ha^{-1}$ with the addition of 1 kg N per 100 kg of straw and in the autumn the green mass of white mustard stubble intercrop in the amount of 15–16 $t \cdot ha^{-1}$. Mineral fertilisation was carried out in early spring at doses of 26.2 kg $P \cdot ha^{-1}$ (triple superphosphate – 17.4% P) and 99.6 kg $K \cdot ha^{-1}$ (potassium salt – 49.8% K), based on the content available forms of these components in the soil. Nitrogen mineral fertilisation was applied in the spring before tuber planting at a dose of 100 kg $N \cdot ha^{-1}$ (nitro-chalk – 27% N). The experiments were structured as a system of random blocks in three replications. The size of the plot was 14.85 m^2.

The research included the following fertiliser objects:

1. A control object – not subject to foliar treatment,

Table 2. Sum of rainfalls and mean air temperature in vegetation period in compare to means of long-term

Year	Month						
	IV	V	VI	VII	VIII	IX	IV–IX
Rainfalls (mm)							
2016	31.4	92.2	85.4	103.6	61.4	9.5	383.5
2017	8.9	10.1	107.5	78.8	61.0	140.8	407.1
1967–2015	37.0	57.0	75.0	76.0	60.0	48.0	352.0
Temperature (°C)							
2016	9.3	15.3	18.7	19.6	18.4	15.7	16.2
2017	7.3	14.1	18.1	18.4	19.4	13.8	15.2
1967–2015	7.8	13.6	16.5	18.4	17.7	13.1	14.5

2. Krzemian with a composition of (% m/m): Si – 2.5 (in the form of orthosilicic acid); Cu – 1.0; Zn – 0.6; B – 0.3; Mo – 0.2 (liquid preparation),
3. Dynamic Plus with a composition of (% m/m): N – 7.7; Zn – 8.0; Mn – 0.5; Cu – 0.5 (liquid preparation),
4. Nano Active Forte with a composition of (% m/m): K – 10.8; N – 10.0; S – 4.8; Mg – 1.2; Mn – 0.2; Cu – 0.15; Fe – 0.02 (nanotechnological preparation from mineral rocks),
5. Kelpak SL with a composition of (% m/m): 11.0 auxins and 0.031 cytokinins (a liquid preparation agent based on an extract of alga *Ecklonia maxima*).

Foliar treatments were performed two times during the growing season. The first treatment was applied during the development of leaves on the main shoot of potato plants (BBCH 19 phase) and the second during the development of lateral shoots, covering the rows between potato plants (BBCH 39 phase). For each treatment, the preparations were dissolved in 300 $l \cdot ha^{-1}$ of water and used in the following amounts: Krzemian 0.8 $l \cdot ha^{-1}$, Dynamic Plus 1.0 $l \cdot ha^{-1}$, Nano Active Forte 2.0 $kg \cdot ha^{-1}$ and Kelpak SL 1.5 $l \cdot ha^{-1}$. The concentration of the aqueous solution in each treatment was: Krzemian – 0.27%; Dynamic Plus – 0.33%; Nano Active Forte – 0.67%; Kelpak SL – 0.5%. Aqueous solutions of the preparations were prepared immediately before application on the potato plants.

Weeds were removed mechanically (twice before the emergence of the potato plants) and chemically (one treatment immediately before the emergence and the second after the emergence of the potato plants). During the growing season, protective measures against potato blight were carried out 4–5 times, and 2–3 times to prevent beetle infestations. An edible potato, a medium early Oberon variety, was planted by hand in the third decade of April with a spacing of 75x33 cm, and harvested using a combine harvester in the second half of September. The number of plants on the plot was 60. During the harvest, the total yield of tubers from each plot was determined. Next, 2 x 5 kg tuber samples were taken to determine yield structure (weight fraction of tubers with a diameter below 35 mm, 35–50 mm, 50–60 mm and above 60 mm), visible defects (weight proportion of deformed and green tubers) and chemical composition (content of starch, nitrates (V) and vitamin C in the fresh mass of tubers). The starch content was determined using the Eversa polarimetric method (PN-EN ISO 10520-2002), starch hydrolysis was carried out in a boiling water bath, and the protein was precipitated with phosphoric acid using readings on the

Polamat S automatic polarimeter. Nitrate content (NO_3) was determined using the colorimetric method based on the Griess reaction using a mixture of zinc and manganese with a reduction of nitrates to nitrites [Zalewski 1971]. The content of vitamin C was determined as the sum of L-ascorbic acid and dehydroascorbic acid using the Tillmans method involving titration with a solution of 2,6-dichlorophenolindophenol [Rutkowska 1981].

The results of the experiments were statistically analysed using variance analysis with the STATISTICA 10 program. The analysis of the average comparisons was carried out using the Tukey's test at p = 0.05.

RESULTS AND DISCUSSION

In the studies, a very high level of potato tuber yield was obtained, especially in the first year, which probably resulted from a significant amount of rainfall during the growing season, i.e. a good supply of water to the plants. In spite of this, statistical analysis showed a proven increase in tuber yield after the application of foliar fertilisation of the potato plants with biostimulative and nutritional preparations, including silicon compared to the control (Table 3). The average

Table 3. The influence of foliar preparations on the yield of tubers ($t \cdot ha^{-1}$)

Object	Years		
	2016	2017	Mean
Control*	68.0 b	52.8 b	60.4 B
Krzemian	74.2 a	59.6 a	66.9 A
Dynamic Plus	75.0 a	61.4 a	68.2 A
Nano Active Forte	73.7 a	62.4 a	68.0 A
Kelpak SL	72.5 a	62.5 a	67.0 A
Mean	72.7 A	59.3 B	–

*– without foliar preparations
Means within columns followed by the same letter are not significantly different at p=0.05

difference in tuber yield during the study years was 6.5 $t \cdot ha^{-1}$, or 10.8% greater following the use of Krzemian compared to the control, which was not subjected to foliar fertilisation. Under the influence of other preparations, only the tendency toward tuber yield increase in relation to the preparation of Krzemian was found, which demonstrates a similar effectiveness on potato plants. The own earlier studies showed a 9% increase in tuber yield after foliar application of marine calcite (Herbagreen Basic) containing 7.99% silicon [Trawczyński 2013]. With respect to the sugar beet, the root crop yield increased by an average of 21% compared to the control [Artyszak et al. 2016]. In Dutch studies, after foliar application of silicic acid, the tuber yield increased by 6.5% compared to the control [Laane 2017]. In glasshouse research, Crusciol et al. [2009] showed an increase tuber yield by 11.4% in relation to the control under conditions of drought stress after using calcium and magnesium silicate. Ryakhovskaya et al. [2016], depending on the type of silicon preparations used (in liquid form, gel, powder), noted growth in tuber yield from 10.7 to 20.3% compared to the control. However, in field trials conducted by Wróbel

[2012], the foliar silicon preparation Actistil did not increase potato tuber yield in comparison to the control. In general, biostimulating formulations have a more beneficial effect on potato yield during growing seasons with unfavourable weather conditions, especially those resulting from the rainfall distribution. Wierzbowska et al. [2015] reported an increase in tuber yield under the influence of foliar biostimulators, including Kelpak SL during conditions of excess rainfall and air temperatures exceeding the average multiyear value, on average 20% higher compared to the control. Similarly, Cwalina-Ambroziak et al. [2015] noted the beneficial effect of this preparation on tuber yield during a period of infection pressure by potato blight resulting from excess rainfall. In the conducted research, the diversification of tuber yield was also due to rainfall distribution during the growing season. In the year with more even rainfall distribution during the vegetation period (2016), the increase in tuber yield under the influence of Krzemian was 9.1%, and with respect to the remaining preparations ranged from 6.6 to 10.3% in relation to the control. In contrast, during the year with less favourable rainfall distribution (2017), the tuber yield increased by 12.9% after applying of Krzemian, and by 16.9 to 18.4% compared to the control following the remaining preparations.

The differentiation between the analysed years was also confirmed in relation to the size and appearance of tubers in the yield structure Table 4). In the first year of research were obtained a significantly smaller share in the tuber yield structure with a diameter less than of 35 mm and from 35 to 50 mm by 5.1 and 18.3% respectively and significantly larger tubers with a diameter of 50–60 mm and above 60 mm by 10.4 and 13.1% respectively than in the second year of the study. Between treated plants and in relation to the control object, there was no significant difference in the size of tubers in the yield (Table 4). According to a study by Wróbel [2012], after using foliar fertilisation with a silicon preparation, only a significant reduction in tuber fraction with a diameter of less than 30 mm was obtained. Głosek-Sobieraj et al. [2018], after using foliar biostimulatory substances containing marine algae, reported an increase in the share of tuber yields with a diameter of 35–50 mm. In turn, Matysiak and Adamczewski [2010] obtained an increase in the share in the yield by 30% of tubers in diameter above 60 mm after the use of Kelpak in a dose of 1.5 $l\cdot ha^{-1}$, and in a dose of 2 $l\cdot ha^{-1}$ by 45% compared to control. The use of silicon as well as other components in the tested preparations did not result in significant differences in the ratio of deformed and green tubers in the yield structure (Table 5). The share of deformed and green tubers among the control sample did not differ significantly in relation to the sample subjected to foliar fertilisation. Generally, the high yield level obtained in 2016 probably contributed to a significant increase in the tuber yield structure with visible defects, deformed by 13.0% and green by 7.2% compared to 2017.

In turn, the chemical composition of tubers differed significantly in relation to the examined objects. Significantly greater beneficial effects on the content of starch in tubers compared to the control were found for all the applied preparations, although in the first year no significant increase in this component was observed under the influence of Krzemian application (Table 6). Due to the high level of precipitation during the growing season, the level of nitrates (V) in the tubers was generally low. On average in the years studied, there was a significant reduction in the level of nitrates (V) in tubers under the influence of foliar fertilisation with Nano Active Forte and Kelpak SL preparations compared to the control (Table 7). However, after the use of Krzemian and Dynamic Plus, an increase of vitamin C in tubers compared to other preparations and the control was observed (Table 8). Wierzbowska et al. [2015] stated that the quality of potato tubers was more dependent on the properties of the variety than the biostimulants used. In relation to the analysed years, it was shown that in the first year, with better rainfall distribution during the growing season, the level of all analysed components was significantly higher in tubers than in the second year of research.

Table 4. The influence of foliar preparations on the structure tubers yield (% by weight)

Object	Percent of tubers in diameter (mm)											
	<35			35-50			50-60			>60		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Control*	1.0 a	6.5 a	3.7 A	19.8 a	48.8 a	34.3 A	40.3 a	23.2 a	31.8 A	38.9 a	21.5 a	30.2 A
Krzemian	1.5 a	6.2 a	3.8 A	22.5 a	43.0 a	32.8 A	36.6 a	23.9 a	30.2 A	39.4 a	26.9 a	33.2 A
Dynamic Plus	2.3 a	10.1 a	6.2 A	21.5 a	36.1 a	28.8 A	27.4 a	20.7 a	24.0 A	48.8 a	33.1 a	41.0 A
Nano Active Forte	1.6 a	5.3 a	3.5 A	24.6 a	37.7 a	31.2 A	34.9 a	24.9 a	29.9 A	38.9 a	32.1 a	35.4 A
Kelpak SL	2.0 a	6.1 a	4.1 A	23.5 a	38.0 a	30.8 A	30.5 a	24.8 a	27.7 A	44.0 a	31.1 a	37.6 A
Mean	1.7 B	6.8 A	–	22.4 B	40.7 A	–	33.9 A	23.5 B	–	42.0 A	28.9 B	–

*– without foliar preparations
Means within columns followed by the same letter are not significantly different at p=0.05

Table 5. The influence of foliar preparations on the share in yield of tubers with outside faults (% by weight)

Object	Faults								
	Deformations			Greens			Sum		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Control*	22.0 a	9.8 a	15.9 A	10.2 a	2.0 a	6.1 A	32.2 a	11.9 a	22.0 A
Krzemian	21.9 a	8.6 a	15.3 A	9.8 a	1.9 a	5.8 A	31.7 a	10.6 a	21.2 A
Dynamic Plus	22.5 a	8.9 a	15.7 A	8.2 a	1.9 a	5.0 A	30.7 a	10.8 a	20.7 A
Nano Active Forte	20.5 a	7.4 a	14.0 A	8.4 a	1.6 a	5.0 A	29.0 a	9.1 a	19.0 A
Kelpak SL	23.0 a	9.0 a	16.0 A	9.2 a	1.8 a	5.6 A	32.2 a	10.8 a	21.5 A
Mean	21.7 A	8.7 B	–	9.1 A	1.9 B	–	30.8 A	10.6 B	–

*– without foliar preparations
Means within columns followed by the same letter are not significantly different at p=0.05

Table 6. The influence of foliar preparations on the content of starch in tubers (%)

Object	Years		
	2016	2017	Mean
Control*	14.6 b	13.1 b	13.8 B
Krzemian	14.7 b	14.3 a	14.5 A
Dynamic Plus	15.5 a	14.0 a	14.7 A
Nano Active Forte	15.4 a	14.1 a	14.7 A
Kelpak SL	15.6 a	14.4 a	15.0 A
Mean	15.0 A	13.9 B	–

*– without foliar preparations; Values followed by the same letter are not significantly different at p=0.05

Table 7. The influence of foliar preparations on the content of nitrates (V) in tubers ($mg \cdot kg^{-1}$)

Object	Years		
	2016	2017	Mean
Control*	43.0 a	11.0 a	27.0 A
Krzemian	39.0 a	7.6 b	23.3 B
Dynamic Plus	36.0 a	6.3 b	21.1 B
Nano Active Forte	28.0 b	5.0 b	16.5 C
Kelpak SL	27.0 b	6.0 b	16.5 C
Mean	36.5 A	7.5 B	–

*– without foliar preparations; Values followed by the same letter are not significantly different at p=0.05

Table 8. The influence of foliar preparations on the content of vitamin C in tubers ($mg \cdot kg^{-1}$)

Object	Years		
	2016	2017	Mean
Control*	243.0 b	224.0 c	233.5 C
Krzemian	250.6 a	232.3 b	241.5 A
Dynamic Plus	245.6 b	239.6 a	242.6 A
Nano Active Forte	245.6 b	233.0 b	239.3 B
Kelpak SL	244.0 b	232.0 b	238.0 B
Mean	246.2 A	232.2 B	–

*– without foliar preparations; Values followed by the same letter are not significantly different at p=0.05

CONCLUSIONS

1. The effect of the Krzemian preparation on the yield of potato tubers did not differ significantly compared to the preparations: Dynamic Plus, Nano Active Forte and Kelpak SL.
2. On average, in the years under the influence of preparations: Krzemian, Dynamic Plus, Nano Active Forte and Kelpak SL, the yield of tubers increased respectively by 10.8; 12.9; 12.6 and 10.9% in compared to the control.
3. A more beneficial effect on the yield of tubers of all preparations was found in the year with a more uneven distribution of rainfall during the growing season.
4. After the application of research preparations, the content of starch and vitamin C can be expected to increase and decrease the level of nitrates (V) in compared to the control object.
5. There were no significant differences in the size, deformed and green of tubers in the yield between of Krzemian and other preparation in relation to the control.

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WPŁYW DOLISTNEGO PREPARATU KRZEMOWEGO NA PLON I JAKOŚĆ BULW ZIEMNIAKA W PORÓWNANIU DO WYBRANYCH BIOSTYMULATORÓW

Synopsis. W badaniach polowych na glebie lekkiej (piasek gliniasty) oceniono wpływ dolistnych preparatów biostymulujacych na plon i wybrane elementy jakości bulw ziemniaka. W okresie wegetacji 2-krotnie (w fazach rozwojowych BBCH 19 i 39) przeprowadzano zabiegi dolistne z wykorzystaniem preparatu Krzemian oraz preparatami: Dynamic Plus, Nano Active Forte i Kelpak SL. Kontrolę stanowił obiekt bez dolistnego dokarmiania. Pod wpływem dolistnego dokarmiania preparatem Krzemian uzyskano istotny przyrost plonu bulw, średnio o 10,8% w stosunku do kontroli. Plon bulw po zastosowaniu preparatu Krzemian nie różnił się istotnie w stosunku do uzyskanego pod wpływem preparatów: Dynamic Plus, Nano Active Forte i Kelpak SL. Stwierdzono istotnie większą zawartość skrobi i witaminy C oraz obniżenie poziomu azotanów w bulwach po zastosowaniu preparatu Krzemian i pozostałych biostymulatorów w stosunku do kontroli. Działanie wszystkich preparatów nie miało istotnego wpływu na strukturę plonu bulw oraz udział w plonie bulw zdeformowanych i zazielenionych w porównaniu do kontroli.

Słowa kluczowe: biostymulacja, dolistne dokarmianie, ziemniak, jakość, plon bulw

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