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Effect of plant growth regulators on potato tuber yield and quality

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Abstract: The aim of the study conducted in 2019–2021 was to determine the effect of biostimulants and growth regulators on the yield size and structure, as well as the chemical composition of edible potato tubers. The cultivar evaluated was Vineta. Asahi SL, Kelpak SL, Aminoplant, Tytanit, gibberellic acid (GA3) and Moddus 250 EC were applied in potato cultivation. The application of biostimulants Asahi SL and Tytanit increased the total and marketable tuber yield, as well as the average tuber weight. Aminoplant had a beneficial effect only on the marketable yield, while Moddus 250 EC decreased tuber yield and mean tuber weight, especially under conditions of high rainfall. Biostimulant Asahi SL caused a decrease in the number of tubers formed, while gibberellic acid stimulated tuberisation. Both preparations increased the share of deformed tubers in the total yield. The effect of biostimulants and growth regulators on the formation of the chemical composition of potato tubers was multidirectional. Tytanit increased protein content in tubers, while the remaining preparations, with the exception of the growth regulator Moddus 250 EC, decreased the amount of this component. GA3 and Moddus 250 EC decreased the content of crude fibre and, in the case of Moddus 250 EC, also the content of mineral components. The highest concentration of nitrates (V) was characteristic for potato tubers treated with Asahi SL and the lowest for those treated with Moddus 250 EC.

Keywords: *Solanum tuberosum* L.; tuberous crop; biologically active substance; starch content; climate change

Agricultural progress, being a part of the modern agriculture model, exerts pressure to look for innovative methods of agricultural production intensification and improvement of quality parameters, with simultaneous reduction of negative environmental impact (Caradonia et al. 2022). Preparations catalysing all metabolic processes, more broadly called biostimulants, are an answer to these needs. Currently, the range of preparations based on biologically active substances shows great diversity in terms of origin, which is the main problem of their definition (Du Jardin 2015). Arafa et al. (2011) and Farouk (2015) showed that the application of biostimulants, especially extracts of marine algae, positively affects the development of aboveground biomass of potato plants, chlorophyll content in leaves and number of tubers. According to Maini (2006), Wadas and Diurgieł (2020) and Mousavi et al. (2022), the use of biostimulants mitigates the negative effects of biotic and abiotic stresses. Zarzecka et al. (2022) demonstrated reduced glycoalkaloid (TGA) content in potato tubers after biostimulant application. Another group of biologically active substances are plant growth regulators, i.e., products whose action consists mainly in inhibiting the processes of excessive shoot growth while maintaining their natural production potential (Rademacher 2000). The advantages of using growth regulators include increased leaf blade thickness, intensification of greenness, and better rooting. Rademacher (2020) distinguishes ethylene releasing compounds, inhibitors of gibberellin translocation and inhibitors of gibberellin biosynthesis in the group of growth regulators.

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Climate change leads to an increase in the frequency of extreme weather events, and some agrotechnical practices negatively affect the yield formation and quality of agricultural products (Van Oort et al. 2012, Sharma et al. 2017). The introduction of an additional agrotechnical treatment, based on the application of biostimulants, aimed at minimising the adverse effects of abiotic and biotic factors on plant growth, development and yield, may be necessary in the near future. Biostimulants are gaining increasing interest in sustainable agriculture because they increase nutrient use efficiency stimulating plant growth, and enable reduced fertiliser use (Ziosi et al. 2013).

The aim of the study was to determine the effect of biostimulants and plant growth regulators on the size and structure of yield and quality of edible potato tubers.

MATERIAL AND METHODS

Field experimental design. The study was conducted in 2019–2021 at the Experimental Station in Prusy (50°07'N and 20°05'E, 272 m a.s.l.) belonging to the Department of Agroecology and Plant Production, Agricultural University of Krakow, Poland. A single-factorial field experiment was established in a randomised block design in 3 replications. Biostimulants and plant growth regulators applied in potato cultivation were the experimental factors. The following objects were evaluated: control; Asahi SL; Kelpak SL; Aminoplant; Tytanit; gibberellic acid (GA3); and Moddus 250 EC (Table 1). Tubers of the early potato cv. Vineta were planted at a spacing of 75.0 × 35 cm in the first decade of April, while harvesting took place in the first decade of September. The harvest plot size was 15.75 m^2. The forecrop for potato was winter wheat. Tillage was carried out according to generally accepted principles of correct potato agrotechnics. Nitrogen fertilisation was applied at the total dose of 135 kg N/ha, 90 kg N before planting, and 45 kg N for top dressing; phosphorus fertilisation was applied at the rate of 26.2 kg P/ha, while potassium fertilisation at the rate of 149 kg K/ha. Weed control was carried out by mechanical-chemical method using Plateen 41.5 WG herbicide (metribuzin 350 g a.i./ha + flufenacet 480 g a.i./ha). Los Ovados 200 SE (acetamiprid, 30 g a.i./ha) was used against potato beetle, while the plants were protected against *Phytophtora infestans* with fungicide Infinito 687.5 SC (fluopicolide 93.8 g a.i./ha + propamocarb hydrochloride 937.5 g a.i./ha).

Soil and meteorological conditions. The field experiment was located on Haplic Chernozem (Siltic). Arable layer of soil (0–25 cm) was characterised by: high abundance of phosphorus (75.8–80.4 mg P/kg); medium abundance of potassium (133.3–146.8 mg K/kg); high abundance of magnesium (56.0–67.0 mg Mg/kg); C_{org} content of 11.3 g/kg; neutral reaction (pH_{KCl} 6.8–7.0); content of sand 120–130 g/kg; silt 533–540 g/kg and clay 337–345 g/kg.

The characteristics of precipitation-thermal conditions are shown in Figure 1 and Table 2. In 2019, the total precipitation from April to August was 70 mm

Table 1. Characteristics of preparations, doses and dates of application

Growth regulator	Characteristic	Doses and dates of application BBCH scale		
		31–32	51–52	61–62
Control	–	–	–	–
Asahi SL	growth regulator, sodium para-nitrophenolate – 3 g/L, sodium ortho-nitrophenolate – 2 g/L, sodium 5–nitroguaiacolate – 1 g/L	0.5 L/ha	0.5 L/ha	0.5 L/ha
Kelpak SL	biostimulant, extract from algae *Ecklonia maxima*, auxins 11 mg/L, cytokinins 0.031 mg/L	2.0 L/ha	2.0 L/ha	
Aminoplant	biostimulant, N_{tot} 9.1%, N_{org} 8.7%, N-NH_4 0.4%, free amino acids > 10.0%, C_{org} > 24.0%, organic substance 63.0% (DM)	1.5 L/ha	1.5 L/ha	
Tytanit	biostimulant, Ti 8.5 g/L	0.3 L/ha	0.3 L/ha	0.3 L/ha
GA3	growth regulator, gibberellic acid	20 mg/L	20 mg/L	
Moddus 250 EC	plant growth regulator, trinexapac-ethyl 250 g/L	0.3 L/ha		

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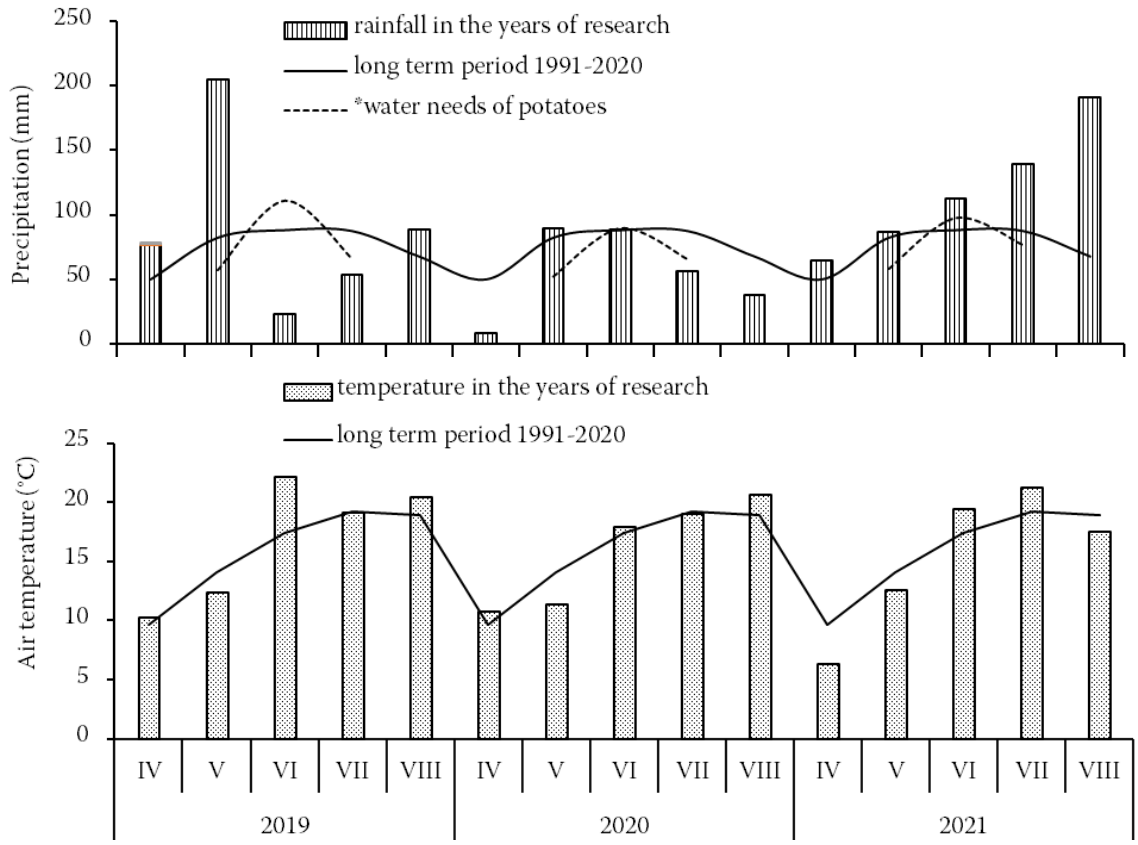

Figure 1. Characteristics of weather conditions, *water needs according to Klatt (citation for Nyc 2006)

(19%) higher than in the corresponding period of the multi-year. A very high amount of precipitation was recorded in May. Particularly unfavourable weather conditions prevailed in June due to a very low amount of precipitation and a higher than average air temperature by 4.5 °C. The year 2020 was characterised by the lowest amount of precipitation in the three-year study cycle (75% of the multi-year average). Precipitation deficits occurred in April and the final period of potato vegetation. Different moisture conditions prevailed in 2021. The total precipitation from April to August was 118 mm (63%) higher than the multi-year average and significantly exceeded the precipitation needs of potatoes.

Assessment of the size and yield structure and chemical composition of tubers. Prior to potato harvest, tuber samples were taken from 15 plants in each plot to determine the number of tubers per plant, mean tuber weight, proportion of marketable (> 35 mm) and large (> 50 mm) tuber fractions, and proportion of deformed tubers. The total tuber yield was determined at harvest, and the marketable yield was estimated based on the proportion of marketable fractions separating the green and deformed tubers. Starch content was determined using a hydrostatic balance, total protein by the Kjeldahl method (N × 6.25), fibre, fat and ash by near-infrared spectroscopy (NIRS), while nitrate (V) by potentiometric method.

Table 2. Characteristics of weather conditions – Sielininov coefficients

Year	Month					Mean
	IV	V	VI	VII	VIII	
2019	2.5	5.5	0.3	0.9	1.4	2.1
2020	0.2	2.6	1.7	1.0	0.6	1.2
2021	3.3	2.3	1.9	2.2	3.6	2.7

extremely dry < 0.4; very dry 0.4–0.7; dry 0.7–1.0; fairly dry 1.0–1.3; optimal 1.3–1.6; fairly wet 1.6–2.0; wet 2.0–2.5; very wet 2.5–3.0; extremely wet > 3.0 (Skowera and Puła 2004)

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Statistical analysis. The results were subjected to statistical evaluation using an analysis of variance. Honestly significant differences (*HSD*) for the investigated features were verified using Tukey's test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

A three-year study showed a significant effect of biostimulants and growth regulators on potato yield, number of tubers per plant and mean tuber weight (Table 3). The greatest effectiveness expressed in the increase of total yield and marketable tuber yield in all years of the study was observed for Asahi SL. The average increase in the total tuber yield compared with the control was 6.5 t/ha (17.8%), while the marketable yield – was 6.8 t/ha (23.0%). The favourable effect of the preparations evaluated in this study on the total yield was also observed after the application of Tytanit and GA3; the increase in yield was 1.6 t/ha (4.4%) and 1.2 t/ha (3.3%), respectively. A significant increase in the marketable tuber yield was observed after the application of biostimulants Aminoplant and Tytanit. On the other hand, the application of the growth regulator Moddus 250 EC had a negative effect on the yield. Different results were obtained by Sawicka (2000) as well as Matysiak and Adamczewski (2010), who showed a yield increase from 13% to 35% depending on the dose and date of this preparation application. Wierzbowska et al. (2015) showed an advantage of Kelpak SL by 17.6% compared to Asahi SL in terms of yield, while Zarzecka et al. (2020) reported higher efficiency of biostimulant Asahi SL than Kelpak SL. The number of tubers set ranged from 11.7 to 12.7 pcs. Treatment of potato plants with gibberellic acid (GA3) stimulated tuberisation, while Asahi SL application resulted in a decrease in the number of tubers set. Growth regulators and biostimulants also differentiated the mean tuber weight. The application of Asahi SL and the biostimulant Tytanit significantly increased the value of this trait, while the application of the regulator Moddus 250 EC caused the tubers to become smaller. In the study by Sawicka (2000), the growth

Table 3. The size and structure of tuber yield

Growth regulator	Total yield (t/ha)				Commercial yield (t/ha)			
	2019	2020	2021	mean	2019	2020	2021	mean
Control	33.0	36.9	39.6	36.5	24.9	29.7	34.1	29.6
Asahi SL	37.1	42.1	49.9	43.0	29.1	36.6	43.5	36.4
Kelpak SL	33.5	37.3	39.7	36.8	25.4	30.1	35.1	30.2
Aminoplant	33.4	37.5	40.5	37.1	25.4	31.3	35.3	30.7
Tytanit	34.3	38.8	41.1	38.1	26.0	33.6	35.1	31.6
GA3	33.7	38.2	41.3	37.7	23.7	32.4	35.0	30.4
Moddus 250 EC	34.6	36.6	34.8	35.3	27.2	29.0	28.7	28.3
Mean	34.2	38.2	41.0		26.0	31.8	35.2	
$HSD_{0.05}$ for:	year 0.5; growth regulator 1.0 interaction year × growth regulator 1.7				year 0.5; growth regulator 0.9 interaction year × growth regulator 1.5			
	Number of tubers per plant (pcs)				Average tuber weight (g)			
Control	11.8	12.7	12.1	12.2	80.2	82.5	92.7	85.1
Asahi SL	10.7	12.4	11.9	11.7	97.8	96.0	112.0	101.9
Kelpak SL	11.8	12.8	12.1	12.2	78.3	82.0	92.0	84.1
Aminoplant	11.7	12.7	12.1	12.1	81.1	82.7	93.3	85.7
Tytanit	11.1	13.3	12.4	12.3	87.1	83.9	93.7	88.2
GA3	11.9	13.1	13.1	12.7	80.7	85.4	87.2	84.4
Moddus 250 EC	10.8	13.1	12.2	12.0	89.3	80.0	77.3	82.2
Mean	11.4	12.9	12.3		84.9	84.7	92.6	
$HSD_{0.05}$ for:	year 0.2; growth regulator 0.3 interaction year × growth regulator 0.4				year 1.2; growth regulator 2.3 interaction year × growth regulator 3.9			

HSD – honestly significant difference

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regulator Moddus 250 ME caused an increase in both the average weight and number of tubers per plant and the yield of seed potatoes. Growth regulators inhibit the synthesis of gibberellic acid, increasing the proportion of medium and large tubers, while exogenous gibberellins stimulating tuber setting cause their smaller size and thus decrease the marketable yield (Alexopoulus et al. 2006, Xu and Geelen 2018).

The most favourable weather conditions for yield were noted in 2021, characterised by the highest rainfall in the three-year study cycle. However, the lowest tuber yields were recorded in 2019. According to Gugała et al. (2013), the most favourable years for yield accumulation are those with low rainfall and higher than the average mean air temperature. The application of Asahi SL resulted in significant increases in tuber yield in all years of the study, but the highest increases in total and marketable yield and average tuber weight were recorded in the season with the highest amount of rainfall by 26.0 and 27.6 and 20.8%, respectively. On the other hand, the application of Moddus 250 EC under high rainfall caused a significant decrease in the values of these traits, for total yield by 12.1%, marketable yield by 15.8% and mean tuber weight by 16.6%, respectively. The favourable effect of Moddus 250 EC on marketable yield and mean tuber weight was recorded in 2019, characterised by particularly unfavourable moisture and thermal conditions prevailing in June.

The proportion of marketable tuber fraction ranged from 82.7% to 88.7%, while that of large tubers ranged from 41.3% to 51.2% (Figure 2A). The application of Asahi SL, Aminoplant, Tytanit and GA3 increased the proportion of marketable tuber fractions, while Kelpak SL and Moddus 250 SE decreased the weight of marketable tubers in the total yield, but the differences were not statistically confirmed. Growth regulators and biostimulants significantly differentiated the share of large and deformed tuber fractions in the yield. A significant increase in the fraction of large tubers was observed after the treatment with Asahi SL (12.5%) and Tytanit (5.7%), while it decreased on objects treated with the growth regulator Moddus 250 EC. The proportion of severely deformed tubers ranged from 1.5 after application of the biostimulant Kelpak SL (auxins and cytokinins) to 6.5% after application of gibberellic acid (Figure 2B). Matysiak and Adamczewski (2010) proved that plant feeding

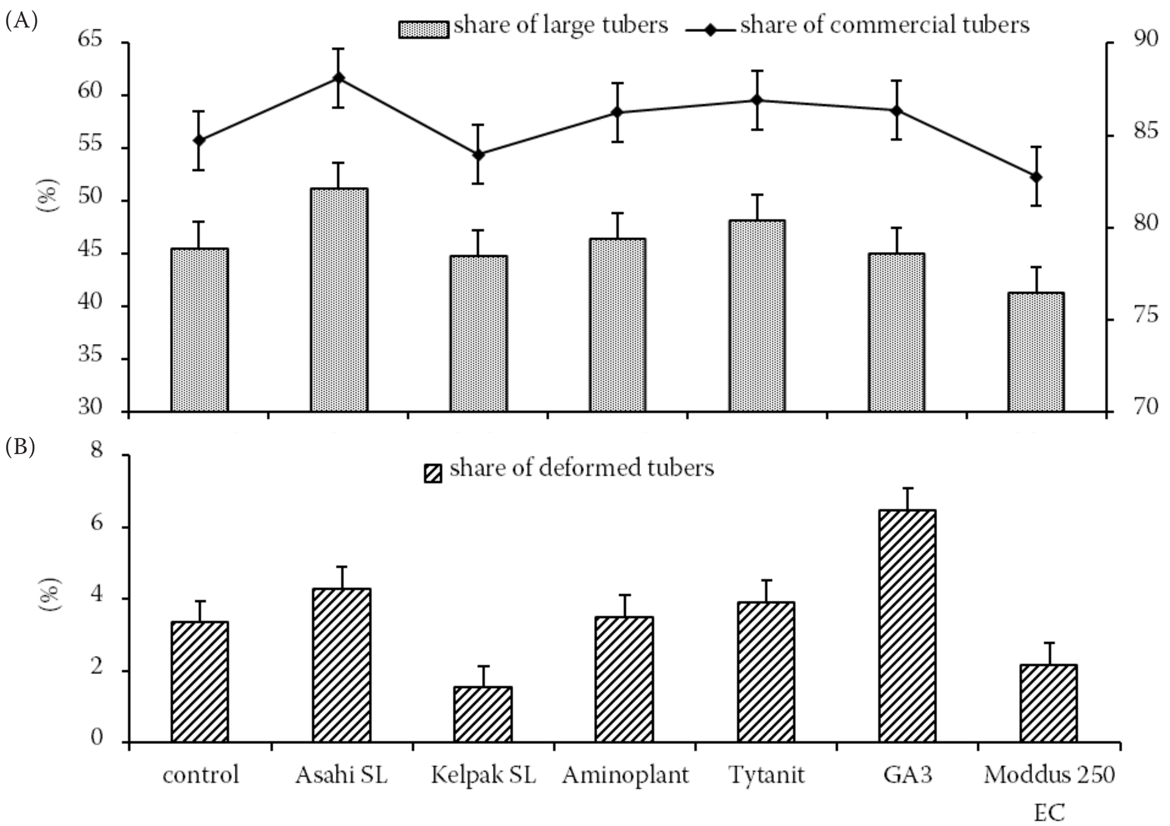

Figure 2. (A) Share of large and commercial tubers and (B) share of deformed tubers depending on plant growth regulators

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Table 4. The chemical composition of the potato tubers

Factor	Starch	Protein	Fat	Fibre	Ash	Nitrates (V)
	(g/kg)					(mg/kg)
Growth regulator						
Control	133.5	19.5	1.1	14.5	11.0	48.4
Asahi SL	134.9	18.6	1.2	15.0	11.3	53.4
Kelpak SL	136.1	17.8	1.0	14.2	10.5	47.3
Aminoplant	135.1	18.9	1.1	14.1	10.6	49.3
Tytanit	133.2	20.3	1.1	14.7	10.7	47.0
GA3	129.2	19.1	1.0	13.3	10.3	47.9
Moddus 250 EC	128.1	19.7	1.1	13.8	9.7	37.2
$HSD_{0.05}$	6.4	0.4	ns	0.6	1.1	4.8
Year						
2019	125.8	19.2	1.1	13.0	9.9	57.3
2020	143.0	18.5	1.1	15.5	11.0	32.9
2021	129.4	19.6	1.1	14.2	10.8	51.5
$HSD_{0.05}$	3.3	0.2	ns	0.3	0.6	23.0

ns – no significant differences; *HSD* – honestly significant difference

with biostimulants increases the share of large tubers (diameter over 60 mm) in the yield even by 45%.

The study showed the differential effects of biostimulants and growth regulators on the chemical composition of potato tubers (Table 4). Asahi SL, Kelpak SL and Aminoplant increased, while GA3 and Moddus 250 EC decreased the starch content in tubers as compared to the control, but the differences were not statistically confirmed. The results of Rudzińska-Mękal (2000) indicate a tendency to increase the starch content in tubers after the application of ethyl trinexapac by 1.5–3.3%. In turn, Maciejewski et al. (2007) claim that potato does not show any reaction to the application of Asahi SL in terms of dry matter and starch accumulation.

Tytanit contributed to a significant increase in the total protein content, while the remaining preparations, with the exception of the growth regulator Moddus 250 EC, caused a significant decrease in the content of this component. The growth regulators GA3 and Moddus 250 EC decreased the crude fiber content in the tubers, and in the case of Moddus 250 EC also, the content of mineral components. The highest content of nitrates (V) was found in potato tubers treated with Asahi SL biostimulant and the lowest after the application of the Moddus 250 EC regulator. Also, Zarzecki et al. (2019) showed increased content of this nitrogen form in tubers under the influence of biostimulant Asahi SL. The chemical composition of tubers also significantly depended on the course of weather conditions during potato vegetation. In the year with the lowest rainfall, the highest content of starch, fiber and mineral components in tubers was recorded, concurrently with the lowest accumulation of nitrates (V). The obtained results are consistent with the study by Grudzińska and Zgórska (2008), which also showed the lowest accumulation of nitrates under conditions of a warm and dry vegetation period.

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