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Analysis of the morphological features of potato tubers after the application of biostimulants and herbicide**

Krystyna Zarzecka[1], *Marek Gugała*[1], *Agnieszka Ginter*[1]*, *Waldemar Durakiewicz*[2], *Iwona Mystkowska*[3]

[1]Faculty of Agricultural Sciences, University of Siedlce, Konarskiego 2, 08-110 Siedlce, Poland
[2]Podlasie Vodka Distillery "POLMOS" S.A. based in Warszawa, Frascati 12, 00-483 Warszawa, Poland
[3]Bialska Academy of John Paul II, Sidorska 95/97, 21-500 Biała Podlaska, Poland

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A b s t r a c t. The test results were based on a field experiment conducted in 2018-2020 at the Zawady Experimental Farm, owned by the University of Siedlce in Poland. Two factors were tested in the experiment: I – two edible potato cultivars – Oberon and Malaga, II – five variants: application of biostimulants: PlonoStart, Aminoplant, and Agro-Sorb Folium with herbicide Avatar 293 ZC, application of only herbicide Avatar 293 ZC, and a control object without the biostimulants and herbicide. Just before harvest, tubers from ten plants were dug from each plant to assess the yield structure. The following morphological features were determined in edible tubers with a diameter above 35 mm: tuber shape, regularity of tuber shape, skin appearance, depth of eyes, and tuber size. The cultivar, variants of application of the biostimulants and herbicide, and weather conditions in the years of research significantly determined the external characteristics of the tubers. The PlonoStart, Aminoplant, and Agro-Sorb Folium biostimulants had a positive effect on the determined morphological features, compared to tubers from the control object.

K e y w o r d s: *Solanum tuberosum* L., cultivars, growth regulators, tuber morphology

1. INTRODUCTION

Potato, or as it is called the "bread of the poor", is a traditional product and the world's fourth largest consumption culture after rice, wheat, and maize (Pilana *et al*., 2018). Compared to other food crops, potatoes have many advantages: easy storage, high yield, low soil requirements, broad adaptability, and a wide cultivation range, and above all, high nutritional value. In addition, the potato is considered a crop with high potential for food security (Teshome *et al*., 2014; Priyadarshini *et al*., 2020). The quality of potato tubers for direct consumption is determined by external characteristics defined as morphological (tuber size, tuber shape, regularity of shape, depth of eyes, skin appearance and defects) and internal, including flesh characteristics, *i.e.* culinary characteristics (culinary type, flesh color, darkening of the flesh of raw and cooked tubers) and nutritional value (chemical composition) and low content of harmful substances (Arslanoglu *et al*., 2011; Zarzecka *et al*., 2014; Leonel *et al*., 2017; Cordeiro *et al*., 2022). These properties depend on many factors, including genetic features of the cultivars, cultivation treatments, fertilization, protection against agrophages, the use of growth stimulants, and weather conditions during the plant vegetation (Haider *et al*., 2012; Trawczyński, 2018; Mystkowska, 2019; Cordeiro *et al*., 2022; Ginter *et al*., 2023).

*Corresponding author e-mail: agnieszka.ginter@uws.edu.pl
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Along with fertilization and plant protection, natural and synthetic biostimulants constitute one of the elements of agrotechnology and they are gaining increasing popularity in modern agriculture. They mitigate the adverse impact of biotic and abiotic stresses and enhance plant resistance, thus positively influencing their growth and development, and subsequently, the quantity and quality of yields (Prajapati *et al*., 2016; Drobek *et al*., 2019; Zarzecka *et al*., 2021; Findura *et a*l., 2022). Most studies on the use of biostimulants in potato cultivation have focused on yield performance, chemical composition, or the consumption-related value of tubers (Wierzbowska *et al*., 2015; Głosek-Sobieraj *et al*., 2018; Mystkowska, 2019; Andrejiová *et al*., 2023). However, there is a paucity of research regarding the effect of agrotechnological practices and environmental conditions on the morphological characteristics of potato tubers (Krzysztofik *et al*., 2005; Flis *et al*., 2012; Priyadarshini *et al*., 2020), the influence of growth regulators being only a sporadically examined issue. Therefore, the aim of the work reported here was to assess the impact of biostimulants and a herbicide on the most important morphological characteristics of tubers to which consumers pay particular attention when purchasing potatoes.

2. MATERIALS AND METHODS

2.1. Description of the study area

The field experiment was conducted between 2021 and 2023 on the Zawady Experimental Farm, owned by the University of Siedlce in Poland. Zawady is located in central-eastern Poland between the 52º03' N latitude and 22º33' E longitude coordinates. The soil for the experiment was classified according to the World Reference Base for Soil Resources (WRB, 2015) as Haplic Luvisol (LV-ha) with sandy clay loam texture. It was acidic (pH in 1 M KCl 5.25-5.42), the organic matter content was 20.9-22.3 g kg^{-1}, and the content of available forms of P, K, and Mg in mg kg^{-1} was as follows: low to medium phosphorus content (35.2-61.0), low to medium potassium content (102.1-141.0), and low to medium magnesium content (36.6-61.0). The soil chemical analyses were performed in a certified laboratory of the Chemical and Agricultural Station in Wesoła near Warsaw. Two factors were tested in the experiment: I – two medium-early edible potato cultivars – Oberon and Malaga, II – five variants of application of biostimulants PlonoStart, Aminoplant, and Agro-Sorb Folium with the herbicide Avatar 293 ZC, application of the only herbicide, and a control object (Table 1). The characteristics of the herbicide and biostimulants are presented in Table 2. The

Table 1. Variants of application of biostimulants and herbicide in the field experiment

Variant	Biostimulants and herbicide
1.	Control object – without biostimulants and herbicide
2.	Herbicide Avatar 293 ZC (clomazone + metribuzin) – without biostimulant
3.	Biostimulant PlonoStart and herbicide Avatar 293 ZC (clomazone + metribuzin)
4.	Biostimulant Aminoplant and herbicide Avatar 293 ZC (clomazone + metribuzin)
5.	Biostimulant Agro-Sorb Folium and herbicide Avatar 293 ZC (clomazone + metribuzin)

Table 2. Characteristics of herbicide and biostimulants (www.gov.pl_web_rolnictwo_wykaz_nawozow Rejestr_NAWOZY_15_04_2024; www.ipm.iung.pulawy.pl.fert wyszukiwarka-nawozów-wyszukiwanie-IUNG)

Preparation	Composition	Action
Avatar 293 ZC	Clomazone – 60 g, metribuzin – 233 g	clomazone inhibits the synthesis of pigments (chlorophyll and carotenoids) in the plant, metribuzin absorbed by the roots and leaves, inhibits the photosynthesis process - weeds turn white and die
PlonoStart	Min.: N_{total} – 16.4,%, K_2O – 0.75%, CaO – 0.07%, MgO – 0.02%, S – 941 mg kg^{-1}, lactic acid bacteria, actinomycetes	the microorganisms it contains intensify metabolism of organic matter in the soil and increase availability of nutrients, improves plant development, which increases the size and quality of crops and plants' resistance to stress
Aminoplant	N_{total} – 9.48%, $N_{organic}$ – 9.2%, N-NH_4 – 0.88%, $C_{organic}$ – 25%, free amino acids – 11.57%, organic matter – 87.7%	contains as many as 18 free amino acids, increases the activity of many enzymes, accelerates the synthesis of proteins and sugars, naturally accelerates the growth and development of plants, increases the yield and improves its quality, increases immunity plants for stresses
Agro-Sorb-Folium	N_{total} – 2.2%, B – 0.02%, Mn – 0.05%, Zn – 0.09%, total amino acids – 13.11%, free amino acids – 10.66%	increases the intensity of photosynthesis, supports plant regeneration after stress, increases the yield and improves its quality characteristics, improves the performance of plant protection products

Table 3. Treatments used in the field experiment

Treatment	Dose	Date
Manure	25 t ha^{-1}	In autumn
Mineral fertilizer - phosphorus per 1 ha and potassium per 1 ha	44.0 kg P ha^{-1} and 124.5 kg K ha^{-1}	In autumn In autumn
Nitrogen fertilizers per 1 ha	100 kg N ha^{-1}	2-3 decade April
Planting potato tubers	-	2-3 decade April
Application once of herbicide Avatar 293 ZC (clomazone + metribuzin)	1.5 dm^3 ha^{-1}	BBCH 00-08
Double application biostimulant PlonoStart and once herbicide	1.0 +1.0 dm^3	BBCH 13-19 + BBCH 31-35
Avatar 293 ZC (clomazone + metribuzin)*		BBCH 13-19 + BBCH 31-35
Double application biostimulant Aminoplant and once herbicide	1.0 + 0.5 dm^3	BBCH 13-19 + BBCH 31-35
Avatar 293 ZC (clomazone + metribuzin)*		
Double application biostimulant Agro-Sorb Folium and once herbicide Avatar 293 ZC (clomazone + metribuzin)*	2.0 +2.0 dm^3	1-2 decade September
Harvesting potato tubers	-	

*Herbicide application in phase BBCH 00-08 and dose 1.5 dm^3 ha^{-1}. BBCH – Biologische Bundesanstalt, Bundessortenamt and Chemical Industry.

dates and doses of the application of the biostimulants and herbicide as well as fertilization are presented in Table 3. Every year, winter triticale was the potato forecrop. The area of one plot was 12.96 m^2 (4.8 m × 2.7 m). Medium-sized seed potatoes (35-55 mm) were planted manually at a row spacing of 0.675 m and at a distance of 0.40 m in the row. Plant protection products against diseases and pests were used in accordance with the recommendations of the Plant Protection Institute – National Research Institute Poznań (Plant Protection Recommendations for 2018/2019, 2018).

2.2. Plant material and determination of morphological features

Just before harvesting, tubers were dug from randomly selected ten plants in each plot and the yield structure was analyzed. Potatoes with a diameter above 35 mm were considered edible tubers and their morphological characteristics were determined (Regulation of the Ministry of Agriculture, 2003). Morphological features, such as tuber shape, regularity of tuber shape, skin appearance, depth of eyes, and tuber size, were determined as in Stypa and Michałowska (2015) and Hara-Skrzypiec *et al*. (2018). Tuber shape is expressed as an index of length to width, and the following types are distinguished: 0.9-1.2 – round, 1.21-1.5 – round oval, 1.51-1.7 – oval, 1.71-2.0 – oblong oval, >2.0 – oblong. Measurements of the tuber length and width were taken with a digital caliper. The remaining morphological features of the tubers were assessed on a scale of 1-9, where 9 is the largest or the best or the shallowest. The parameters adopted were regularity of tuber shape - scale 1-9, where 9 – perfect shape, 8 – very good, 6 – quite good, 4 - irregular, 2-1 – all tubers extremely deformed, irregular; skin appearance, where 9 – very thin, smooth, and shiny, 7 – smooth, thin, or slightly mesh, 6 – thick, matte, but not cracked, 4 – medium thin, matte, and slightly mesh, 3-2-1 – thick, rough, slightly to strongly cracked; depth of eyes, where 9 – very shallow, imperceptible eyes, 7 – shallow but noticeable, approx. 1 mm, 6 - medium 2-3 mm, 4 – deep 3-4 mm, 1 – very deep – over 5 mm; tuber size, where 3 – up to 20% of the weight fraction of tubers over 50 mm, 4 – 21-30% of the weight fraction of tubers over 50 mm, 5 – 31-40% tuber fraction over 50 mm, 6 – 41-50% of the tuber fraction above 50 mm, 7 – 51-60% tuber fraction over 50 mm, 8 – 61-70% tuber fraction over 50 mm, 9 – over 70% of the tuber fraction over 50 mm.

2.3. Statistical analysis and meteorological conditions

The test results regarding morphological features were subjected to a two-way analysis of variance, and the differences were assessed with the Tukey (*HSD)* test at the level of $p \leq 0.05$ between the compared means (Trętowski and Wójcik, 1991).

Precipitation and average daily air temperature data were obtained from the Zawady meteorological station located in a straight line approximately 0.2 km from the experimental field. Based on the data, the Sielianinow hydrothermal index was calculated for appropriate periods of the growing season (Table 4). The weather conditions during the field research varied (Fig. 1). In 2018, the air temperature in all months was higher than in 1980-2009, and the precipitation was lower than in the multi-year period. It was a dry year. The following 2019 was very dry. The 2020 season was relatively dry – the precipitation was similar to the 1980-2009 data (higher by only 4.5 mm), and the air temperature was by 1.3ºC higher.

Table 4. Sielianinov hydrothermal index, precipitation and air temperature in years of study

Year	Sielianinov hydrothermal index (K)	Precipitation (mm)	Temperature (°C)
2018	0.93 dry	295.7	17.6
2019	0.66 very dry	192.6	15.6
2020	1.05 relatively dry	312.4	15.7
1980-2009	–	307.9	14.4

K= P/ 0.1 Σt (Skowera *et al*., 2014), where: P – the sum of the monthly rainfalls in mm, Σt – monthly total air temperature > 0°C. Ranges of values of this index were classified as follows: K ≤ 0.4 – extremely dry (ed), 0.4 < K ≤ 0.7 – very dry (vd), 0.7 < K ≤ 1.0 – dry (d), 1.0 < K ≤ 1.3 – relatively dry (rd), 1.3 < K ≤ 1.6 – optimal (o), 1.6 < K ≤ 2.0 – relatively humid (rh), 2.0 < K ≤ 2.5 – humid (h), 2.5 < K ≤ 3.0 – very humid (vh), K > 3.0 extremely humid (eh).

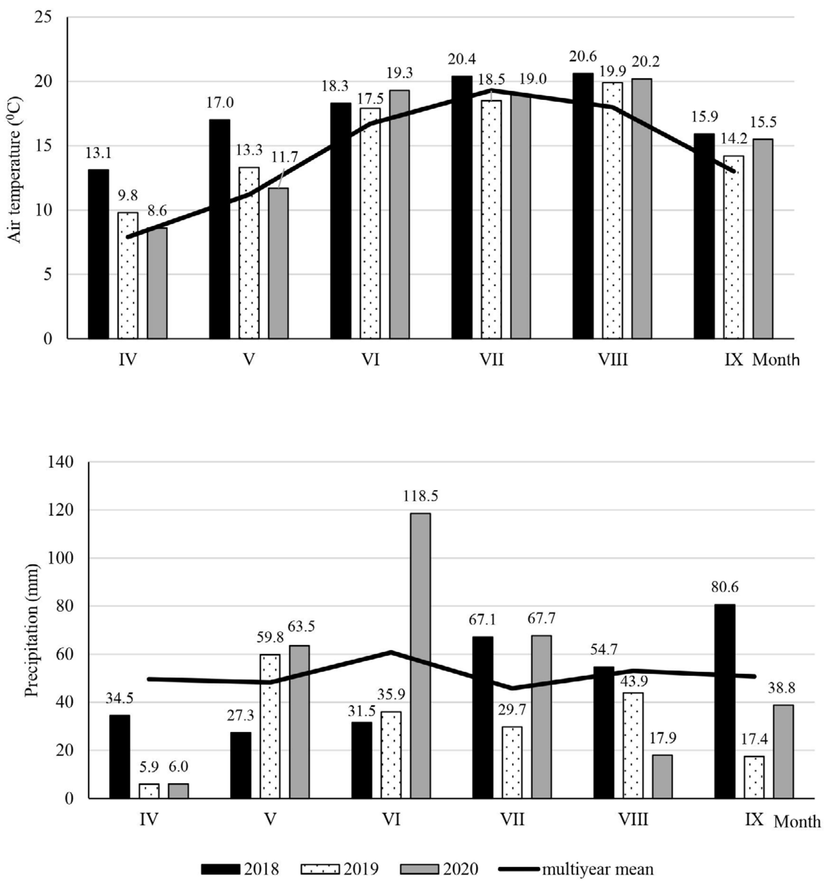

Fig. 1. Mean air temperature and precipitation comparison with the mean multiyear 1980-2009.

3. RESULTS AND DISCUSSION

The external appearance of fresh potato tubers offered to consumers and the processing industry is a very important quality criterion. Such parameters as tuber shape and size, regularity of shape, skin characteristics, and eye depth are significant factors when purchases are made for direct consumption and decisions are taken in the processing industry (chips, crisps, frozen products, and culinary potatoes). These characteristics also affect the amount of tuber mass loss during peeling (Krzysztofik *et al*., 2005; Zarzecka *et al*., 2014; Ndungutse *et al*., 2019). The studied cultivars are Polish medium-early cultivars. Both were included in the Polish National List of Agricultural Plant Cultivars: cv. Malaga on 5 March 2013 and *cv.* Oberon on 9 February 2012. The tuber shape of both cultivars is round oval (Nowacki, 2021), as described in the study conducted by Zarzecka *et al*. (2023a and 2023b). The skin color of *cv*. Oberon is red, whereas *cv*. Malaga skin is yellow. Both cultivars have light yellow flesh. Their cooking type differs, *i.e. cv*. Oberon represents the AB type while *cv*. Malaga is

Table 5. Morphological features of tubers depending on the cultivars and variants of application biostimulants with herbicide

Variants of application biostimulants and herbicide	Cultivar		Mean
	Malaga	Oberon	
Tuber shape			
1.	1.40 ± 0.057	1.78 ± 0.294	1.59 b ± 0.137
2.	1.43 ± 0.042	1.88 ± 0.291	1.66 ab ± 0.125
3.	1.48 ± 0.061	1.99 ± 0.362	1.74 a ± 0.176
4.	1.46 ± 0.047	1.99 ± 0.380	1.72 a ± 0.170
5.	1.44 ± 0.049	1.95 ± 0.326	1.70 a ± 0.140
Mean	1.44b ± 0.052	1.92a ± 0.292	1.68 ± 0.138
Regularity of tuber shape (scale 1-9)			
1.	7.10 ± 0.501	7.09 ± 0.795	7.10 b ± 0.594
2.	7.75 ± 0.293	7.27 ± 0.856	7.51 a ± 0.565
3.	7.84 ± 0.321	7.29 ± 0.741	7.57 a ± 0.512
4.	7.82 ± 0.280	7.31 ± 0.805	7.57 a ± 0.539
5.	7.77 ± 0.327	7.34 ± 0.881	7.56 a ± 0.595
Mean	7.66 a ± 0.416	7.26 b ± 0.697	7.46 ± 0.511
Skin appearance (scale 1-9)			
1.	6.90 ± 0.866	6.56 ± 1.142	6.73 b ± 1.006
2.	7.08 ± 0.754	6.75 ± 1.032	6.92 a ± 0.892
3.	7.12 ± 0.781	6.78 ± 1.034	6.95 a ± 0.908
4.	7.19 ± 0.720	6.88 ± 0.973	7.03 a ± 0.843
5.	7.22 ± 0.676	6.97 ± 0.922	7.09 a ± 0.796
Mean	7.10 a ± 0.655	6.78 b ± 0.876	6.94 ± 0.765
Depth of eyes (scale 1-9)			
1.	7.32 ± 0.502	6.72 ± 0.485	7.02 b ± 0.425
2.	7.59 ± 0.350	6.82 ± 0.396	7.22 ab ± 0.241
3.	7.65 ± 0.311	7.07 ± 0.115	7.36 a ± 0.122
4.	7.71 ± 0.231	7.11 ± 0.348	7.41 a ± 0.116
5.	7.78 ± 0.204	7.18 ± 0.306	7.48 a ± 0.101
Mean	7.61 a ± 0.328	6.98 b ± 0.349	7.30 ± 0.260
Tuber size (scale 1-9)			
1.	6.68 ± 1.335	5.33 ± 0.879	6.00 b ± 1.093
2.	7.78 ± 0.693	6.11 ± 0.510	6.95 ab ± 0.582
3.	8.00 ± 1.001	7.01 ± 0.595	7.51 a ± 0.769
4.	7.56 ± 0.768	6.22 ± 0.387	6.89 ab ± 0.508
5.	7.79 ± 1.031	7.35 ± 1.172	7.57 a ± 1.034
Mean	7.56 a ± 0.966	6.40 b ± 0.978	6.98 ± 0.913

± Standard deviation. The same letters indicate no significant differences between the results. Different letters (a, b) indicate the occurrence of significant differences between the variants and between cultivars. 1 – control, 2 – Avatar 293 ZC, 3 – PlonoStart+Avatar 293 ZC, 4 – Aminoplant+Avatar 293 ZC, 5 – Agro-Sorb Folium+Avatar 293 ZC.

assigned the B-BC types (B – potatoes for versatile use; AB – salad potatoes for versatile use; BC – versatile potatoes with floury flesh). Cv. Malaga has more vitamin C than *cv*. Oberon (235.0 and 188.0 mg in kg of fresh matter, respectively). Nitrate content (NO_3) is the same in both cultivars; it is low – below 100 mg in kg of fresh matter (Zarzecka *et al*., 2023a). The Breeding Centre of the studied cultivars is the same – Potato Breeding Zamarte, Poland. *Cv*. Malaga has a higher total yield (56.7 t ha^{-1}) than *cv*. Oberon (53.1 t ha^{-1}), likewise the starch content (15.0 and 13.5%, respectively). Both cultivars are used for cooking, and *cv*. Oberon is also used for baking (Zarzecka *et al*., 2023b).

The results and statistical analysis revealed that the shape of potato tubers was significantly affected by the cultivar, biostimulant, and herbicide treatment options, along with moisture and thermal conditions prevailing during the study years (Tables 5 and 6). *Cv*. Malaga tubers were oval in shape (on average, 1.44 on a scale of 1-9), while *cv*. Oberon had elongated-oval tubers (on average, 1.92). The applied biostimulants and herbicide significantly contributed to changes in tuber shape, which became increasingly elongated compared to control tubers. The influence of the biostimulants and herbicide used on the shape of the tubers was similar. The main cause of the elongation of the shape of the tubers after spraying with the biostimulants was the

Table 6. Morphological features of tubers depending on the cultivars and years of study

Year	Cultivar		Mean
	Malaga	Oberon	
	Tuber shape		
2018	1.40 ± 0.029	1.92 ± 0.133	1.66 b ± 0.078
2019	1.43 ± 0.050	2.24 ± 0.107	1.84 a ± 0.074
2020	1.49 ± 0.024	1.59 ± 0.029	1.54 c ± 0.029
Mean	1.44b ± 0.052	1.92a ± 0.292	1.68 ± 0.138
	Regularity of tuber shape (scale 1-9)		
2018	7.77 A ± 0.580	7.51 A ± 0.206	7.64 ab ± 0.375
2019	7.34 AB ± 0.249	6.35 B ± 0.103	6.85 b ± 0.165
2020	7.87 A ± 0.124	7.91 A ± 0.065	7.89 a ± 0.09
Mean	7.66 a ± 0.416	7.26 b ± 0.697	7.46 ± 0.511
	Skin appearance (scale 1-9)		
2018	6.78 ± 0.218	6.27 ± 0.31	6.53 b ± 0.257
2019	6.56 ± 0.143	6.13 ± 0.145	6.34 b ± 0.134
2020	7.97 ± 0.048	7.95 ± 0.055	7.96 a ± 0.05
Mean	7.10 a ± 0.655	6.78 b ± 0.876	6.94 ± 0.765
	Depth of eyes (scale 1-9)		
2018	7.53 ± 0.290	6.67 ± 0.385	7.10 b ± 0.316
2019	7.35 ± 0.221	7.27 ± 0.238	7.32 ab ± 0.221
2020	7.95 ± 0.045	7.00 ± 0.001	7.48 a ± 0.022
Mean	7.61 a ± 0.328	6.98 b ± 0.349	7.30 ± 0.260
	Tuber size (scale 1-9)		
2018	8.08 ± 0.887	6.68 ± 1.489	7.38 a ± 1.152
2019	6.54 ± 0.693	5.94 ± 0.83	6.24 b ± 0.725
2020	8.07 ± 0.148	6.6 ± 0.152	7.34 a ± 0.117
Mean	7.56 a ± 0.966	6.40 b ± 0.978	6.98 ± 0.913

± Standard deviation. The same letters indicate no significant differences between the results. Different letters (a, b) indicate the occurrence of significant differences between the years and between cultivars. Different letters (A, B) indicate the occurrence of significant interactions.

influence of minerals and free amino acids on the development of the tubers. The weather conditions during the growing season also affected the tuber shape. More elongated tubers were produced by cv. Malaga in the relatively dry year and by *cv*. Oberon in the very dry year 2019, confirming the significant cultivar × year interaction. Skrzypiec *et al.* (2018) confirmed that tuber shape and its regularity were strongly determined by the genetic factor, but they also demonstrated that the genotype x environment interaction significantly affected these traits. The impact of the cultivar and environmental conditions on tuber shape has also been reported by Park *et al*. (2021). These authors (2021) have also found that tuber shape is an important agronomic trait in potato processing, as it affects the efficiency of peeling, production costs, and the quality of the final processed food products, such as French fries and potato chips.

In the study reported here, the tuber shape regularity was significantly affected by the cultivar, the application of the biostimulants and herbicide, and the weather conditions during the potato growing season (Tables 5 and 6). The *cv*. Malaga tubers exhibited greater regularity of shape, compared with cv. Oberon.

The applied biostimulants with the herbicide (variants 3-5) and the treatment with a single herbicide (variant 2) significantly improved this trait and created homogeneous groups, compared with the control tubers (variant 1). The superior regularity of shape was observed for tubers harvested in 2020, which was relatively dry, but the poorest shape regularity was recorded in 2019, which was very dry. In the study conducted by Hara-Skrzypiec *et al*. (2018), the heritability of tuber shape regularity was moderate, while Bradshaw *et al*. (2008) considered the heritability of this characteristic to be high. Other authors (Flis *et al*., 2012) found that the regularity of shape was significantly influenced by the cultivar, cultivation system, and research location, and the cultivar x location interaction significantly influenced tuber morphological traits, such as tuber shape, regularity of shape, and eye depth.

Another important quality characteristic in tuber morphology is skin appearance. The skin prevents water loss from tubers, protects against pathogen invasion, and affects potato tuber quality during storage. Moreover, skin appearance is a very important marketing factor, as esthetic values are essential for direct sale (Domański *et al*., 2010; Zarzecka *et al*., 2014; Keren-Keiserman *et al*., 2019). In the present work, the skin appearance was influenced by the potato cultivar, applied biostimulants and herbicide, and study years (Tables 5 and 6). *Cv*. Malaga had distinctly superior skin appearance (an average score of 7.10 on a scale of 1-9), compared with cv. Oberon (on average, 6.78). Flis *et al*. (2012) and Keren-Keiserman *et al*. (2019) demonstrated that skin appearance is a genetically inherited trait. According to Domański *et al*. (2010), the threshold values for skin appearance in table, processing, and starchy potatoes are ≥ 6 on a scale of 1-9. The biostimulants and herbicide applied in the experiment had a positive effect on the discussed characteristic. Tubers collected from plots sprayed with the biostimulant Agro-Sorb Folium and herbicide Avatar 293 ZC had the smoothest and thinnest skin, which was probably due to the presence of boron, manganese, and zinc microelements as well as free amino acids, which increase the activity of many enzymes. The skin quality significantly deteriorated (it became thicker and slightly rougher) as the growing season advanced in the dry and very dry seasons, compared to the relatively dry one. These findings are consistent with studies reported by Kumar and Ginzberg (2022), who found that periderm, a protective tissue, responds to stress conditions. Additionally, Ginzberg *et al*. (2009) demonstrated that potato periderm responds to heat stress by increasing the production and accumulation of skin layers, creating a thick and russetted protective cover.

The threshold for the depth of eyes in table and processing potatoes, as mentioned by Domański *et al*. (2010), is ≥7. Deeper eyes are undesirable as they increase losses during potato peeling (Abong *et al*., 2010). The cultivars examined in the present work differed significantly in terms of the discussed characteristic, with values on a scale of 1-9 being 6.98 and 7.61 (Tables 5 and 6). The impact of the cultivar on the depth of eyes has also been found by other workers (Abong *et al.*, 2010; Arslanoglu *et al.*, 2011; Flis *et al.*, 2012; Ndungutse, 2019). The applied biostimulants had a positive effect on the discussed tuber morphology trait, as they contributed to reduced eye depth, compared to the control tubers. The tubers harvested from variant 5, where the herbicide and biostimulant Agro-Sorb Folium were applied, had the shallowest eyes. This could be due to the fact that this biostimulant supports plant regeneration after stress and improves the effect of plant protection products. There is a lack of research in the available literature on the influence of biostimulants on eye depth. The analysis of the effect of hydrothermal conditions revealed that shallower eyes were formed in 2020 (relatively dry), compared to the remaining study years (dry and very dry). Lindqvist-Kreuze *et al*. (2015) also observed an influence of environmental conditions on eye depth, suggesting a possible connection between tuber shape and eye depth. The research reported here showed an interaction between the applied products and study years. Greater variation in eye depth occurred in unfavorable weather conditions, whereas the biostimulants mitigated the differences in the value of the discussed trait in the relatively dry year (Fig. 2).

The tuber size was significantly affected by all the experimental factors (Tables 5 and 6). Cv. Malaga had larger tubers than Oberon. The impact of cultivar on tuber size and the share in the yield of large tubers with the diameter > 50 mm was confirmed in studies of other authors (Barbaś and Sawicka, 2019; Ndungutse *et al*., 2019; Ginter *et al*., 2023). The applied biostimulants and herbicide affected the size of potato tubers. Compared with the control potatoes, the largest tubers were harvested in plots treated with the biostimulants PlonoStart and Agro-Sorb Folium with

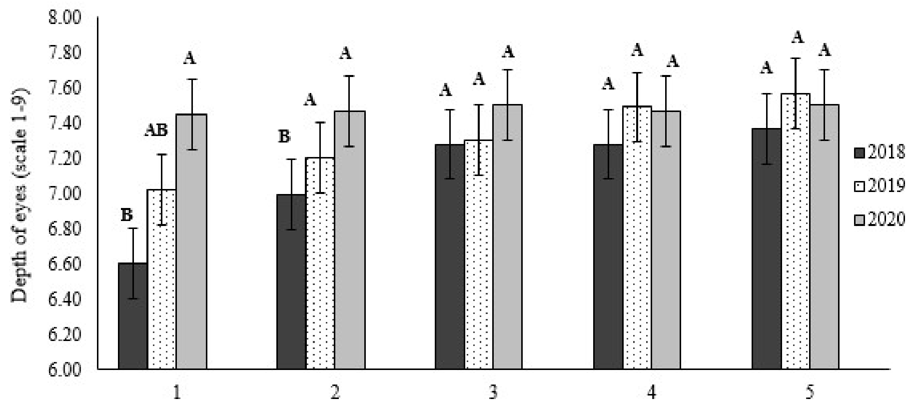

Fig. 2. Depth of potato eyes depending on variants of aplication biostimulants and herbicide in study years HSD at $p \leq 0.05$. The same letters indicate no significant differences between the results. Different letters (A, B) indicate the occurrence of significant interaction. The explanation of numbers (1-5): 1 – control object; 2 – herbicide Avatar 293 ZC; 3 – biostimulant PlonoStart + herbicide Avatar 293 ZC; 4 – biostimulant Aminoplant + herbicide Avatar 293 ZC; 5 – biostimulant Agro-Sorb Folium + herbicide Avatar 293 ZC.

the herbicide Avatar 293 ZC, as tubers above 50 mm in diameter constituted 51-60%. The beneficial effect of the PlonoStart biostimulant could be a consequence of the total nitrogen content of 16.4% in this biostimulant. The positive effect of the Agro-Sorb Folium biostimulant could be due to the high content of free amino acids and the addition of micronutrients supporting plant regeneration after stressful periods and increasing the intensity of photosynthesis. The smallest tuber size was recorded in the control unit with no biostimulants or herbicide. Also other researchers demonstrated a beneficial effect of biostimulants on tuber size (Głosek-Sobieraj *et al*., 2018; Trawczyński, 2018, 2020; Karak *et al*., 2023). Furthermore, Barbaś and Sawicka (2019) found that the herbicide Sencor 70 WG, applied alone or with other herbicides, significantly increased the share of potatoes with a diameter > 50 mm. The analysis of the tuber size in the study years showed that the smallest tubers were harvested in the very dry year 2019, while the tubers were significantly larger and of similar size in the remaining years. It should be mentioned that the 2018 season was the warmest, and the rainfall was evenly distributed, contributing to tuber formation. Barbaś and Sawicka (2019) also reported the most favorable crop structure in a year with optimum rainfall and temperature. The influence of thermal and rainfall conditions in the study years on tuber size was also confirmed by Trawczyński (2018, 2020).

4. CONCLUSIONS

1. Genetic traits significantly affected the morphological characteristics of table potato tubers. *Cv*. Malaga exhibited more favorable tuber shape, regularity of tuber shape, skin appearance, depth of eyes, and tuber size, compared with *cv*. Oberon.

2. After the application of the biostimulants and herbicides, a significant improvement was observed in the measured morphological characteristics of the tubers, compared with the control tubers. PlonoStart and Aminoplant had the most positive impact on tuber shape and regularity, Aminoplant and Agro-Sorb Folium on skin appearance and depth of eyes, and PlonoStart and Agro-Sorb Folium on tuber size.

3. Meteorological conditions during the potato growing season influenced tuber morphological traits. In 2020, characterized by rainfall and air temperature similar to the long-term means, the developed tubers exhibited the best external characteristics, while the very dry season was the least favorable.

4. The analysis of the morphological traits of the potato tubers after the application of biostimulants and herbicide indicated that these products affect the quality of fresh tubers and have clearly contributed to increasing their attractiveness.

Conflict of interest: The authors declare no conflict of interest.

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