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Glycoalkaloids in leaves and potato tubers depending on herbicide application with biostimulants

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Abstract: The aim of the study was to determine the influence of herbicide application with biostimulants on total glycoalkaloid (TGA) content in potato leaves and tubers. The study was based on a two-factor field experiment established in a split-plot arrangement in three replications. The factors were as follows: factor I – two cultivars of edible potato – Oberon and Malaga; factor II – five methods of using herbicide and biostimulants: 1. control object; 2. herbicide clomazone + metribuzin (Avatar 293 ZC); 3. herbicide clomazone + metribuzin and biostimulant PlonoStart; 4. herbicide clomazone + metribuzin and biostimulant Aminoplant; 5. herbicide clomazone + metribuzin and biostimulant Agro-Sorb Folium. The herbicide clomazone + metribuzin significantly increased the concentration of glycoalkaloids in potato leaves, and the herbicide used together with the biostimulant Aminoplant significantly reduced the content of TGA in potato leaves compared to the control. The herbicide whether applied with the biostimulants (PlonoStart, Aminoplant, Agro-Sorb Folium) contributed to a reduction in the concentration of glycoalkaloids in tubers compared to the control. Leaves and tubers of the cultivar Malaga were characterised by a significantly lower TGA content than the cultivar Oberon.

Keywords: *Solanum tuberosum* L.; tuberous crop; natural toxin; anti-weed preparation

The potato (*Solanum tuberosum* L.) is the fourth most important plant in the world after wheat, rice and corn that provides food. It is characterised by high efficiency and high nutritional value (Halterman et al. 2016). Potato tubers contain numerous nutrients necessary for the functioning of the body, such as carbohydrates, protein, fibre, vitamin C, vitamin B_6, magnesium, potassium and iron. The nutritional value of potatoes, their taste and ease of cooking as well as the price and availability on the market made them a very popular vegetable and snack in the world (Zaheer and Akhtar 2016, Beals 2019). In addition to nutrients, potato tubers contain naturally occurring toxins called glycoalkaloids (TGA), dominated by solanine and chaconine, making up 95% of this compound (Kasnak and Artik 2018). Most glycoalkaloids are found in flowers, fruits, sprouts, eyes and leaves and can be up to 5 000 mg/kg FW (fresh weight), and the smallest amount in tubers is 10–155 mg/kg FW (Zarins and Kruma 2017, Nowacki 2020, Schrenk et al. 2020). The accumulation of these substances in the tubers depends on the cultivar, weather and soil conditions, agrotechnical treatments, the use of plant protection products and storage conditions (Zarzecka et al. 2013, Hamouz et al. 2014, Kasnak and Artik 2018, Wszelaczyńska et al. 2020). It should be added that the glycoalkaloids present in potatoes have a protective effect against pests and plant diseases

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(Andrivon et al. 2003, Schrenk et al. 2020). The aim of these studies was to find out whether herbicides and biostimulants alter the content of glycoalkaloids in leaves and potato tubers.

MATERIAL AND METHODS

A field experiment was carried out at the Agricultural Experimental Station – Zawady (52°03'N and 22°33'E) in the region of East-Central Poland in three growing seasons 2018, 2019, and 2020. It was established in a split-plot arrangement with three replicates. The forecrop was winter triticale each year. Two factors were examined in the experiment:

– factor I – two cultivars of edible potato – Oberon and Malaga;
– factor II – five methods of using herbicide and biostimulants: 1. control object – only mechanical weeding; 2. herbicide clomazone + metribuzin (Avatar 293 ZC); 3. herbicide clomazone + metribuzin and biostimulant PlonoStart; 4. herbicide clomazone + metribuzin and biostimulant Aminoplant; 5. herbicide clomazone + metribuzin and biostimulant Agro-Sorb Folium.

The biostimulants PlonoStart, Aminoplant and Agro-Sorb Folium were selected based on the list of fertilisers and plant conditioners, which can be traded on the Polish market compiled by the Ministry of Agriculture and Rural Development on 10 September 2021 (2021), and the list of fertilisers and soil conditioners recommended by the Institute of Soil Science and Plant Cultivation (IUNG) Pulawy of 1 February 2021 (2021). The agronomic characteristics of the experiment are presented in Table 1. 10 potato leaves were sampled during the flowering phase (BBCH 65–69) and 10 tubers from each plot were sampled at harvest. Chemical analyses were performed in three replications in fresh material. Glycoalkaloids content in the collected samples was determined by the Bergers' method (Bergers 1980). Results of the study were statistically verified by analysis of variance. The significance of differences between the compared averages was verified by Tukey's test at the significance level of $P \leq 0.05$ (Trętowski and Wójcik 1991).

Mean monthly air temperature and precipitation sum in the vegetation period are presented in Table 2. The year 2018 was the warmest and the precipitation was lower than the long-term sum. The following year was 2 °C colder, and the precipitation was 115.3 mm lower than in the multi-year period. The weather conditions the most conducive to potato growing were recorded in 2020, with rainfall similar to the long-term sum.

Table 1. Agronomic characteristics of the experiment

Specification	Date		
	2018	2019	2020
Forecrop	winter triticale	winter triticale	winter triticale
Soil acidity	acidic	acidic	acidic
Soil texture class	sandy loam	sandy loam	sandy loam
Content of available nutrients: P, K, Mg	low	medium	medium
Manure 25 t/ha and mineral fertiliser (44.0 kg P/ha and 124.5 kg K/ha)	22 November 2017	23 October 2018	19 November 2019
Nitrogen fertilisers 100 kg N/ha	23 April	15 April	20 April
Date of planting tubers	23 April	18 April	20 April
Single herbicide spraying clomazone + metribuzin (Avatar 293 ZC) 1.5 L/ha – BBCH 00–08	7 May	29 April	7 May
Double spraying with the biostimulant PlonoStart 1.0 L/ha – BBCH 13–19 + 1.0 L/ha – BBCH 31–35	19 May and 24 May	27 May and 6 June	3 June and 9 June
Double spraying with the biostimulant Aminoplant 1.0 L/ha – BBCH 13–19 + 0.5 L/ha – BBCH 31–35	19 May and 24 May	27 May and 6 June	3 June and 9 June
Double spraying with the biostimulant Agro-Sorb Folium 2.0 L/ha – BBCH 13–19 + 2.0 L/ha – BBCH 31–35	19 May and 24 May	27 May and 6 June	3 June and 9 June
Potato harvest date	4 September	17 September	8 September

BBCH – Biologische Bundesanstalt, Bundessortenamt and Chemical Industry

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Table 2. Mean monthly air temperature (°C) and precipitation (mm) in the vegetation period

	Month						April–September
	April	May	June	July	August	September	
Air temperature							mean
2018	13.1	17.0	18.3	20.4	20.6	15.9	17.6
2019	9.8	13.3	17.9	18.5	19.0	14.2	15.6
2020	8.6	11.7	19.3	19.0	20.2	15.5	15.7
30-year mean	7.9	11.2	16.7	19.3	18.0	13.0	14.4
Precipitation							sum
2018	34.5	27.3	31.5	67.1	54.7	80.6	295.7
2019	5.9	59.8	35.9	29.7	43.9	17.4	192.6
2020	6.0	63.5	118.5	67.7	17.9	38.8	312.4
30-year mean	49.6	48.2	60.7	45.7	53.0	50.7	307.9

30-year mean for 1980–2009

RESULTS AND DISCUSSION

In the present study, glycoalkaloid content in tested potato leaves fell within the range of 210.3 to 256.4 mg/kg of fresh matter and was significantly dependent on the cultivar, methods of using herbicide and biostimulants as well as weather conditions in the growing seasons (Tables 3 and 4). A significantly higher amount of glycoalkaloids was accumulated by the cv. Oberon than in cv. Malaga. The effect of cultivar on these traits has been reported by many researchers (Zarzecka et al. 2013, Zarins and Kruma 2017, Li et al. 2020). The herbicide clomazone + metribuzin (Avatar 293 ZC) used in the experiment increased the concentration of glycoalkaloids in comparison to the control. Herbicide used together with the biostimulant Aminoplant significantly reduced the content of TGA in potato leaves. Mystkowska (2019) also observed the reduction of glycoalkaloids content in leaves after biostimulants application. In

Table 3. The content of glycoalkaloids in potato leaves and tubers (mg/kg fresh matter)

Methods of using herbicide and biostimulants	Cultivar		Mean
	Oberon	Malaga	
Potato leaves			
Control object	248.0	214.5	231.4
Clomazone + metribuzin (Avatar 293 ZC)	250.5	215.6	233.0
Clomazone + metribuzin (Avatar 293 ZC) and PlonoStart	248.6	213.7	231.1
Clomazone + metribuzin (Avatar 293 ZC) and Aminoplant	245.2	212.1	228.7
Clomazone + metribuzin (Avatar 293 ZC) and Agro-Sorb Folium	249.3	214.8	232.1
Mean	248.3	214.1	231.2
$LSD_{0.05}$ for: cultivars – 2.14; methods – 2.36; interaction: cultivars × method – ns			
Potato tubers			
Control object	96.52	87.56	92.04
Clomazone + metribuzin (Avatar 293 ZC)	96.55	87.32	91.94
Clomazone + metribuzin (Avatar 293 ZC) and PlonoStart	92.41	88.38	90.40
Clomazone + metribuzin (Avatar 293 ZC) and Aminoplant	90.41	88.63	89.53
Clomazone + metribuzin (Avatar 293 ZC) and Agro-Sorb Folium	91.35	89.02	90.19
Mean	93.45	88.18	90.82
$LSD_{0.05}$ for: cultivars – 0.30; methods – 0.55; interaction: cultivars × method – 0.55			

LSD – least significant difference; ns – not significant

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Table 4. The content of glycoalkaloids in potato leaves and tubers in the years of research (mg/kg fresh matter)

	Cultivar		Mean
	Oberon	Malaga	
Potato leaves			
2018	252.2	210.9	231.6
2019	236.4	210.3	223.4
2020	256.4	221.2	238.8
Mean	248.3	214.1	231.2
$LSD_{0.05}$ for: cultivars – 2.14; years – 3.29; interaction: cultivars × years – 5.57			
Potato tubers			
2018	91.96	86.93	89.45
2019	91.57	86.11	88.84
2020	96.82	91.51	94.17
Mean	93.45	88.18	90.82
$LSD_{0.05}$ for: cultivars – 0.30; years – 0.46; interaction: cultivars × years – ns			

LSD – least significant difference; ns – not significant

this study, no interaction between the experimental factors was confirmed. Weather conditions in the research years had a significant effect on the content of glycoalkaloids in potato leaves (Table 4, Figure 1). The richest in this component were the leaves collected in 2020, with the highest rainfall. Whereas, the lowest TGA was determined in the growing season of 2019 with the lowest rainfall. A similar response associated with the weather conditions was reported by other researchers (Żołnowski 2001, Gugała et al. 2016, Mystkowska 2019).

Variance analysis revealed a significant effect of cultivars examined in the study, methods of using herbicide and biostimulants and weather conditions on the level of glycoalkaloids in potato tubers (Tables 3 and 4). The total glycoalkaloid content in potato tubers registered in the National Register of Cultivar in Poland in 2020 ranged from 25 to 155 mg/kg of fresh matter (Nowacki 2020). Żołnowski (2001) reported glycoalkaloids concentrations which were about 50 times higher in leaves as compared to mature potato tubers. In the present study, the content of glycoalkaloids in tubers fell within the range of 86.11 to 96.82 mg/kg. The TGA content was higher in the cv. Oberon than in cv. Malaga. Zarzecka et al. (2013), Hamouz et al. (2014), Kasnak

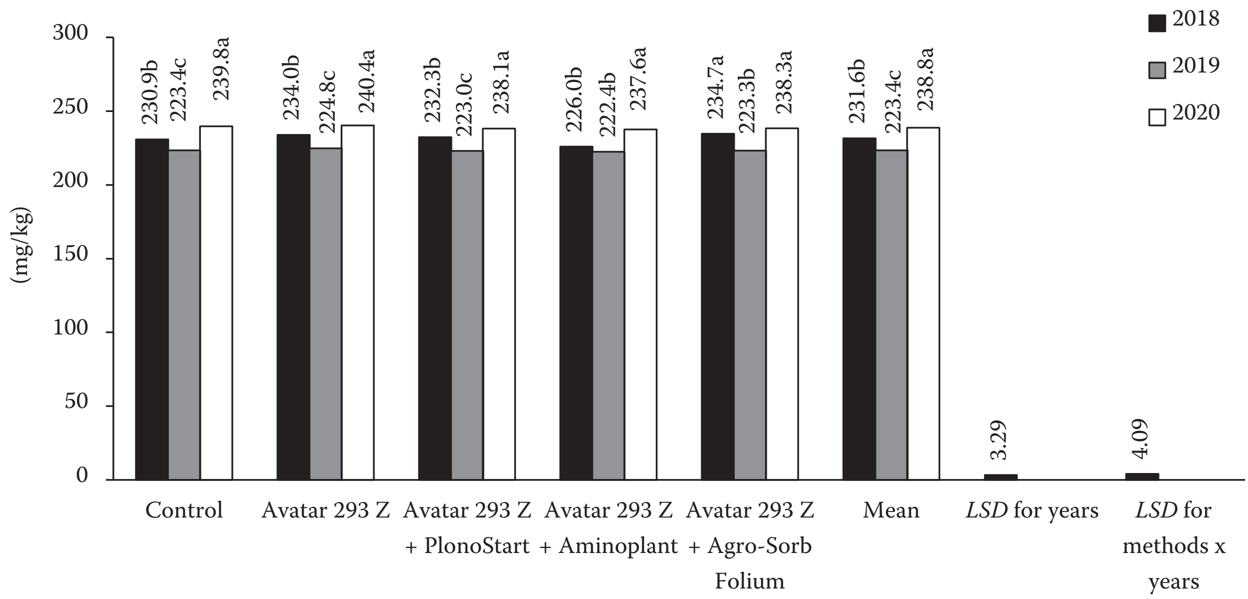

Figure 1. The content of glycoalkaloids in potato leaves in the years of research

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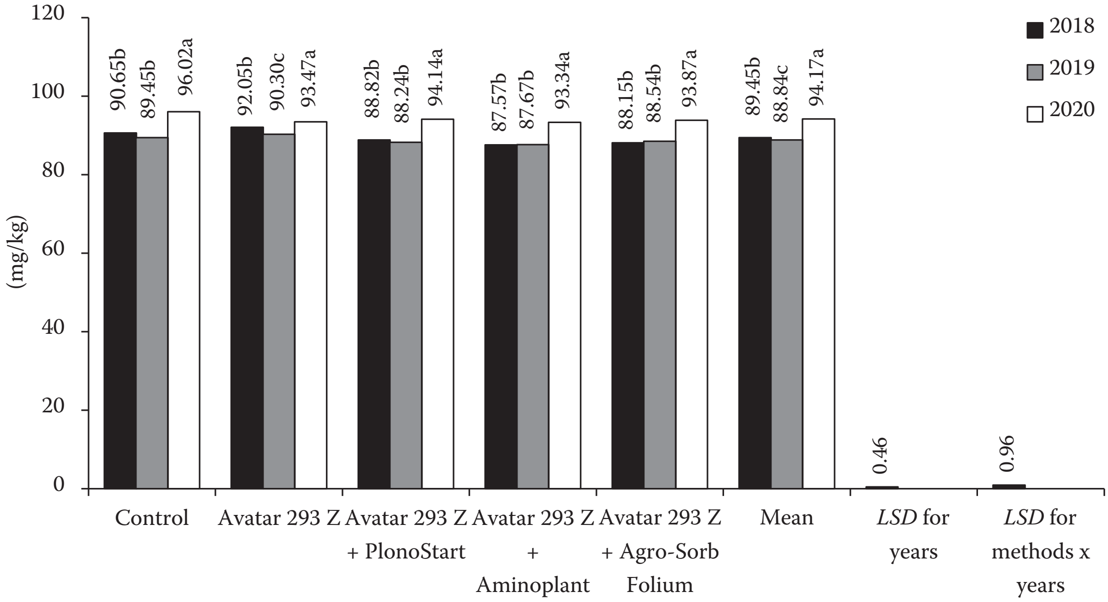

Figure 2. The content of glycoalkaloids in potato tubers in the years of research

and Artik (2018) and Li et al. (2020) also showed that the genotype had a dominant effect on the content of glycoalkaloids in potato tubers. The herbicide clomazone + metribuzin whether applied with the biostimulants PlonoStart, Aminoplant and Agro-Sorb Folium, contributed to a decrease in the concentration of glycoalkaloids compared with the control – it had a positive effect on the content of these compounds. The lowest TGA content was recorded after clomazone + metribuzin was applied in combination with the biostimulant Aminoplant. The decrease in the content of glycoalkaloids in potato tubers after the application of biostimulants was also observed by Gugała et al. (2016) and Mystkowska (2019). Meteorological conditions in the growing seasons influenced the glycoalkaloids content in potato tubers (Table 4, Figure 2). It has been shown that the highest concentration of glycoalkaloids, on average 94.17 mg/kg of fresh matter, occurred in 2020, when rainfall was the highest, and the lowest in 2019, characterised by low rainfall. Similar results were described by Zarzecka et al. (2013), Hamouz et al. (2014), Mystkowska (2019), Wszelaczyńska et al. (2020). Żołnowski (2001) found that high levels of glycoalkaloids occur in plants when metabolism is very intense. In the conducted experiment, statistical calculations showed an interaction between methods of using herbicide and biostimulants and years of study. The lowest glycoalkaloids in tubers were recorded in all years after the application of the herbicide and Aminoplant biostimulants (Figure 2).

The acceptable limit of total glycoalkaloid content for consumption in tubers is 200 mg/kg of fresh matter. Potatoes with elevated amounts of this compound (above 100 mg/kg) are characterised by a bitter, burning taste, and the content of glycoalkaloids above 200 mg/kg can be harmful to consumers' health (Żołnowski 2001, Beals 2019, Schrenk et al. 2020, Wszelaczyńska et al. 2020). In the experiment presented in this paper, the concentration of TGA in potato tubers was below 100 mg/kg and such potatoes are suitable for consumption. Moreover, the applied biostimulants reduced the content of glycoalkaloids in tubers, which indicates the possibility of improving the quality of the edible potato.

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