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The effect of hydrogel and precipitation-thermal conditions on the yield and content of antinutritional compounds in potato

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Abstract: A field experiment was conducted with potatoes to examine the effects of hydrogel application and weather conditions on total tuber yield and the content of potentially harmful compounds – glycoalkaloids and nitrates. The first experimental factor comprised three table cultivars: Lawenda, Rima and Provita. The second factor consisted of three treatments: the application of the hydrogel AgroNanoGel Basic at 60 and 90 kg/ha, and a control treatment without hydrogel. Statistical analysis demonstrated significant effects of cultivar, hydrogel application rates, and hydrothermal conditions in the study years on potato tuber yield. The highest yields were produced by cv. Lawenda, and the most favourable yield-forming effects were observed when the hydrogel had been applied at 90 kg/ha. The levels of antinutritional compounds were significantly affected by the experimental factors and weather conditions during the study years. Cv. Rima accumulated the lowest levels of glycoalkaloids, whereas cv. Lawenda contained the least nitrates (V). The hydrogel increased the content of both glycoalkaloids and nitrates relative to the control treatment, although their levels posed no risk to human health. Higher concentrations of antinutritional compounds were recorded in the dry and warm 2024 season than in the cooler and more humid 2025 season.

Keywords: *Solanum tuberosum* L.; phytochemical; antinutritional substance; climatic condition; drought stress

The potato is an important agricultural crop because it can be cultivated under a wide range of climatic and soil conditions. It is available year-round at an affordable price and contains numerous constituents that determine the high quality of its tubers. From a nutritional perspective, potato tubers are a good source of carbohydrates, protein, vitamins, dietary fibre, and numerous macro- and microelements. Tubers also contain substantial amounts of phytochemicals, including anthocyanins and phenolic compounds, which enhance their nutritional and functional properties (Nowacki 2020, Gustavsen 2021). In addition to these nutrients, potato tubers also contain compounds undesirable in human nutrition, the so-called antinutritional substances – glycoalkaloids and nitrates (Wszelaczyńska et al. 2022, Figueira et al. 2026). Tuber yield and the accumulation of antinutritional compounds are affected by numerous factors, including climatic conditions, cultivar, and agronomic practices (Urban et al. 2018, Mystkowska 2019, AL-Taey et al. 2019). One of the key determinants of yield is the optimal water supply. The water requirements of potatoes during the growing season are relatively high and, under Polish conditions, amount to approximately 300 mm for early cultivars and 360 mm for late cultivars, and may reach 450 mm in some regions (Nowacki 2000). Insufficient rainfall combined with high air temperatures may reduce tuber yield by 10–50%, and in extreme cases by as much as 50–70% (Rykaczewska

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2015, Král et al. 2019, Nowacki 2020, Al-Taey and Hussain 2023). Modern, environmentally friendly agriculture, therefore, seeks new technologies to mitigate the adverse effects of drought. Drought stress can be alleviated through careful cultivar selection, mulching, composting, irrigation, or the application of hydrogels (Král et al. 2019, Smagin et al. 2019, Nowacki 2020, Piętka 2020).

Table potato tubers should contain the lowest possible amounts of antinutritional compounds – glycoalkaloids and nitrates. Glycoalkaloids are secondary metabolites which, when present in high concentrations (above 200 mg/kg fresh weight), exert toxic effects on the human body and may cause symptoms of poisoning (Schrenk et al. 2020). At the same time, these compounds play a key role in the plant's defence mechanisms against pests, fungi, bacteria, and viruses (Figueira et al. 2026). The European Commission has established a guideline level of 100 mg/kg for glycoalkaloids in potato tubers and potato products, which is considered a critical reference value for producers, consumers, and industry (Commission Recommendation 2022). Nitrates (V) are chemical compounds of relatively low toxicity to humans; however, under the influence of gut microbiota, they may be converted into highly toxic nitrites (III). According to Commission Regulation (EU) No 1822/2005 of 8 November 2005, the nitrate content of potatoes should not exceed 200 mg/kg fresh weight of tubers (Commission Regulation 2005). Elevated nitrate levels in potato tubers pose a threat to human health (Wszelaczyńska et al. 2022, Gościnna et al. 2025).

Based on extensive research, the Scientific Committee on Food (SCF) and the FAO/WHO Joint Expert Committee on Food Additives (JECFA) established the maximum acceptable daily intake (ADI) of nitrates for an adult at 3.7 mg/kg body weight (Opinion of the Scientific Panel 2008). The present study aimed to determine the effects of the hydrogel AgroNanoGel Basic on yield and the content of glycoalkaloids and nitrates in potato tubers under varying hydrothermal conditions.

MATERIAL AND METHODS

The field experiment was conducted to determine the effects of hydrogel application and weather conditions on yield and the content of antinutritional compounds in edible potato tubers. The trial, established as a split-plot arrangement with three replicates, comprised two factors: three potato cultivars (Lawenda, Rima, Provita) and three treatments involving the application of the hydrogel AgroNanoGel Basic (1. control treatment – without hydrogel; mechanical weed control before and after potato emergence; 2. AgroNanoGel Basic 60 kg/ha – mechanical weed control before emergence, followed by post-emergence herbicide application using a mixture of Arcade 880 EC (prosulfocarb + metribuzin) at 4 L/ha and Basagran 480 SL (bentazon) at 2 L/ha; 3. AgroNanoGel Basic 90 kg/ha – mechanical weed control before emergence, followed by the same post-emergence herbicide mixture (Arcade 880 EC 4 L/ha + Basagran 480 SL 2 L/ha). The characteristics of the cultivars and AgroNanoGel Basic are presented in Tables 1 and 2. The soil at the experimental site was light, sandy-loam, and acidic (pH_{KCl} = 4.7). Available phosphorus (P) and potassium (K) levels were very high (respectively, 127.2 and 186.8 mg/kg), and magnesium (Mg) content was high (41.4 mg/kg soil). In 2004, the preceding crop was winter triticale. Farmyard manure was applied at 25 t/ha, along with mineral fertilisers at the following rates: 100 kg N/ha, 44.0 kg P/ha, 124.5 kg/K ha. In 2005, potatoes were planted on the same field as in the previous year. No manure was applied, mineral fertiliser rates were increased by 30%, and hydrogel rates were increased by 20% (as a supplementary rate).

The hydrogel was placed in the rows into which the seed tubers were subsequently planted. Potatoes were planted manually on 18 April 2024 and 17 April 2025, and harvested on 3 September in both years. Glycoalkaloids (TGA) and nitrates were determined in fresh tuber tissue 5–6 days after harvest. Glycoalkaloids were quantified using the colourimetric method of Bergers (Bergers 1980), following the

Table 1. Description of the cultivars grown in the experiment (Descriptive List 2025)

Cultivar	Year of registration	Skin colour	Flesh colour	Maturity	Yield of tubers (t/ha)	Starch (g/kg fresh matter)
Lawenda	2016	light red colour	yellow	early	48.0–45.3	132
Rima	2023	light yellow	cream	medium early	43.0–48.9	143
Provita	2021	purple	purple	early	20.0–28.0	129

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Table 2. Parameters hydrogel of AgroNanoGel Basic (Piętka 2020)

AgroNanoGel Basic	A modern agent that improves soil properties
Manufacturer	Artagro Polska Sp. z o.o. Miechów, Poland
Composition	Crosslinked poliakrylan potasu
Formulation	Powder – fine, hygroscopic crystals
Function	Storage and gradual release of water
Use	Field crops, ornamental plants, vegetable crops, fruit crops, lawns, nursery crops
Doses	50–200 kg/ha (depending on type of plant and soil)
Application depth	15–25 cm
Degree of absorption water	1 g of AgroNanoGel Basic can store up to 500 mL of water
Reduces of watering	Can reduce watering by 20% to as much as 50%
Length of action	Up to 5 years, then biodegradable
Safety	Non-toxic, biodegradable, safe for plants and soil
Registration/marketing authorisation	Ministry of Agriculture and Rural Development No. G-800/19
Price	PLN 60–80/kg

procedure described in detail by Mystkowska (2019). Nitrates were determined potentiometrically using a nitrate ion-selective electrode and a silver chloride reference electrode (Kolbe and Müller 1987).

Tuber yields obtained in the experiment and the results of chemical analyses were statistically processed using analysis of variance. The significance of differences between means (*HSD*) was tested at $P \leq 0.05$ using Tukey's test (Trętowski and Wójcik 1991).

Air temperature and precipitation data were obtained from a meteorological station located approximately 100 m from the experimental site. According to the Sielianinov hydrothermal coefficient, the years 2024 and 2025 were dry, although variable in terms of hydrothermal conditions (Table 3). In 2024, the mean air temperature in all months of plant growth and development was higher than in 2002–2024 and exceeded the long-term average by 2.2 °C. In contrast, thermal conditions in 2025 were close to the long-term mean. The distribution of precipitation in 2024 was also unfavourable, and total rainfall was 58.5 mm lower than the long-term average. In 2025,

Table 3. Mean temperature and total rainfall in the vegetation period

Year	Month						April–September
	April	May	June	July	August	September	
Air temperature (°C)							mean
2024	10.8	16.6	19.0	21.6	20.7	18.1	17.8
2025	10.5	11.0	17.9	19.7	18.8	16.1	15.7
Mean of 2002–2024	8.8	14.1	17.7	19.8	19.0	14.2	15.6
Rainfall (mm)							sum
2024	23.2	5.2	65.4	59.7	55.5	25.5	234.5
Sielianinow hydrothermal coefficients 2024*	0.72 dry	0.10 extreme dry	1.15 relatively dry	0.90 dry	0.87 dry	0.47 very dry	0.72 dry
2025	15.4	63.8	36.0	78.4	14.2	41.5	249.3
Sielianinow hydrothermal coefficients 2025*	0.49 very dry	1.93 relatively humid	0.49 very dry	1.33 optimum	0.25 extreme dry	0.86 dry	0.88 dry
Mean of 2002–2024	25.0	57.0	57.0	57.0	58.0	39.0	293.0
Rainfall requirements for potato cultivars**	33	67	94	88	18	–	300

*Skowera et al. (2014); **Nowacki (2020)

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moisture conditions were more favourable, with the difference between total rainfall and the long-term average reduced to 43.7 mm.

RESULTS AND DISCUSSION

The total yield of potato tubers ranged from 23.83 to 73.0 t per ha and was significantly affected by cultivar, hydrogel rate, and weather conditions in the study years (Table 4). Among the cultivars tested, cv. Lawenda produced the highest yield, followed by cv. Rima, while the lowest yield was recorded for cv. Provita, a cultivar with purple flesh. The effect of cultivar on tuber yield has been reported by numerous authors (Rykaczewska 2015, AL-Taey et al. 2019, Rzążewska et al. 2025). In recent years, adverse climatic changes and weather anomalies (rising mean temperatures, insufficient and unevenly distributed rainfall, and excessive water evaporation) have contributed to reduced yields, the formation of defective tubers, and changes in tuber quality traits (Král et al. 2019, Nowacki 2020, Piętka 2020, Figureira et al. 2026). An innovative solution to alleviate these risks is the use of NanoGels, also referred to as superabsorbents or hydrogels, in potato cultivation (Piętka 2020).

In the present study, the application of AgroNanoGel Basic at two rates resulted in an average yield increase of 5.3% at 60 kg/ha and 17.8% at 90 kg/ha compared with the control. Significant interactions were also observed: rate × cultivar – each cultivar showed a greater yield increase at the higher rate; cultivar × study year – cultivars responded differently to varying weather conditions; rate × study year – under the more favourable conditions of 2005, hydrogel rates produced a stronger yield-enhancing effect. The advantage of AgroNanoGel Basic lies in its ability to absorb water from rainfall and irrigation and subsequently release it to plants, with this cycle repeating multiple times. Smagin et al. (2019) reported that the use of acrylic hydrogels increased tuber yield by 6–15 t/ha and reduced water use by 1.3-2-fold. Moreover, reduced irrigation protected tubers from common potato pathogens, including *Phytophthora infestans*. Under the weather conditions of 2025, the mean tuber yield was 18.36 t/ha higher than in 2024, which was due to more favourable hydrothermal conditions, as the mean air temperature was close to the long-term average and rainfall was higher than in 2024. In May and July, precipitation exceeded the long-term average, likely allowing the hydrogel to

Table 4. Yield (t/ha) of potato cultivars in the years of study

Cultivar	Doses of AgroNanoGel Basic hydrogel (kg/ha)	Year		Mean
		2024	2025	
Lawenda	control object	44.81	52.96	48.89
	60	44.84	58.29	51.57
	90	51.60	73.00	62.30
	mean	47.08	61.42	54.25
Rima	control object	42.71	55.96	49.34
	60	42.82	57.42	50.12
	90	42.96	65.75	54.36
	mean	42.83	59.71	51.27
Provita	control object	23.83	42.99	33.41
	60	24.44	49.59	37.02
	90	24.81	52.10	38.46
	mean	24.36	48.23	36.29
Mean	control object	37.12	50.64	43.88
	60	37.37	55.10	46.23
	90	39.79	63.62	51.70
	mean	38.09	56.45	47.27

$HSD_{0.05}$ for: cultivars – 2.10; doses – 2.28; years – 1.38;
interaction: cultivars × doses – 3.96; cultivars × years – 2.97; doses × years – 3.23

HSD – honestly significant difference

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absorb excess water, forming "water crystals", and subsequently release it to the plants. According to Král et al. (2019), the optimal temperature for potato growth and development is 16–20 °C.

Potato glycoalkaloid (TGA) content ranged from 68.27 to 95.97 mg/kg fresh weight, values similar to those reported by other authors (Hamouz et al. 2014, Urban et al. 2018, Mystkowska 2019, Zarzecka et al. 2022) and safe for human consumption (Commission Recommendation 2022). The accumulation of these compounds was significantly influenced by cultivar, hydrogel rate, and study year (Table 5). The highest TGA content was recorded in the coloured-flesh cv. Provita. Urban et al. (2018) likewise observed that coloured-flesh cultivars accumulated more glycoalkaloids than white-fleshed cultivars. Hydrogel application significantly increased TGA content relative to the control. However, increasing the rate from 60 to 90 kg/ha did not raise TGA levels in cv. Rima. Analysis of cultivar responses across study years showed that all cultivars accumulated more TGA in the dry growing season of 2024 than in 2025, confirming the interaction between cultivars and years. Other authors have also reported that dry rather than humid years contribute to glycoalkaloid accumulation (Hamouz et al. 2014, Urban et al. 2018, Zarzecka et al. 2022).

The nitrate (V) content in the tested potato cultivars ranged from 156.1 to 181.8 mg/kg fresh weight (Table 6) and did not exceed the limit of 200 mg/kg fresh weight, ensuring consumer safety (Commission Regulation 2005). The accumulation of these compounds was significantly affected by cultivar, hydrogel rate, and hydrothermal conditions during the experiment. The lowest nitrate levels were recorded in Lawenda, the yellow-fleshed cultivar, while significantly higher levels were found in the remaining cultivars. The influence of cultivar on nitrate concentration has been confirmed by other researchers (Zarzecka et al. 2019, Wszelaczyńska et al. 2022, Gościnna et al. 2025). Hydrogel application contributed to increased nitrate accumulation compared with the control. A significant increase in nitrate content in response to raising the AgroNanoGel Basic rate from 60 to 90 kg/ha was observed only in cv. Rima, a finding confirmed by the significant cultivar × rate interaction. Weather conditions also influenced nitrate content: higher levels were recorded in the dry, warm year 2024 than in the cooler, more humid 2025. Zarzecka et al. (2019) and Trawczyński

Table 5. Glycoalkaloid content (mg/kg) in potato cultivars in fresh tuber weight

Cultivar	Doses of AgroNanoGel Basic hydrogel (kg/ha)	Year		Mean
		2024	2025	
Lawenda	control object	76.02	68.60	72.31
	60	77.69	68.70	73.20
	90	80.41	68.83	74.62
	mean	78.01	68.71	73.38
Rima	control object	72.63	68.27	70.45
	60	73.93	68.90	71.42
	90	73.94	68.30	71.12
	mean	73.50	68.49	71.00
Provita	control object	92.91	77.07	84.64
	60	93.83	77.90	85.87
	90	95.97	78.53	87.25
	mean	94.00	77.83	85.92
Mean	control object	80.29	71.31	75.80
	60	81.82	71.83	76.83
	90	83.44	71.89	77.66
	mean	81.85	71.68	76.76

$HSD_{0.05}$ for: cultivars – 3.25; doses – 0.38; years – 2.14;
Interaction: cultivars × years – 4.60

HSD – honestly significant difference

Table 6. Nitrate content (mg/kg) in potato cultivars in fresh tuber weight

Cultivar	Doses of AgroNanoGel Basic hydrogel (kg/ha)	Year		Mean
		2024	2025	
Lawenda	control object	156.1	160.5	158.3
	60	160.8	160.6	160.7
	90	161.1	160.9	161.0
	mean	159.4	160.7	160.0
Rima	control object	161.0	160.6	160.8
	60	180.3	164.6	172.5
	90	181.8	164.9	173.4
	mean	174.4	163.4	168.9
Provita	control object	171.0	160.6	165.8
	60	173.2	162.4	167.8
	90	173.7	161.7	167.7
	mean	172.6	161.6	167.1
Mean	control object	162.7	160.6	161.7
	60	171.4	162.5	166.9
	90	172.2	162.5	167.4
	mean	168.8	161.9	165.3

$HSD_{0.05}$ for: cultivars – 3.1; doses – 0.8; years – 2.0;
interaction: cultivars × doses – 1.4; cultivars × years – 4.3

HSD – honestly significant difference

(2020) similarly reported that in years with rainfall deficits and high temperatures, potatoes showed a greater tendency to accumulate nitrates than in cooler, wetter years.

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