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The content of harmful compounds in potatoes with coloured flesh and food and environmental safety

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ABSTRACT

Solanum tuberosum L. contains bioactive compounds, such as glycoalkaloids and nitrates, which in high concentrations can be harmful to human health. It was demonstrated that the content of harmful substances in both groups of analysed compounds depended to a large extent on a variety of environmental and agrotechnical factors. The highest content of glycoalkaloids was found in the Eurostar variety with light yellow flesh, and the lowest average content of these compounds was recorded in the Salad Blue variety with purple flesh. In the case of nitrates, the lowest average content was also found in the Eurostar variety, and the highest in the Rote Emmalie variety with red flesh. Analysis of the results from individual years of research showed that the highest accumulation of both TGA and nitrates occurred in 2021, while the lowest values were recorded in 2023. During the three years of the field experiment, air temperature and total precipitation were recorded. On the basis of the collected data, the Sielianinow hydrothermal index (K) was calculated. In 2021 and 2022, the values of this index were classified as optimal, while in 2023 the conditions were described as very dry. The results obtained indicate that the concentration of most undesirable substances was within the applicable food safety standards, although some varieties showed elevated levels of glycoalkaloids and nitrates, which justifies the need for further monitoring of their content.

Keywords: TGA, nitrates, environmental safety.

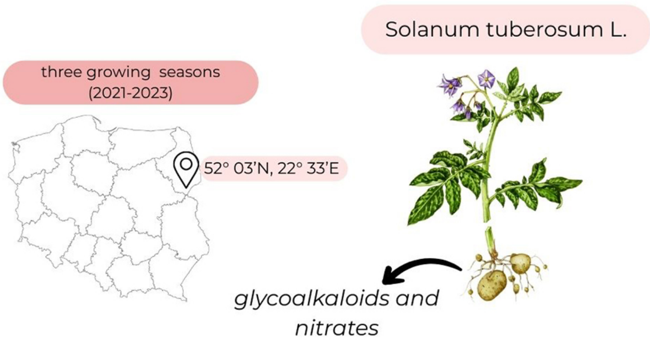
INTRODUCTION

As numerous authors point out (Lachman et al., 2016, Pęksa et al., 2024), the potatoes with coloured flesh are more visually appealing due to their unusual colour, which distinguishes them from traditional varieties and increases the attractiveness of the products made from them (Rasheed et al., 2022). The coloured potatoes with a TGA content of 85–182 mg·kg^{-1} dry weight and 12 mg of glycoalkaloids per 100 g of fresh weight have a bitter taste and are unacceptable to consumers (Pęksa et al., 2024). The varieties with low glycoalkaloid content include those with coloured flesh (Figueria et al., 2025). It is believed that the potato can significantly contribute to maintaining food security (Pobereżny et al., 2025). Glycoalkaloids, such as solanine and chaconine, exhibit antimicrobial activity but require careful monitoring due to their potential toxicity, although recent evidence suggests that controlled doses may provide health benefits (Vescovo et al., 2025). A safe concentration of nitrates (V) in the potatoes intended for consumption is considered to be no more than 200 mg NO_3^- per kilogram of product (Uddin et al., 2021). Exceeding the permissible concentrations of nitrates in vegetables can lead to adverse health effects (Zhu et al., 2025). The process of glycoalkaloid or nitrate accumulation is complex and depends not only on genetic factors, but also on environmental factors, agronomic practices, and post-harvest storage and handling conditions (Rytel, 2012; Di, 2024; Molmann and Johansen, 2025; Piekutowska and Niedbała, 2025). Although the coloured-flesh potatoes have beneficial nutritional properties, their unique metabolic and physiological characteristics may affect the levels of harmful compounds compared to conventional white and yellow-flesh varieties (Friedman, 2015). From an environmental and food safety perspective, it is crucial to understand how the coloured flesh varieties affect the growing environment and whether they exhibit altered tendencies to accumulate the substances that are harmful from a regulatory standpoint (Ben Ammar et al., 2025). Systematic assessment of undesirable compounds in the coloured-flesh potatoes contributes not only to consumer protection but also to the development of sustainable agricultural systems that minimise environmental risks. The research emphasised the importance of incorporating environmental safety criteria into the selection and cultivation of the coloured-flesh potatoes within sustainable farming systems. The results contribute to improving risk assessment frameworks and support informed decision-making in ecological crop management and food quality assurance.

The aim and scope of the study was to determine changes in dry matter content (TGA) and nitrate levels in tubers of seven edible potato varieties with coloured flesh and one variety with light yellow flesh in the years 2021–2023.

MATERIAL AND METHODS

The experiment design is shown in (Figure 1). Potato tubers were grown after winter triticale at the Agricultural Experimental Station in Zawady, planting them by hand in the third decade of April at intervals of 67.5 × 40 cm, and harvested in the second decade of September. The experiment was conducted on soil classified as Haplic Luvisol (LV-ha) with an acidic reaction (pH in 1N KCl 5.00–5.62) (Figure 2) using a one- factor randomised block design with in three replicates. Farmyard manure was applied in the autumn at the rate of 25 t·ha^{-1}, and mineral fertilisation with phosphorus and potassium was applied at the following rates: 44.0 kg·ha^{-1} P (as 46% triple superphosphate) and 124.5 kg·ha^{-1} K (in the form of 60% potassium chloride salt, granulated). In the spring, before planting the tubers, nitrogen was applied in the amount of 100 kg N per 1 ha (in the form of 34% ammonium salt). During the growing season, three treatments against potato blight and three against the Colorado potato beetle (Figure 1). Laboratory tests of the glycoalkaloid content in fresh tuber mass were determined using the Bergers method (Bergers, 1980), which enables the detection and determination of these compounds in plant samples. The nitrate (V) content in fresh potato tubers was determined using an ion-selective nitrate electrode and a silver-silver chloride reference electrode. Statistical analysis of the results was performed based on a one-factor analysis of variance. The Tukey test was used to assess the significance of differences between objects at a significance level of $p \leq 0.05$.



Treatments	Fertilizer s and plant protection products
Fertilization	Manure - 25 t·ha,$^{-1}$ N 100 kg·ha^{-1}, P 44,0 kg·ha^{-1}, K 124,5 kg·ha^{-1}
Weed control	Herbicide - Bandur 600 SC (aclonifene 600 g·dm^{3})
Colorado potato beetle control	Insecticides: Decis Mega 50 EW (deltamethrin 60 g·dm'), Coragen 200 SC (chlorantraniliprole 200 g·dm'), Mospilan 20 SP (acetamipryd (200 g·dm")
Late blight control	Fungicides: Infinito 687.5 SC (propamocarb hydrochloride 625 g ·dm3 + fluopicolide 62,5 g ·dm^{3}), Cabrio Duo 112 EC (dimetomorph 72 g·dm^{3} + pyraclostrobine 40 g·dm^{3}) + Carial Star 500 SC (mandiopropamide 250 g·dm^{3}+ difenoconazole 250 g·dm^{3})

Cultivar	Flesh color
Eurostar	Light Yellow
Provita	Purple
Rote Emma Emmalie	Red
Salad Blue	Purple
Blaue Annelise	Purple
Vitelotte	Purple
Herbie 26	Red
Bora Valley	Dark purple

Figure 1. Experience factors and agrotechnical measures applied

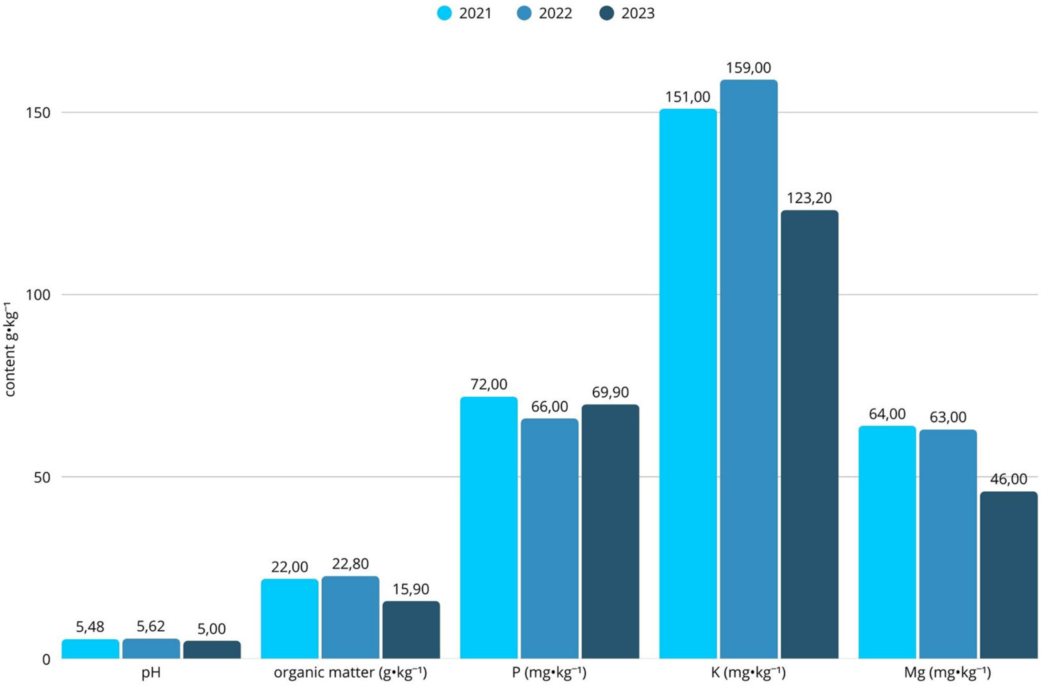


Figure 2. Chemical parameters of soil

RESULTS AND DISCUSSION

The research results showed that the level of glycoalkaloids was statistically significantly influenced by the variety and the weather conditions occurring in the individual years of the experiment, and that there was mutual interaction between these factors (Figure 4). Genotypic differences play a key role, as different potato varieties have varying levels of TGA biosynthesis, with some naturally producing higher concentrations (Ben Ammar et al., 2025). In the conducted study, the TGA level in potato tubers ranged from 69.00 to 94.13 mg·kg^{-1} fresh weight. The highest glycoalkaloid content was found in the Eurostar tubers with light yellow flesh (90.58 mg·kg^{-1} fresh weight) and the lowest in the Salad Blue tubers with purple flesh (82.26 mg·kg^{-1} fresh weight). In the studies by Urbana et al. (2018), eight varieties with coloured flesh had a lower TGA content compared to the yellow-white control potatoes. As indicated by Pęksa et al. (2025), the TGA content in the tested tubers ranged from 33.69 to 167.77 mg·kg^{-1} FM and was lower compared to tubers with yellow flesh. For comparison, Friedman and Levin (2016) reported values of 8.0–63.1 mg·kg^{-1} FW in tubers with varying flesh colours. The highest glycoalkaloid content was found in the Eurostar tubers with light yellow flesh (90.58 mg·kg^{-1} fresh weight) and the lowest in Salad Blue tubers with purple flesh (82.26 mg·kg^{-1} fresh weight). In the studies by Urbana et al. (2018), eight varieties with coloured flesh had a lower TGA content compared to the yellow-white control potatoes. Pęksa et al. (2024) report that the TGA level in tuber tissue ranged from 33.69 to 167.77 mg·kg^{-1} (FM) and was lower compared to yellow-fleshed tubers. Friedman and Levin (2016) reported that the TGA content in potato tubers with different flesh colours ranges from 8.0 to 63.1 mg·kg^{-1} FW. The research by Rytel et al. (2014) shows that the varieties with red and purple flesh have a higher TGA content compared to the varieties with white flesh. The varieties with coloured flesh have undergone long-term breeding selection aimed at enhancing desirable sensory characteristics and reducing toxicity, which has resulted in a significant reduction in glycoalkaloid content (Knuthsen et al., 2009). There are significant differences in the TGA concentrations in tubers, depending on the potato variety and stage of maturity, as well as variable environmental conditions during cultivation, such as high temperatures or heavy rainfall (Martinez-Garcia et al., 2024). The studies conducted showed a statistically significant the impact of weather conditions prevailing during the years of the study on the discussed trait, which was presented using the Sielianinow hydrothermal index (Figure 3). All varieties accumulated the highest amount of glycoalkaloids in 2021,

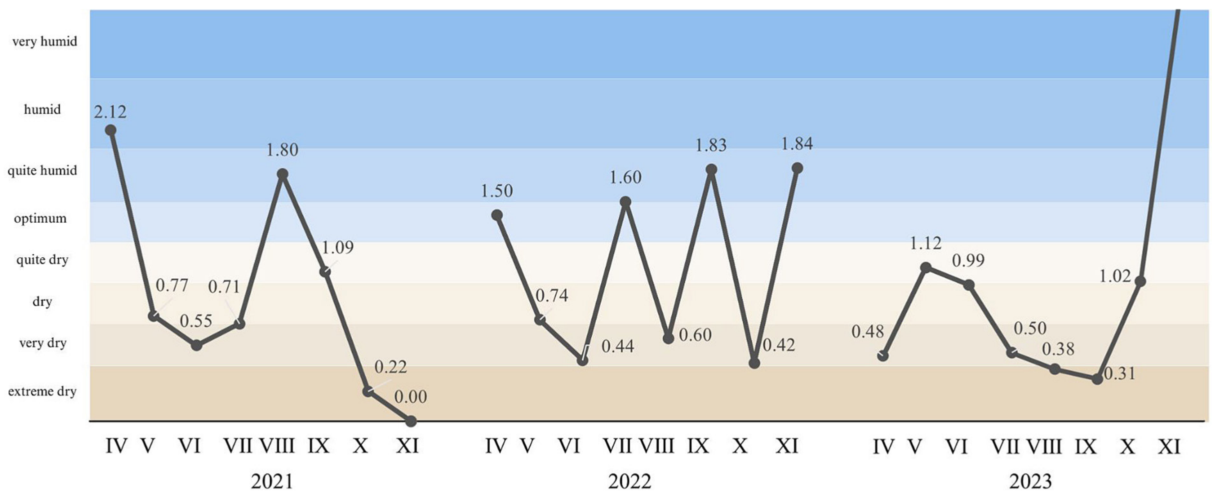


Figure 3. Hydrotelmal index calculated based on precipitation and temperature

with an average of 89.98 mg·kg^{-1} FW, which was optimal, but in which August was quite humid, and the lowest in 2023 (81.25 mg·kg^{-1} FW). The warmest and very dry years, characterised by low rainfall, were extremely dry, very dry and dry, which was not conducive to crop yields and the varieties responded differently to changing weather conditions. Weather conditions and the interaction of varieties with years of research significantly affected the TGA content (Figure 4). Muñoa et al. (2022) reached similar conclusions, showing that tubers accumulate lower concentrations of TGA even under conditions of elevated temperature. Other authors have also noted the influence of weather conditions on the glycoalkaloid content of potato tubers (Pęksa et al. (2024) and found that the glycoalkaloid content depended on the variety and weather conditions during the years of the study. According to Markosyan et al. (2025), climatic conditions had a significant

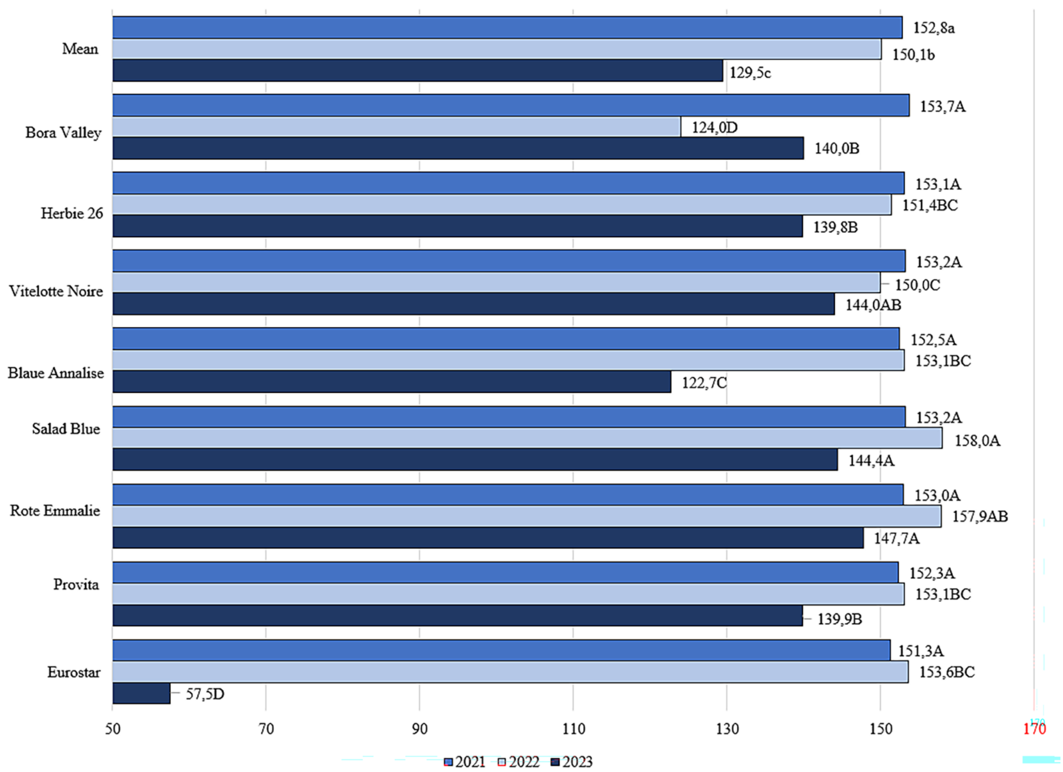


Figure 4. Glycoalkaloid content depending on variety and weather conditions in 2021–2023 mg·kg^{-1} fresh weight

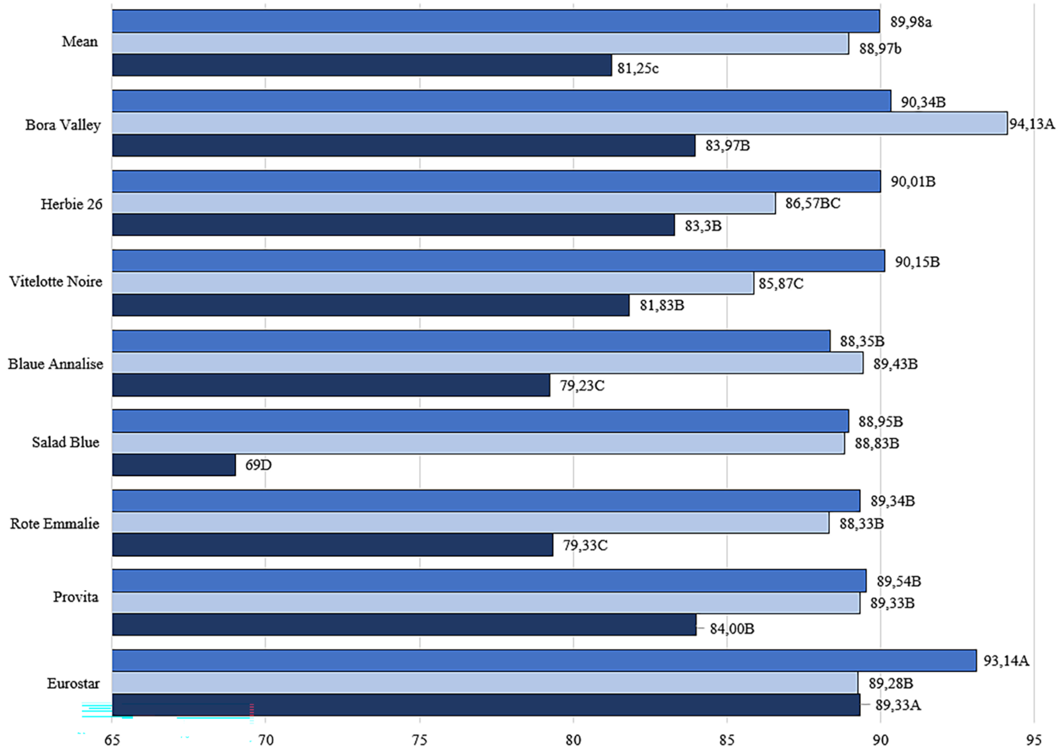


Figure 5. Nitrate content depending on variety and weather conditions in 2021–2023 mg·kg^{-1} of fresh weight

impact on tuber productivity and composition. Nitrates are the main source of nitrogen for cultivated plants, which can have potentially harmful health effects if consumed in excess by the body (Wang et al., 2024). During nitrate assimilation, nitrate reductase acts as a rate-limiting enzyme, and NiR reduces nitrate to NH_4^+, which then enters the nitrogen metabolic pathway (Kishorekumar et al., 2020). The nitrate content in plants is largely determined by the genetic characteristics of a given variety, but it is also significantly influenced by environmental factors and agronomic practices, such as nitrogen fertilisation intensity, irrigation method, soil type and prevailing climatic conditions (Seno Nascimento et al., 2024). Soil pH is crucial for nitrogen availability and plant metabolism, and thus for nitrate accumulation. The appropriate soil pH promotes a balance between nitrogen availability and its utilisation by plants. The nitrate content in tubers is highly variable and depends on the variety (Pobereżny et al., 2025). Studies have shown that all varieties differed in nitrate content from 57.5 to 158.0 mg kg^{-1}FM and was significantly dependent on weather conditions. The highest amount of this component was found in the red-fleshed Rote Emmalie variety (average 152.90 mg·kg^{-1} FW), and the lowest amount was found in the light yellow-fleshed Eurostar variety (average 120.8 mg·kg^{-1} FW) (Figure 5). The nitrate concentration in the tubers was similar to the values reported by other authors, Trawczyński (2021) and Rytel (2012). The results of the conducted research confirmed that the level of nitrate accumulation in potato tubers is largely determined by genotype, as evidenced by clear differences in their content between the varieties studied. The amount and distribution of precipitation and air temperature influence the extent of nitrogen compound transformations in potato tubers. The highest nitrate accumulation was obtained in 2021, with an optimal average of 152.8 mg·kg^{-1} FW for all varieties, and the lowest average of 129.5 mg·kg^{-1} FW in 2023, which was very dry and the warmest compared to the long-term average. Nitrate content was significantly affected by weather conditions and the interaction of varieties with years of research (Figure 5). Studies by other authors, Pobereżny et al. (2025) and Kołodziejczyk and Gwóźdź (2022) also report the lowest nitrate accumulation in the potato tubers produced under more favourable weather conditions. This indicates that nitrate concentration is determined not only by the genotypic characteristics of the potato, but also by the prevailing meteorological conditions.

CONCLUSIONS

The study highlighted the importance of considering environmental safety criteria when selecting and cultivating the coloured-flesh potatoes within sustainable agricultural systems. The results contribute to improving the risk assessment framework and support informed decision-making in the areas of ecological crop management and food quality assurance. Differences in the content of harmful substances found in the coloured flesh varieties depended on the variety, the year of the study and the cultivation technology used in the experiment. The highest level of glycoalkaloids was found in the Eurostar tubers with light yellow flesh, and the lowest in the Salad Blue tubers with purple flesh. The lowest average nitrate content was found in the Eurostar variety, and the highest in the Rote Emmalie variety with red flesh. The amount and distribution of rainfall and air temperature influenced the range of changes in glycoalkaloids and nitrates in the potato tubers during the study period. The highest concentrations of TGA and nitrates were observed in 2021, and the lowest in 2023, which was very dry and the warmest compared to the long-term average. The concentrations of most undesirable substances are within the applicable food safety standards. Some varieties showed elevated levels of glycoalkaloids and nitrates, highlighting the need for further monitoring of their content.

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