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# Content of polyphenols and carotenoids in edible potato tubers with coloured flesh

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**Abstract:** Polyphenols and carotenoids are important bioactive compounds in potato tuber. Knowledge of these features makes it possible to select cultivars for cultivation, consumption, and processing with desirable properties. For this purpose, the content of polyphenols and carotenoids in edible potato tubers from different countries was analysed. The research material consisted of eight cultivars, including one light yellow – Eurostar, two with red flesh – Rote Emmalie and Herbie 26 and five cultivars with purple flesh – Provita, Salad Blue, Blue Annelise, Vitelotte Noire and Bora Valley. They were cultivated in a three-year, single-factor field experiment. The content of polyphenols in the analysed cultivars ranged from 165.0 to 283.8 mg/kg of fresh weight and depended on the cultivar, year of research and cultivar-year interactions. The highest average amounts of these compounds were noted in the Herbie 26, Rote Emmalie and Vitelotte Noire cultivars. The content of carotenoids ranged from 1.122 to 3.173 mg/kg of fresh weight and depended significantly on the cultivar, weather conditions in the years of the study and the interaction of cultivars with years. The highest amounts of carotenoids were determined in the purple-fleshed cultivars Blaue Annelise and Vitelotte Noire and the red-fleshed cultivar Rote Emmalie.

**Keywords:** *Solanum tuberosum* L.; nutrition; red and purple tuber flesh; bioactive substances

Health-promoting components in raw materials and plant-based products are increasingly recognised and appreciated by producers, dieticians, and consumers alike. This stems, among other things, from lifestyle and societal affluence changes, growing awareness, and shifting dietary patterns. Modern consumers are showing greater concern for their health, are interested in preventing diet-related diseases, and expect food to be produced from raw materials with enhanced nutritional value and rich in phytochemicals such as polyphenols, carotenoids, vitamins, polyunsaturated fatty acids, proteins, or mineral compounds (Thakur et al. 2020, D'Amelia et al. 2022). Of importance is the fact that plant-based bioactive compounds are safe for use in food, are characterised by multiple health-promoting effects, and can potentially be used as natural substances which strengthen the body and enrich the diet (Berindean et al. 2022). Among the plants that are a good source of valuable bioactive compounds is the potato, whose various flesh colours range from creamy and yellow to red, purple, and dark purple (Rytel et al. 2019, Zarzecka et al. 2022). The phenolic compounds found in potato tubers are secondary plant metabolites divided into two main groups: phenolic acids and flavonoids. Of all phenolic acids, chlorogenic acid is predominant, accounting for 90% of the phenolic compounds in potato tuber skins (Ezekiel et al. 2013, Hamouz et al. 2013). Potato polyphenols are natural antioxidants – they help protect the body from the harmful effects of free radicals and prevent cardiovascular diseases and neoplasms (Rasheed et al. 2022). Studies have shown that polyphenol content is primarily determined by the potato cultivar as well as environmental and agronomic factors and their interaction with the genotype (Orsák et al. 2019, Berindean et al. 2022, D'Amelia et al. 2022, Rasheed et al. 2022).

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Table 1. Characteristics of the potato cultivars examined in this study

| Cultivar | Flesh colour | Skin colour | Yield of tubers | Country of origin |
|---|---|---|---|---|
| Eurostar | light yellow | light yellow | large | Netherlands |
| Rote Emmalie | red | red | large | Germany |
| Herbie 26 | red | red | medium | Czech Republic |
| Provita | purple | purple | medium | Poland |
| Salad Blue | purple | dark blue | medium | United Kingdom |
| Blue Annelise | purple | dark purple | medium | Germany |
| Vitelotte Noire | purple | purple | medium | Peru-France |
| Bora Valley | dark purple | dark purple | very large | Korea |

Carotenoids are an important group of natural organic pigments synthesised in plants. They can be divided into orange carotenes and yellow xanthophylls, with lutein being the dominant representative of the latter group (Lachman et al. 2016, Trawczyński et al. 2019). They exhibit antioxidant and anti-inflammatory properties and contribute to skin health and good vision, as they protect the eyes from macular degeneration and cataracts (Saini et al. 2015, Lal et al. 2021). Hamouz et al. (2016) and Mystkowska et al. (2023) reported that the total carotenoid content in potato tubers depends on the cultivar, location, weather conditions, and agronomic practices. The aim of the study was to evaluate the content of polyphenols and carotenoids in potato tubers with coloured flesh under different weather conditions.

## MATERIAL AND METHODS

Potato tubers for chemical analysis came from a three-year, single-factor field experiment conducted in 2021–2023. They were established using the random block method in three replications on a medium soil with a granulometric composition of sandy loam, acidic to slightly acidic and medium to high abundance in available P, K, and Mg forms. Eight edible potato cultivars were grown and evaluated in the experiment – a control cultivar with light yellow flesh Eurostar, two cultivars with red flesh and five cultivars with purple flesh. The characteristics of the cultivars are shown in Table 1. Fertilisation and control of diseases and pests in accordance with the requirements of agricultural practice are presented in Table 2.

Every year, potatoes are grown after winter triticale. The size of a single plot was 12.96 $m^2$ (4.8 × 2.70 m). Potato tubers were planted by hand in the third decade of April at a spacing of 67.5 × 40 cm and harvested in the second and third decade of September, at the stage of full physiological maturity.

Polyphenols and carotenoids content was determined in fresh potato tubers 3–5 days after harvest. The polyphenols were determined by a spectrophotometer (Spectroblue, AMETEK Inc., Jena, Germany) with Folin-Ciocâlteu reagent. These compounds were determined using the method proposed by Mystkowska et al. (2020). Total carotenoid analysis was performed in accordance with the Polish Standard PN-90/A-75101/12 (1990). The detailed procedure for determining these compounds was carried out using the method proposed by Mystkowska et al. (2023).

The results obtained from the conducted chemical analyses were statistically processed using the analysis of variance. The significance of differences (*HSD* –

Table 2. Fertilisation and preparations of plant protection applied in the experiment

| Treatment | Fertilisers and plant protection products |
|---|---|
| Fertilisers | manure – 25 t/ha, 100 kg N/ha, 44.0 kg P/ha, 124.5 kg K/ha |
| Weed control | herbicide – Bandur 600 SC (aclonifene) 0.3 L/ha |
| Colorado potato beetle control | insecticides: Decis Mega 50 EW (deltamethrin) 0.1 L/ha, Coragen 200 SC (chlorantraniliprole) 0.05 L/ha, Mospilan 20 SP (acetamipryd) 0.1 kg/ha |
| Late blight control | fungicides: Infinito 687.5 SC (propamocarb and fluopicolide) 1.5 L/ha, Cabrio Duo 112 EC (dimetomorph and pyraclostrobine) 2.5 L/ha, Carial Star 500 SC (mandiopropamide and difenoconazole) 0.6 L/ha |

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Table 3. Meteorological conditions in 2021–2023, according to Zawady Meteorological Station (Poland)

| Year | Rainfalls sum (mm) | In comparison to multi-year | Air temperature (°C) | In comparison to multi-year |
|---|---|---|---|---|
| 2021 | 292.8 | –15.1 | 15.4 | +1.0 |
| 2022 | 289.0 | –18.9 | 14.8 | +0.8 |
| 2023 | 185.5 | –122.4 | 16.6 | +2.2 |
| 1980–2009 | 307.9 | | 14.4 | – |

honestly significant difference) between the objects was verified using the Tukey's test at a significance level of $P \leq 0.05$ (Trętowski and Wójcik 1991).

The study presents meteorological conditions and hydrothermal coefficient from an experimental station located in the study area at a distance of about 200 m from the experiment. The years 2021 and 2022 were relatively dry, with rainfall deficits in these seasons of 15.1 mm and 18.9 mm, respectively, compared to the multi-year period (Tables 3 and 4). The year 2023 was very dry. All months, with the exception of May, were characterised by low rainfall, extremely dry, very dry and dry. Rainfalls during the growing season were 122.4 mm less, and air temperature was 2.2 °C higher than in the multi-year period.

## RESULTS AND DISCUSSION

The polyphenol content determined in the fresh weight of tubers varied according to the cultivar and study year, ranging from 165.0 to 283.8 mg/kg (Table 5, Figure 1A). These values align with the findings of other authors (Hamouz et al. 2013, Zarzecka et al. 2019, Mystkowska et al. 2020, D'Amelia et al. 2022, Cebulak et al. 2023). The genetic properties of the test cultivars significantly influenced the analysed trait. The highest average polyphenol amounts (calculated across three study years) were recorded for cv. Herbie 26, Rote Emmalie, and Vitelotte Noire, with no significant differences between these cultivars (Figure 1A). The lowest average polyphenol amounts were found in cv. Provita (purple) and cv. Eurostar (light yellow).

The high concentration of this component in cvs. Herbie 26, Rote Emmalie, and Vitelotte was found in studies by Hamouz et al. (2013), and in cv. Herbie 26 in the research by Rytel et al. (2019). Of the eight cultivars with different flesh colours which they tested, Cebulak et al. (2023) recorded the highest polyphenol content in cv. Vitelotte, while Nemś et al. (2015) reported the same finding for cv. Blaue Annelise. Weather conditions during the study years proved to be a factor affecting polyphenol content in tubers, the factor being no less significant than the cultivar itself (Tables 4 and 5). The year 2022, which was relatively dry with alternating dry, very dry, and relatively dry months, was the most favourable for the concentration of this component. The influence of climatic conditions on polyphenol content was confirmed in studies by Hamouz et al. (2013), Escuredo et al. (2018), and Mystkowska et al. (2020). Variance analysis revealed a significant interaction between cultivars and study years, indicating varied responses to meteorological conditions. The highest polyphenol accumulation was observed in cv. Bora Valley (purple) and cv. Herbie

Table 4. Hydrothermal Sielianinov index (*K*) in the years of study

| Year | Month | | | | | | Mean IV–IX |
|---|---|---|---|---|---|---|---|
| | April | May | June | July | August | September | |
| 2021 | 2.13<br>humid | 0.79<br>dry | 0.55<br>very dry | 0.73<br>dry | 1.86<br>relatively humid | 1.09<br>relatively dry | 1.19<br>relatively dry |
| 2022 | 1.51<br>optimal | 0.76<br>dry | 0.44<br>very dry | 1.66<br>relatively humid | 0.62<br>very dry | 1.84<br>relatively humid | 1.14<br>relatively dry |
| 2023 | 0.48<br>very dry | 1.16<br>relatively dry | 0.99<br>dry | 0.52<br>very dry | 0.39<br>extremely dry | 0.31<br>extremely dry | 0.64<br>very dry |

Skowera et al. (2014) classified index (*K*) values as: $K \leq 0.4$ – extremely dry; $0.4 < K \leq 0.7$ – very dry; $0.7 < K \leq 1.0$ – dry; $1.0 < K \leq 1.3$ – relatively dry; $1.3 < K \leq 1.6$ – optimal; $1.6 < K \leq 2.0$ – relatively humid; $2.0 < K \leq 2.5$ – humid; $2.5 < K \leq 3.0$ – very humid, $K > 3.0$ extremely humid

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Table 5. Content of total polyphenols in cultivar potato tubers (mg/kg fresh matter)

| Cultivar | 2021 | 2022 | 2023 |
|---|---|---|---|
| Eurostar | 256.4 | 180.3 | 169.9 |
| Rote Emmalie | 240.4 | 282.3 | 282.2 |
| Herbie 26 | 252.4 | 283.4 | 273.4 |
| Provita | 240.9 | 184.5 | 165.0 |
| Salad Blue | 235.0 | 277.2 | 187.4 |
| Blue Annelise | 244.7 | 282.2 | 262.1 |
| Vitelotte Noire | 247.5 | 281.4 | 271.1 |
| Bora Valley | 249.2 | 283.8 | 253.4 |
| Mean | 245.8 | 256.9 | 233.1 |
| $HSD_{0.05}$ for: years – 5.6; interaction cultivars × years – 15.8 | | | |

*HSD* – honestly significant difference

Table 6. Content of total carotenoids in cultivar potato tubers (mg/kg fresh matter)

| Cultivar | 2021 | 2022 | 2023 |
|---|---|---|---|
| Eurostar | 2.513 | 1.368 | 1.370 |
| Rote Emmalie | 2.803 | 2.167 | 3.163 |
| Herbie 26 | 2.820 | 2.347 | 2.167 |
| Provita | 2.727 | 1.122 | 1.843 |
| Salad Blue | 2.807 | 2.203 | 2.840 |
| Blue Annelise | 2.823 | 2.282 | 3.173 |
| Vitelotte Noire | 2.927 | 2.273 | 3.073 |
| Bora Valley | 2.973 | 2.423 | 2.320 |
| Mean | 2.800 | 2.020 | 2.490 |
| $HSD_{0.05}$ for: years – 0.046; interaction cultivars × years – 0.130 | | | |

*HSD* – honestly significant difference

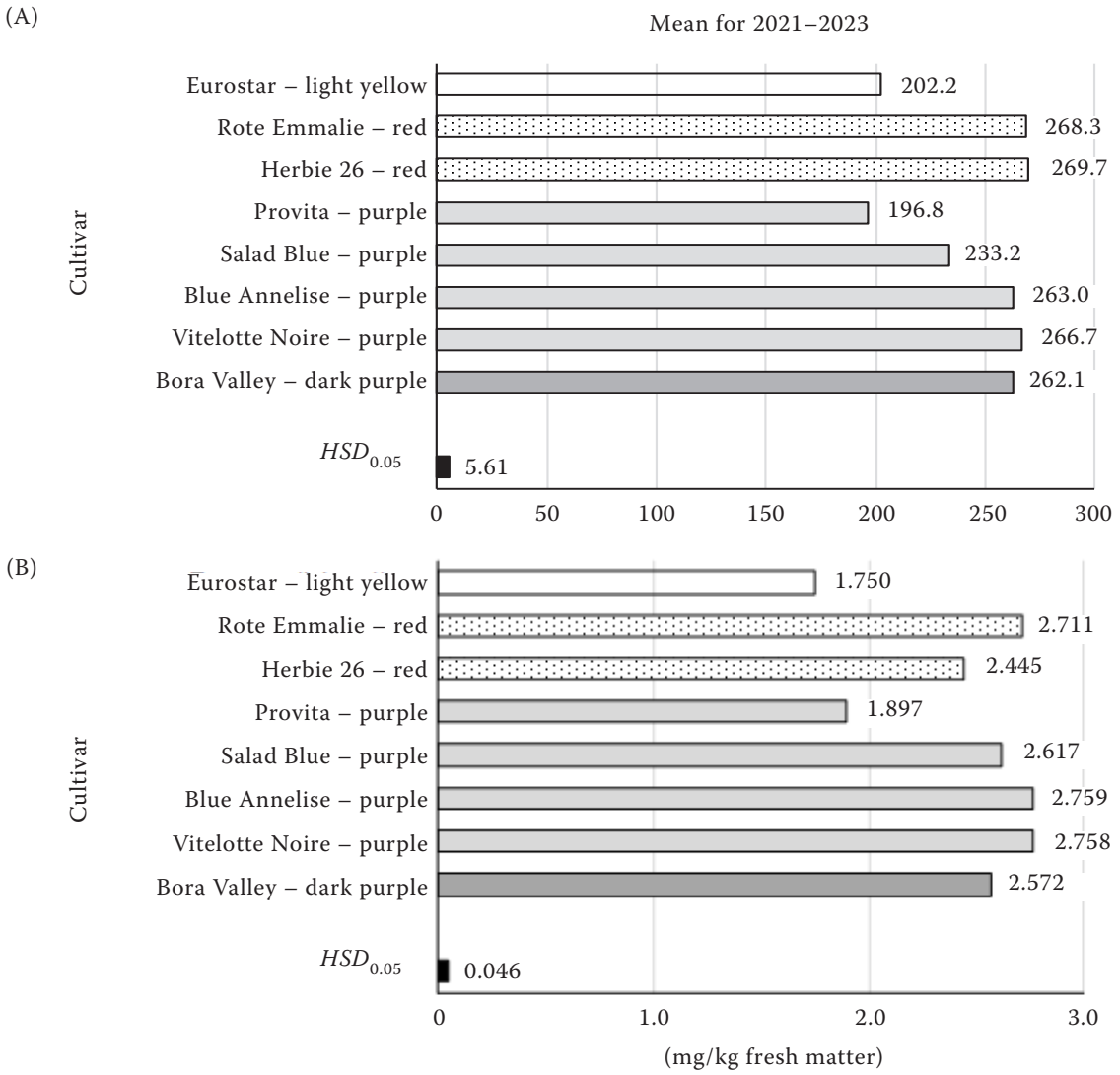


Figure 1. (A) Total polyphenols and (B) total carotenoid content in potato tubers; *HSD* – honestly significant difference

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26 (red) in 2022, while the lowest was determined in cv. Provita (purple) and cv. Eurostar (light yellow) in the dry year 2023. In 2023 (dry), among groups of cultivars with coloured flesh, a tendency toward higher polyphenol accumulation was observed in red-fleshed cultivars. In contrast, Orsák et al. (2019) observed this trend in cultivars with purple flesh. The interaction between cultivars and study years was also noted by other researchers (Hamouz et al. 2013, Orsák et al. 2019, Mystkowska et al. 2020).

The carotenoid content in potato tubers ranged from 1.122 to 3.173 mg/kg of fresh weight and was significantly influenced by the cultivar, weather conditions during the study years, and the interaction between cultivars and years (Table 6, Figure 1B).

The highest average values of this component were recorded in the purple-fleshed cv. Blaue Annelise and cv. Vitelotte Noire, as well as in the red-fleshed cv. Rote Emmalie, amounting to 2.759, 2.758, and 2.711 mg/kg, respectively (Figure 2). The lowest carotenoid levels were found in cv. Eurostar (light yellow) and cv. Provita (purple). The influence of cultivar on this trait in potatoes with different flesh colours was noted by other authors who reported that white-fleshed potato cultivars contained lower amounts of carotenoids compared to coloured ones (Hamouz et al. 2016, Lachman et al. 2016, Cima et al. 2020, Samaniego et al. 2020, Lal et al. 2021). Weather conditions during the potato growing season significantly affected the discussed trait. The highest carotenoid content – 2.800 mg/kg – was recorded in 2021, when May, June, July, and September were dry, very dry, and relatively dry, while the lowest average content – 2.020 mg/kg – was observed in 2022. The impact of hydrothermal conditions on carotenoid accumulation was demonstrated in studies by other authors (Hamouz et al. 2016, Escuredo et al. 2018, Mystkowska et al. 2023). Statistical calculations confirmed varying responses of the test cultivars to climatic conditions. The highest carotenoid accumulation was observed in cv. Bora Valley in 2021 and 2022, which were relatively dry and in cv. Blue Annelise in a very dry 2023. In contrast, the lowest amounts of these compounds across all the study years were recorded in cvs. Eurostar and Provita. The significant interaction between cultivars and study years was confirmed in research by Escuredo et al. (2018) and Mystkowska et al. (2023). Hamouz et al. (2016) and Samaniego et al. (2020) demonstrated varied responses of cultivars to both diverse weather conditions and different cultivation locations.

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