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Monitoring of selected heavy metals and bioactive compounds in potato (*Solanum tuberosum* L.) tubers

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Potato (*Solanum tuberosum* L.) tubers are a significant part of agricultural production and an important part of the food for human nutrition. Tubers of seven potato cultivars (Annalena, Anuscha, Elfe, Impala, Marena, Riviera, Rosara) were analyzed in this study. Total polyphenol content in analyzed cultivars ranged from 161.7 to 496.1 mg GAE.kg^{-1} FW (641.5 to 2418.6 mg GAE.kg^{-1} DM). Antioxidant activity in analyzed cultivars ranged from 0.27 to 0.67 mmol TE.kg^{-1} FW (1.08 to 6.18 mmol TE.kg^{-1} DM). Significant differences were determined in the TPC and AA of Annalena and Rosara, Anuscha and Rosara, Annalena and Riviera, and Anuscha and Riviera. Cd content in analyzed cultivars ranged from 0.006 to 0.064 mg.kg^{-1} FW (0.02 to 0.278 mg.kg^{-1} DM). Pb content in analyzed cultivars ranged from 0.015 to 0.370 mg.kg^{-1} FW (0.05 to 1.47 mg.kg^{-1} DM). The limit for Pb, set by Commission Regulation (EC) no. 1881/2006 was exceeded in cultivars Annalena, Elfe, Impala, Marena, and Rosara. Significant differences were determined in the Cd content of Annalena and Marena, Annalena and Riviera, and Annalena and Rosara. Significant differences were determined in the Pb content of Annalena and Riviera, and Annalena and Rosara. Positive correlations ($p < 0.001$) were determined between TPC and AA ($r = 0.658$). Negative correlations were determined ($p < 0.05$) between TPC and Cd content, and AA and Cd content.

Keywords: *Solanum tuberosum*, polyphenols, antioxidants, cadmium, lead

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Introduction

Potato (*Solanum tuberosum* L.) tubers are the third most important crop in the world (after rice and wheat) and they contribute to the nutrition of people in many parts of the world (Venkatasalam et al., 2019). According to FAOSTAT, worldwide potato consumption reached 234802223.6 tonnes in 2019 (30.66 kg per capita).

Potato tubers are primarily composed of carbohydrates, but they are also an important source of proteins and essential amino acids, fiber, potassium, and other minerals, vitamin C, B_6, and bioactive compounds (Pineros-Nino et al., 2017; Sood et al., 2017). Nutritional properties such as starch digestibility, glycemic index, and relative glycemic impact are important for human health. The relationship between potato tuber composition and its effect on blood glucose release has been explored through various *in vitro* and *in vivo* studies (Singh and Kaur, 2016).

Potatoes are known as one of the richest sources of antioxidants in the human diet (Ramadan and Oraby, 2016). Polyphenols are considered the most widespread antioxidants in the human diet, able to prevent the formation of free radicals with harmful effects on health, and are therefore important in reducing the risk of developing diseases (Amoroso et al., 2019). These compounds may have multiple effects such as reduction of the initiation of tumors, the induction of apoptosis and platelet aggregation, modulation of lipid metabolism, stimulation of the immune system, and antibacterial, antiangiogenic, and antimutagenic properties (Laib and Barkat, 2018). Studies on animals or cultured human cell lines demonstrate the role of polyphenols in the prevention of cardiovascular diseases, cancer, neurodegenerative diseases, osteoporosis, and diabetes (Scalbert et al., 2005). The content of phenols in potatoes is highly dependent on the cultivar, cultivation, stress factors, growing conditions, climatic conditions, tuber maturity level, and processing (Hamouz et al., 2006; Sood et al., 2017; Laib and Barkat, 2018).

Potato plants are exposed to different types of compounds that are present in polluted air, soil, and water. Foreign elements represent a stress factor for most plants, and after entering the food chain, they can pose a danger to the human organism. (Goncalves et al., 2009; Musilová et al., 2011). Heavy metals are involved in reducing the quality of the environment. Non-essential chemical elements, such as Cd and Pb are toxic even at relatively low concentrations (Musilová et al., 2017).

Cadmium (Cd) is an element with highly toxic effects on humans due to its cumulative effect, mainly in the liver and kidneys. Cadmium is naturally present in most soils as a trace element, but it is also widespread in the environment due to human activity (Mengist et al., 2017).

Lead (Pb) is a highly toxic element with effects on almost every organ in the body, with the most affected target being the nervous system. Major anthropogenic sources of Pb, such as smelting, lead-based painting, lead-containing pipes, and lead-acid batteries battery, etc. contribute to the adverse effects of lead on humans and the environment (Ara and Usmani, 2015).

This study aimed to investigate and evaluate the total content of polyphenols and antioxidant activity in selected cultivars of potato tubers, determine the presence of selected heavy metals in selected cultivars of potato tubers, and evaluate the correlations between heavy metal content and the total content of polyphenols and antioxidant activity.

Material and methodology

Plant samples

Samples of potato (*Solanum tuberosum* L.) cultivars (Annalena, Anuscha, Elfe, Impala, Marena, Riviera, Rosara) were taken at the stage of full maturity from selected localities of the Slovak Republic (Nedanovce, Bytčica, Spišská Stará Ves).

Extract preparation

25 g of homogenized potato tubers were extracted in 50 mL of 80% methanol for 12 hours and filtered through Munktell No. 392 filtrating paper.

Total polyphenol content

Total polyphenol content was determined by Folin-Ciocalteau colorimetric method (Lachman et al., 2003) using Folin – Ciocalteu phenol reagent (Merck, Germany), 20% Na_2CO_3 (Sigma Aldrich, USA), and distilled water. 0.1 mL of extract was pipetted into a 50 mL volumetric flask. 0.85 mL of Folin Ciocalteau reagent was added, and after 3 minutes, 5 mL of 20% Na_2CO_3 was added. After stirring the mixture, flasks were filled with distilled water to the mark. Flasks were left for 2 hours at laboratory temperature and then measured againsta blank solution at 765 nm, using Shimadzu UV/VIS scanning spectrophotometer. Total polyphenol content was expressed as mg of gallic acid equivalent in 1 kg of fresh matter, based on the calibration curve (R^2 = 0.996)

Antioxidant activity

Antioxidant activity was measured by DPPH radical scavenging assay (Brand Williams et al., 1995), using DPPH•+ radical (2,2-diphenyl-1-picrylhydrazyl) (Sigma Aldrich, USA). DPPH•+ radical and methanol (Sigma Aldrich, USA) were used to produce a working DPPH solution. 1 mL of extract was pipetted into 3.9 mL of working DPPH solution, stirred, and left in dark. After 10 minutes, the solution was measured against a blank solution at 515.6 nm, using Shimadzu UV/VIS scanning spectrophotometer. Antioxidant activity was expressed as mmol of Trolox equivalent in 1 kg of fresh matter, based on the calibration curve ($R^2 = 0.997$).

Cadmium and lead content

Cd and Pb content were determined after mineralization in a mixture of 5 mL of HNO3 (Suprapur®, Merck, Darmstadt, Germany) and 5 mL of deionized water (0.054 $\mu S.cm^{-1}$) in the Mars Xpress 5 closed microwave digestion system (CEM Corp., Matthews, NC, USA). Mineralized samples were analyzed by the atomic absorption spectrometer SpectrAA 240Z. The limit of detection of Cd and Pb was set at 10 $ng.kg^{-1}$, and the limit of quantification was set at 30 $ng.kg^{-1}$.

Statistical analysis

Statistical analysis was performed using XLSTAT software. To determine significant differences ($p < 0.001$) between individual cultivars, Kruskal-Wallis nonparametric ANOVA test, and Dunn pairwise test were performed. The Spearman correlation coefficient was performed to determine significant correlations between monitored parameters.

Results and discussion

Total polyphenol content and antioxidant activity of potato tubers

Total polyphenol content in analyzed cultivars ranged from 161.7 to 496.1 mg $GAE.kg^{-1}$ FW (641.5 to 2418.6 mg $GAE.kg^{-1}$ DM). Significant differences ($p < 0.001$) were determined between the TPC of Annalena and Rosara, Anuscha and Rosara, Annalena and Riviera, and Anuscha and Riviera. The difference in the content of polyphenols can be attributed to the variety, genotype, and harvesting sites, which influence the accumulation of phenolic compounds (Hesam et al., 2012). André et al. (2009) reported that the content of total phenols in the tubers of 13 potato cultivars was significantly influenced by the growing environment. However, the genotypic component (cultivar) contributed the most to the observed variability. Giusti et al. (2014) reported the polyphenol content from 1133.7 to 1146.3 mg $GAE.kg^{-1}$ DW in yellow-fleshed potatoes. Gugała et al. (2017) reported this parameter from 161.9 to 179.2 mg $GAE.kg^{-1}$ FW in potato tubers. Lachman et al. (2008) reported TPC from 2904 to 3295 mg $GAE.kg^{-1}$ DM, depending on the cultivar and location. Franková et al. (2022) reported about wide range of values from 1140 to 33400 mg $GAE.kg^{-1}$ DM, depending on cultivar and maturity. Deußer et al. (2012) also reported about a wide range of values from 400 to 5400 mg $GAE.kg^{-1}$ DM in potatoes grown in Luxembourg. Karim et al. (2017) reported about higher values of polyphenol content from 3205.9 to 5289.4 mg $GAE.kg^{-1}$ DM. The cultivar significantly influenced the TPC content. Hamouz et al. (2007) also reported higher values – from 3040 to 7700 mg $GAE.kg^{-1}$ DM depending on the cultivar, location, and fertilization. Hesam et al. (2012), however, reported about lower values of TPC from 165.7 to 362.4 mg GAE. kg^{-1} DM.

Antioxidant activity of analyzed cultivars ranged from 0.27 to 0.67 mmol $TE.kg^{-1}$ FW (1.08 to 6.18 mmol $TE.kg^{-1}$ DM). Significant differences ($p < 0.001$) were determined between AA of Annalena and Rosara, Anuscha and Rosara, Annalena and Riviera, and Anuscha and Riviera. Kita et al. (2013) reported that AA was from 4.6 to 14.4 mmol $TE.kg^{-1}$ DM in potato cultivars. According to Hu et al. (2012), several factors influence antioxidant activity, namely maturity,

Table 1 Total polyphenol content and antioxidant activity of analyzed potato cultivars

Cultivar	TPC (mg $GAE.kg^{-1}$ FW)	TPC (mg $GAE.kg^{-1}$ DM)	AA (mmol $TE.kg^{-1}$ FW)	AA (mmol $TE.kg^{-1}$ DM)
Annalena	161.7 ±1.96	641.5 ±7.76^{A}	0.27 ±0.005	1.08 ±0.018^{A}
Anuscha	248.0 ±4.87	811.3 ±15.9^{AB}	0.67 ±0.012	2.18 ±0.038^{AB}
Elfe	199.5 ±9.70	1832.6 ±89.1^{ABC}	0.67 ±0.012	6.18 ±0.108^{ABC}
Impala	496.1 ±14.0	2418.6 ±68.4^{ABC}	0.58 ±0.009	2.83 ±0.042^{ABC}
Marena	465.8 ±8.08	1848.3 ±32.1^{ABC}	0.31 ±0.006	1.23 ±0.022^{ABC}
Riviera	312.1 ±8.62	2853.0 ±78.83^{BC}	0.50 ±0.008	4.59 ±0.075^{BC}
Rosara	248.9 ±2.10	814.2 ±6.86^{C}	0.46 ±0.008	1.50 ±0.025^{C}

Note: Different letters indicate significant differences ($p < 0.001$)

Table 2 Cadmium and lead content in analyzed potato cultivars

Cultivar	Cd (mg.kg^{-1} FW)	Cd (mg.kg^{-1} DM)	Pb (mg.kg^{-1} FW)	Pb (mg.kg^{-1} DM)
Annalena	0.030 ±0.004	0.28 ±0.03A	0.143 ±0.016	1.31 ±0.14A
Anuscha	0.024 ±0.003	0.08 ±0.01AB	0.015 ±0.002	0.05 ±0.01AB
Elfe	0.064 ±0.008	0.25 ±0.03AB	0.370 ±0.043	1.47 ±0.17AB
Impala	0.006 ±0.001	0.02 ±0.002AB	0.428 ±0.049	1.40 ±0.16AB
Marena	0.028 ±0.004	0.26 ±0.03B	0.138 ±0.015	1.27 ±0.13AB
Riviera	0.021 ±0.002	0.10 ±0.01B	0.020 ±0.003	0.10 ±0.01B
Rosara	0.055 ±0.006	0.22 ±0.03B	0.325 ±0.042	1.29 ±0.17B

Note: Different letters indicate significant differences ($p < 0.001$)

Table 3 Relationships between monitored parameters

	TPC	AA	Cd	Pb
TPC	–			
AA	0.658***	–		
Cd	-0.426*	-0.391*	–	
Pb	-0.005	0.055	0.353	–

Note: * $p < 0.05$, *** $p < 0.001$

agrotechnical conditions, and genetic factors. The antioxidant activity also increases with the content of pigments, which is why it is higher in purple cultivars. Lee et al. (2016) indicate that the antioxidant activity is higher in purple cultivars than in white or yellow cultivars. According to Hamouz et al. (2011), higher antioxidant activity is associated with a higher content of anthocyanins.

Heavy metal content in potato tubers

Cadmium values in our samples ranged from 0.006 to 0.064 mg.kg^{-1} FW (0.02 to 0.278 mg.kg^{-1} DM) (Table 2).

According to Commission Regulation (EC) no. 1881/2006, the highest permissible amount of cadmium in fresh potatoes is 0.1 mg.kg^{-1}. This limit was not exceeded in monitored cultivars. According to World Health Organization (WHO), the recommended maximal concentration of Cd for potatoes is 0.05 mg.kg^{-1} fresh weight. This concentration was exceeded in cultivars Rosara and Elfe. Significant differences ($p < 0.001$) were between the Cd content of Annalena and Marena, Annalena and Riviera, and Annalena and Rosara. Dunbar et al. (2003) reported that potatoes contribute to 50% of dietary cadmium intake. Potato cultivars vary in their ability to accumulate Cd, as do many other plants. Ashrafzadeh et al. (2017) reported Cd content from 0.05 to 0.21 mg Cd.kg^{-1} DM depending on the cultivar. Jalali and Meyari (2016) reported about wide range of Cd values from 0.01 to 3.6 mg.kg^{-1} DM. Sanderson et al. (2019) reported that this parameter was from 0.01 to 0.22 mg Cd.kg^{-1} FW.

Lead values in our samples ranged from 0.015 to 0.370 mg.kg^{-1} FW (0.05 to 1.47 mg.kg^{-1} DM). According to Commission Regulation (EC) no. 1881/2006, the highest permissible amount of lead in fresh potatoes is 0.1 mg.kg^{-1}. This limit was exceeded in cultivars Annalena, Elfe, Impala, Marena, and Rosara. Significant differences ($p < 0.001$) were between the Pb content of Annalena and Riviera, and Annalena and Rosara. Musilová et al. (2016) determined the lead content in potato samples in the range from 0.020 to 0.630 mg.kg^{-1} FW. Musilová et al. (2017) reported from BDL (below detection limit) to 0.230 mg Pb.kg^{-1} FW. Mansour et al. (2009) reported about wide range of Pb values in potato tubers from 0.08 to 0.62 mg.kg^{-1} FW.

The relationships between the content of heavy metals and the content of polyphenols and antioxidant activity

In the natural environment, plants are exposed to various stress factors that are responsible for the overproduction of reactive oxygen species. One of these factors is the effect of heavy metals on plants (Zeneli et al., 2013). Environment and heavy metals significantly affect total phenolic values in potato tubers (André et al., 2009). The relationships between individual monitored parameters are presented in Table 3.

Positive correlations ($p < 0.001$) were determined between TPC and AA ($r = 0.658$). Negative correlations were determined ($p < 0.05$) between TPC and Cd content, and AA and Cd content. Musilová et al.

(2015) reported that a statistically significant positive correlation was confirmed between Cd content and total antioxidant capacity in potato cultivars. Musilová et al. (2009) reported a positive correlation between TPC and Cd content in potato tubers.

A weak correlation was determined between Cd and Pb content. Despite the fact that potatoes are less sensitive to a higher content of lead in the soil than to the content of cadmium, there is an increase in its content in the tubers, which is probably influenced by the synergistic effect of cadmium (Musilová et al., 2011).

Conclusions

Based on the results, it can be concluded that potato tubers are a source of bioactive compounds. Significant differences were determined in the TPC and AA of Annalena and Rosara, Anuscha and Rosara, Annalena and Riviera, and Anuscha and Riviera. Potatoes accumulate heavy metals, such as Cd and Pb, which are toxic to humans. The limit for Pb, set by Commission Regulation (EC) no. 1881/2006 was exceeded in cultivars Annalena, Elfe, Impala, Marena, and Rosara. Significant differences were determined in the Cd content of Annalena and Marena, Annalena and Riviera, and Annalena and Rosara. Significant differences were determined in the Pb content of Annalena and Riviera, and Annalena and Rosara. Positive correlations ($p < 0.001$) were determined between TPC and AA ($r = 0.658$). Negative correlations were determined ($p < 0.05$) between TPC and Cd content, and AA and Cd content. Results of this study will be useful for cultivar selection, and for future studies.

Conflicts of interest

The authors declare no conflict of interest.

Ethical statement

This article doesn't contain any studies that would require an ethical statement.

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