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TOTAL PHENOLIC, FLAVONOID, AND ANTHOCYANIN CONTENT IN RUSSIAN POTATO

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SUMMARY

Potato (*Solanum tuberosum* L.) is a promising source of antioxidants with health benefits. The presented study evaluated 15 white and colored potato cultivars, comparing each for total antioxidant compounds. In this research, the skin samples showed higher levels of total phenolic, flavonoid, and anthocyanin compounds than tuber flesh samples. However, in tuber flesh samples, the total phenolic content ranged from 23.55 to 48.39, and the total flavonoid content varied from 9.54 to 21.24 mg 100 g^{-1} of fresh weight. The highest total phenolic content occurred in the flesh of the purple potato cultivar Monakh (48.39 mg 100 g^{-1} of fresh weight), and the highest total flavonoid content surfaced from the Udacha cultivar (21.24 mg 100 g^{-1} of fresh weight). According to these results, potato cultivars with yellow and white tubers have demonstrated total phenolic and flavonoid contents comparable with colored tuber cultivars. However, tubers' total phenolic and flavonoid contents showed no correlations with the total anthocyanin content (r = 0.3872 and r = 0.1947, respectively). The established results could be beneficial in developing potato cultivars with high concentrations of substances with high antioxidant activities, such as anthocyanins. Potato cultivars with the highest concentration of phenolics and anthocyanin can be alternative functional foods for human nutrition**.**

Keywords: Potato (*Solanum tuberosum* L.), white and colored potato cultivars, pigmented potato, phenolics, flavonoids, anthocyanin compounds

Key findings: The total phenolic content (TPC) and the total flavonoid content (TFP) showed moderate correlations with the color of potato tubers. Potato cultivars with white and yellow skin had relatively high phenolic and flavonoid content levels in the skin and flesh. Potato genotypes with high levels of phenolic can benefit breeding programs for developing new cultivars. Such varieties represent an important natural source of antioxidants with potentially beneficial effects on human health.

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INTRODUCTION

Potato is one of the most important food crops in the world and Russia. It is a cheap available source of vitamins (C, B1, B6, and riboflavin), minerals (magnesium, potassium, and phosphorus), carbohydrates, and proteins (Ezekiel *et al.,* 2013; Beals, 2019). Non-nutrient bioactive compounds like phenolics are also present in potato tubers. Plant phenolic compounds have the highest antioxidant activity, disease-preventing properties, and ability to protect cell complexes from the destruction associated with oxidative stress.

Some researchers have demonstrated potato's high antioxidant properties, especially in colored potato cultivars. Past studies also proved colored potato phytochemicals have anticancer, anti-inflammatory, anti-obesity, antidiabetic, and antihypertensive activities in human clinical studies, experimental animals, and cell cultures. Moreover, consuming red tuber potato flakes enhanced the expression of superoxide dismutase and reduced serum lipid oxidation (Han et al., 2007). It has appeared that potato tubers with purple flesh have antihypertensive properties and can reduce the risk of cardiovascular disease and stroke developing in patients suffering from hypertension (Vinson et al., 2012).

Studies on rats with diabetes have shown that intake of powder from purple potato tubers reduced blood lipid levels and normalized cholesterol, insulin, and glucose levels (Choi *et al.,* 2013). Some studies have also shown that potato extracts could protect from liver and erythrocytes' oxidative damage and prevent breast cancer development (Singh and Rajini, 2008; Thompson *et al.,* 2009). The anthocyanins found in purple potatoes could be an effective therapeutic agent in alcohol-induced liver injuries by inhibiting CYP2E1 expression and thereby strengthening antioxidant defenses (Jiang *et al.,* 2016). Earlier reports suggested that polyphenols contained in the pigmented potato tubers could reduce oxidative stress and inflammatory processes in humans (Kaspar *et al.,* 2011). Some studies have found antiproliferative, pro-apoptotic, and cytotoxic properties of phenolic compounds and anthocyanins in colored-flesh potatoes against different cancer cell lines (Reddivari *et al.,* 2007b; Madiwale *et al.,* 2011; De-Masi *et al.,* 2020; Rasheed *et al.,* 2022).

Total antioxidant activity correlates with total phenolic content; however, it varies in composition among the potato cultivars (Camire *et al.,* 2009). Phenolic acids and flavonoids are the most abundant phenolic compounds. In potato cultivars, chlorogenic acid is the chief phenolic acid, amounting to more than 90% of total phenolic acids (Furrer *et al.,* 2018). The other phenolic acids in potatoes are caffeic, cinnamic, coumaric, gallic, ferulic, protocatechuic, and salicylic acids (Reddivari *et al.,* 2007a). In micropropagated potatoes, the phenolic compounds showed in a bound form of phenolic acids, including caffeic and vanillic acids (Kim *et al.,* 2019). In potatoes with white skin and flesh, chlorogenic acid and other phenolic acids mainly contributed to the total antioxidant activity. However, reports revealed that the phenolic acid contents were 10 times higher in pigmented cultivars than in non-pigmented potato cultivars (Stushnoff *et al.,* 2008).

Potato cultivars with purple and red flesh usually contain the highest levels of phenolic compounds than cultivars with white and yellow flesh (Visvanathan *et al.,* 2016; Cebulak *et al.,* 2023). The main phenolic compounds in colored potatoes are anthocyanins, belonging to the flavonoids. Anthocyanins are water-soluble pigments found in potatoes in acetylated and glycosylated forms (Camire *et al.,* 2009). In purple and red potato cultivars, cyanidin, delphinidin, malvidin, pelargonidin, peonidin, and petunidin derivatives occur (Oertel *et al.,* 2017). According to Cebulak *et al.* (2023), the predominant pigment in colored potatoes was petunidin-3,5-di-O-glucoside. Although the concentration of anthocyanidins in the peel was higher than in the flesh, they still had the same dominant anthocyanidins (Yin *et al.,* 2016). The prevailing study sought to estimate the total phenolic, flavonoid, and anthocyanin content of some prominent and prospective potato cultivars in the Russian market.

MATERIALS AND METHODS

Genetic material

Mature tubers of 15 potato cultivars (Syurpriz, Fioletovyy, Red Scarlet, Grand, Tayfun, Vympel, Golubizna, Zhukovskiy ranniy, Monakh, Sineglazka, Gala, Udacha, Hybrid 1683, Gulliver, and Mechta) of local selections (Figure 1), commercially available cultivars, and a pigmented potato hybrid were samples for determining total contents of phenolic, flavonoids, and anthocyanin (Table 1).

Growing the tubers of all the potato cultivars commenced in the crop season of 2018 at the experimental field of the Lorch Potato Research Institute, Moscow region, Russia. Plant cultivation used soddy-podzolic sandy loam. The planting pattern was 70 cm × 35 cm. The prime fertilizer before planting was N, P, and K in a ratio of 60:60:90. Fertilizing after germination continued with N, P, and K in a ratio of 30:30:45. Pre-emergent treatment with Metribuzin herbicide also ensued. During the growth period, the treatment of plants against late blight (Metaxil treatment) and against Colorado potato beetle (Bizkaia treatment) occurred two and three times, respectively.

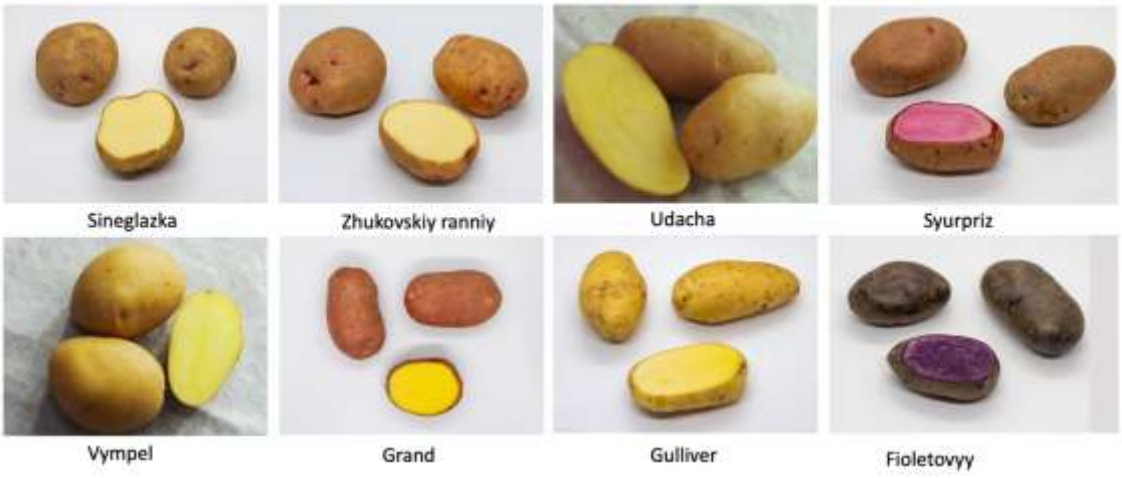

Figure 1. Cultivars of Russian selection presented in the study.

Table 1. Potato cultivars and hybrids studied in the presented research.

No.	Varieties	Skin color	Flesh color	Ripeness	Origin
1	Golubizna	Yellow	White	Mid-ripening	Russia
2	Sineglazka	Partially blue	White	Mid-ripening	Russia
3	Tayfun	Red	White	Mid-ripening	Poland
4	Udacha	Yellow	White	Early-ripening	Russia
5	Zhukovskiy ranniy	Red	White	Early-ripening	Russia
6	Vympel	Yellow	Light yellow	Mid-ripening	Russia
7	Gala	Yellow	Yellow	Mid-ripening	Germany
8	Grand	Red	Yellow	Mid-ripening	Russia
9	Gulliver	Yellow	Yellow	Early-ripening	Russia
10	Mechta	Yellow	Yellow	Mid-ripening	Russia
11	Red Scarlet	Red	Yellow	Early-ripening	Netherlands
12	Syurpriz	Red	Pink	Mid-ripening	Russia
13	Hybrid 1683	Red	Pink	Mid-ripening	Russia
14	Fioletovyy	Violet	Violet	Mid-ripening	Russia
15	Monakh	Violet	Violet	Mid-ripening	Russia

Analyses transpired four months after harvesting. Before analyses, the tubers incurred storage at 4 °C. The tubers' skin and flesh of various cultivars served as study samples. All the performed measurements were in triplicate.

Sample's preparation for total phenolic and flavonoid determination

Three medium-sized tubers of each cultivar incurred peeling, cutting to thin slices, and grinding using a blender. Approximately 50 mg of the grounded flesh and peel (precisely weighed quantity) attained mixture with 2 ml of 96% ethanol for extracting phenolics and flavonoids. Tubes with extract sustained incubation at room temperature for 48 h in a shaking incubator at 500 rpm. After incubation, centrifuging the tubes for 15 min was at 4000 g. Using supernatants, estimated total phenolic and flavonoid contents.

Phenolic determination

The total phenolic content's spectrophotometric measurement used the Folin-Chocalteu reagent (Ainsworth and Gillespie, 2007), using a gallic acid solution as standard. The 400 μL of Folin-Chocalteu reagent and 1600 μL 700 mM Na_2CO_3 solution received an additional 200 μL of ethanol sample extract. After 2 h of incubation, the absorption measuring at 765 nm employed a UV-spectrophotometer (Varian, USA). Expressing the phenolic content was at a mg of gallic acid equivalent (GAE) per 100 g of fresh weight (FW).

Flavonoid determination

The flavonoid content estimation spectrophotometrically followed the method by Garg *et al.* (2012), using quercetin solution as a standard. Mixing 0.5 ml of 1.2% $AlCl_3$ solution and 0.5 ml of 120 mM CH_3COOK to 1.0 ml of ethanol sample extract followed. The reaction mixture underwent incubation for 30 minutes to measure the absorption at 415 nm. The total flavonoid content's expression was a mg of quercetin equivalent (QE) per 100 g of FW.

Anthocyanin determination

In determining the anthocyanin content, the study employed the pH differential method. Three grams of each sample bore grinding in 20 ml of extraction solution containing ethanol (90%) and hydrochloric acid (1 M) at the ratio of 85:15. The homogenized sample extraction took 1.5 h at 4 °C (Jansen and Flamme, 2006). The extracts' centrifugation at 14000·g (Eppendorf, Germany) totaled 15 min using the supernatants for the anthocyanin content determination. A dilution with hydrochloric acid–potassium chloride buffer (0.025M; pH 1.0) and the other with sodium acetate buffer (0.4 M; pH 4.5) proceeded for each sample (Lee e*t al*., 2016). The recorded absorbance of the samples included malvidin at 545 nm, pelargonidin at 515 nm, and cyaniding at 530 nm and 700 nm. The total anthocyanin content calculation used the following formulas:

$$A = (A_{515,530\ or\ 545} - A_{700})_{pH\ 1.0} - (A_{515,530\ or\ 545} - A_{700})_{pH\ 4.5}$$

$$C = A \times MV \times DF \times 1000 \div (\varepsilon \times 1 \times m),$$

Where:
C was anthocyanin content (mg g^{-1}); MW was a molecular weight of anthocyanin (718.5 g M^{-1} for malvidin-3-p-coumarylglycoside, 486.5 g M^{-1} for pelargonidin-3-glucoside, and 449.2 g M^{-1} for cyanidin 3-glucoside); DF was the dilution factor, and ε was the molar absorptivity of malvidin-3-p-coumarylglycoside (27300 M^{-1} cm^{-1}), pelargonidin- 3-glucoside (26900 M^{-1} cm^{-1}), and cyanidin 3-glucoside (30200 M^{-1} cm^{-1}); l was the optical path length, and m was a mass of a sample.

Statistical analysis

The study presented results as a mean standard deviation (±SD) of three replicates. The one-way analysis of variance (ANOVA) with a significance level of $P < 0.05$ by Duncan's multiple range test determined the significance of differences. The correlation analysis continued by utilizing Pearson's method.

RESULTS

Total phenolic and flavonoid

The results on total phenolic and flavonoid contents appear in Table 2. For all studied potato cultivars, the total phenolic and flavonoid contents were higher in the skin samples than in the flesh samples. Potato cultivars with red and violet skin, such as Tayfun, Fioletovyy, Zhukovskiy ranniy, and Monakh, contain the highest values of polyphenols in the potato skin samples (Table 2). However, some potato cultivars with yellow skin, i.e., Vympel, Gulliver, Mechta, and Golubizna, also demonstrated maximum levels of polyphenols and even higher than some red-skinned potato cultivars, i.e., Syurpriz, Red Scarlet, and Grand. In the skin samples, the utmost values of polyphenol were evident in the potato cultivar Tayfun (323.85 ± 143.79 mg 100 g^{-1} GAE), with the lowest for cultivar Syurpriz (35.19 ± 5.72 mg 100 g^{-1} GAE).

On potato flesh, the highest concentration of total phenolic appeared for the cultivar Monakh — a cultivar with violet flesh, which amounted to 48.39 ± 16.88 mg 100 g^{-1} GAE. However, the lowest concentration of phenolics in tuber flesh was prominent for cultivar Mechta (a cultivar with yellow flesh) amounting to 23.55 ± 1.45 mg 100 g^{-1} GAE. Significantly, there was no difference in the total phenolic contents of four potato cultivars with white, yellow, and violet flesh, i.e., Fioletovyy, Grand, Udacha, and Gulliver (Table 2).

In the potato tuber skin, the highest level of total flavonoid content manifested for the cultivar Grand, amounting to 46.42 mg 100 g^{-1} QE of FW (Table 2). The potato cultivars with red skin, Hybrid 1683, Tayfun, Red Scarlet, and with yellow skin, Vympel, and Gala, have comparable high levels of flavonoids, ranging from 29.74 to 26.48 mg 100 g^{-1} QE of FW. For flavonoid content, the considerable difference was not evident

Table 2. Total phenolic and flavonoid content of studied potato varieties (mg 100 g^{-1} GAE of FW and mg 100 g^{-1} quercetin of FW).

No.	Varieties	Total phenolic content (mg 100 g^{-1} GAE, mean±SD)		Total flavonoid content (mg 100 g^{-1} quercetin, mean±SD)	
		Flesh	Skin	Flesh	Skin
1	Golubizna	41.06±6.78bc	92.58±46.61^{abcd}	9.54±1.22^{a}	21.13±10.18^{ab}
2	Sineglazka	29.01±9.31^{abc}	67.19±1.30^{abc}	13.98±0.27^{cd}	21.99±4.01^{abc}
3	Tayfun	26.28±2.56^{b}	323.85±143.79^{e}	11.02±0.41^{abc}	28.44±6.50^{bcd}
4	Udacha	35.76±5.26^{abcd}	55.98±4.71^{abc}	21.24±2.69^{e}	22.19±2.05^{abc}
5	Zhukovskiy ranniy	41.36±5.52^{bcd}	124.03±8.04^{cd}	10.49±1.46^{ab}	25.07±5.77^{abc}
Mean for white flesh cultivars		34.69±6.02		13.25±4.17	
CV		0.20		0.13	
6	Vympel	43.90±3.13^{cd}	129.45±52.70^{cd}	11.60±1.62^{abc}	29.69±3.09^{cd}
7	Gala	29.56±9.05^{abc}	46,15±10,03^{ab}	16.78±0.99^{d}	29.74±6.05^{cd}
8	Grand	33.79±20.81^{abcd}	68.38±46.21^{abc}	13.55±2.58^{bcd}	46.42±12.96^{e}
9	Gulliver	37.21±4.92^{abcd}	104.56±14.73^{abcd}	13.96±3.48^{cd}	19.36±1.88^{a}
10	Mechta	23.55±1.45^{a}	103.43±12.49^{abcd}	16.12±2.45^{d}	24.78±0.81^{abc}
11	Red Scarlet	24.20±16.60^{a}	68.23±17.41^{abc}	10.44±1.00^{ab}	26.48±6.64^{abcd}
Mean for yellow flesh cultivars		32.04±6.30		13.74±1.97	
CV		0.25		0.18	
12	Syurpriz	24.58±5.56^{ab}	35.19±5.72^{a}	9.83±1.86^{a}	22.95±1.26^{abc}
13	Hybrid 1683	43.73±8.60^{cd}	105.77±15.43^{abcd}	15.89±3.28^{d}	28.16±6.64^{bcd}
14	Fioletovyy	38.43±4.43^{abcd}	115.80±5.30^{bcd}	9.78±1.80^{a}	22.21±1.65^{abc}
15	Monakh	48.39±16.88^{d}	153.73±4.22^{d}	15.88±2.55^{d}	34.13±2.73^{d}
Mean for colored flesh cultivars		38.78±10.10		12.85±3.44	
CV		0.27		0.27	

Maximum and minimum values within each group are with orange and blue highlights, respectively.
CV – coefficient of variation

Table 3. Total anthocyanin content of studied potato varieties (mg 100 g^{-1} FW).

No.	Varieties	Malvidin-3-p-coumarylglycoside		Pelargonidin- 3-glucoside		Cyanidin 3-glucoside	
		Flesh	Skin	Flesh	Skin	Flesh	Skin
1	Golubizna	0^{a}	0.59 ± 0.44^{ab}	0^{a}	0.50 ± 0.12^{a}	0.14 ± 0.03^{ab}	0.77 ± 0.34^{a}
2	Sineglazka	2.15 ± 0.59^{bc}	1.54 ± 0.72^{ab}	2.16 ± 0.65^{b}	1.51 ± 0.46^{ab}	2.12 ± 0.74^{ab}	1.06 ± 0.35^{ab}
3	Tayfun	0.68 ± 0.33^{a}	3.91 ± 1.2^{9c}	0.71 ± 0.40^{a}	7.80 ± 0.95^{cde}	0.64 ± 0.18^{ab}	7.01 ± 1.00^{ab}
4	Udacha	0.87 ± 0.02^{ab}	0.91 ± 0.74^{ab}	0.76 ± 0.07^{a}	0.85 ± 0.36^{a}	0.73 ± 0.13^{ab}	1.33 ± 0.47^{ab}
5	Zhukovskiy ranniy	0^{a}	1.33 ± 0.59^{ab}	0.37 ± 0.08^{a}	1.05 ± 0.3^{3a}	0.74 ± 0.17^{ab}	0.8 ± 0.19^{a}
Mean for white flesh cultivars		0.74±0.70		0.80±0.71		0.87±0.65	
CV		1.00		1.00		0.85	
6	Vympel	0^{a}	0.58 ± 0.29^{ab}	0.41 ± 0.38^{a}	0.66 ± 0.21^{a}	0.28 ± 0.06^{ab}	0.53 ± 0.36^{a}
7	Gala	0^{a}	0^{a}	0^{a}	0.48 ± 0.41^{a}	1.31 ± 0.52^{ab}	0.66 ± 0.47^{a}
8	Grand	0.48 ± 0.10^{a}	2.09 ± 0.43^{b}	0.42 ± 0.40^{a}	2.01 ± 0.71^{ab}	0^{a}	2.32 ± 0.39^{ab}
9	Gulliver	0^{a}	1.18 ± 0.50^{ab}	0^{a}	0.50 ± 1.18^{a}	0^{a}	1.40 ± 0.33^{ab}
10	Mechta	0.63 ± 0.59^{a}	0.87 ± 0.58^{ab}	0.87 ± 0.57^{a}	0^{a}	0.47 ± 0.32^{ab}	0.56 ± 0.03^{a}
11	Red Scarlet	0^{a}	4.22 ± 2.02^{c}	0^{a}	3.85 ± 1.10^{abc}	0^{a}	4.90 ± 2.72^{ab}
Mean for white flesh cultivars		0…0.23		0.28±0.28		0…0.41	
CV		1.57		1.24		1.50	
12	Syurpriz	0.89 ± 0.06^{ab}	5.90 ± 1.20^{d}	2.17 ± 0.25^{b}	10.84 ± 1.49^{e}	1.78 ± 0.40^{ab}	9.60 ± 1.46^{b}
13	Hybrid 1683	3.37 ± 1.08^{cd}	6.28 ± 0.22^{d}	7.72 ± 3.06^{d}	$9.54\pm0.93d^{e}$	5.37 ± 4.44^{c}	8.61 ± 0.98^{ab}
14	Fioletovyy	3.78 ± 2.88^{d}	8.83 ± 4.03^{e}	3.48 ± 0.84^{b}	6.01 ± 2.76^{bcd}	2.20 ± 0.81^{b}	4.74 ± 2.42^{ab}
15	Monakh	6.99 ± 1.30^{e}	25.40 ± 1.15^{e}	5.32 ± 1.53^{d}	30.41 ± 10.95^{f}	4.82 ± 1.56^{c}	41.72 ± 12.32^{c}
Mean for white flesh cultivars		2.68±2.45		4.46±2.36		3.12±1.88	
CV		0.93		0.54		0.58	

Maximum values are highlighted with orange.
CV – coefficient of variation

evident among the potato cultivars with yellow skin (Mechta, Udacha, and Golubizna), red (Syrpriz), violet (Fioletovyy), and partially blue skin (Sineglazka). In these potato cultivars, the flavonoid contents varied from 21.13 to 25.07 mg 100 g^{-1} QE of FW. However, the lowest flavonoid content level was notable for the potato cultivar Gulliver (19.36 ± 1.88 mg 100 g^{-1} QE of FW).

In the flesh samples, the maximum level of flavonoid content emerged for potato cultivars with white and yellow flesh, i.e., Udacha (21.24 ± 2.69 mg 100 g^{-1} QE of FW), Gala (16.78 ± 0.99 mg 100 g^{-1} QE of FW), and Mechta (16.12 ± 2.45 mg 100 g^{-1} QE of FW). However, their genotypes were comparable or even higher for flavonoid content than the cultivars with colored flesh samples.

Anthocyanins

The results of determining the total anthocyanin content are available in Table 3. Potato cultivars with purple flesh and skin, i.e., Monakh and Fioletovyy, contained the highest anthocyanins. In potato cultivars with red-skinned tubers, the anthocyanin content varied from 1.33 to 6.28 mg 100 g^{-1} of FW in terms of malvidin equivalent. However, similar results also occurred through the pelargonidin and cyaniding equivalents (Table 3). The pertinent results have not shown a strong correlation between the total phenolics, flavonoids, and anthocyanin contents. The determination coefficient R^2 regarding the phenolic and anthocyanin contents was 0.1499 (r = 0.3872, P < 0.01). The determination coefficient for the total flavonoids and anthocyanin contents amounted to 0.0379 (r = 0.1947, P < 0.01).

DISCUSSION

Given their high consumption level, potatoes are generally one of the most important sources of antioxidants in human nutrition. The total phenolic and anthocyanin contents of potato tubers in the context of antioxidant

activity have many reports to emphasize the benefits of colored potatoes. Hamouz *et al.* (2011) revealed that red and purple potato cultivars had approximately 10 times more antioxidant activity than yellow and white genotypes. Lachman *et al.* (2008) authenticated the highest antioxidant activity values in potato genotypes with purple flesh compared to yellow flesh. Stushnoff *et al*. (2008) showed that among 90 potato cultivars obtained from the Colorado Potato Breeding Program, the red and purple-colored genotypes had the highest total phenolic and chlorogenic acid levels. Among 60 cultivars of potato grown in Ireland, the tubers with blue skin had the maximum total phenolic content (Valcarcel *et al.,* 2015). As a result, potato germplasm showed marked cultivars based on total phenolic content and antioxidant profile (Stushnoff *et al.,* 2008).

Various groups of substances, such as vitamins E and C, carotenoids, and phenolic compounds, determine the antioxidant activity of potatoes. However, phenolic compounds, including phenolic acids, flavonoids, and anthocyanin contents, significantly contributed to the formation of antioxidant profiles of potato cultivars. The total phenolic content of potatoes was comparable to and even higher than other vegetables and fruits like carrots, onions, and tomatoes (Akyol *et al.,* 2016). Phenolic compounds are mainly in the whole tuber but have an uneven distribution. The prevailing results of the total phenolic and flavonoid contents were consistent with previous findings, confirming that potato peels contain higher amounts of phenolic than flesh (Yin *et al.,* 2016; Singh *et al.,* 2020). About 50% of phenolic compound concentration occurs in the peel and neighboring tissues and gradually decreases toward the tuber center (Visvanathan *et al.,* 2016; Haq *et al*., 2021; Gins *et al*., 2022). This fact makes the potato peels an attractive source of antioxidants for nutrition and industrial applications. Also, potato peels, as a food processing waste, are a low-cost raw material for obtaining extracts with antioxidant activity. Past findings suggested that potato peel extracts can become a natural additive to prevent lipid and protein oxidation (Amado *et al.,* 2014; Akyol *et al.,* 2016).

Potato genotypes with purple and red flesh and skin contained significantly higher levels of phenolic antioxidants than cultivars with white and yellow flesh (Stushnoff *et al.,* 2008). However, according to this research, the potato cultivars with yellow skin, such as Vympel, Gulliver, Mechta, and Golubizna, have demonstrated high levels of total phenolics. These results may be due to the high concentration of phenolic acids in yellow-skinned cultivars. Phenolic acids are the most common phenolic compounds in potato peel, and their values were even higher than anthocyanins, a subclass of flavonoids responsible for the color of purple and red potatoes (Furrer *et al.,* 2018). Similar results also emerged in the assessed potato cultivars for the total flavonoid content. The studied cultivars with yellow flesh, such as Udacha, Gala, and Mechta, have classified a maximum level of flavonoids. According to previous data, the total flavonoid contents nearly doubled because of anthocyanins in purple and red-fleshed potatoes. However, the most abundant flavonoids in potatoes are catechin, quercetin, and kaempferol, which exhibited high concentrations in white and yellow-fleshed genotypes (Akyol *et al.,* 2016).

Valcarcel *et al.* (2015) have reported about the Lady Claire, a potato cultivar with yellow skin, which had comparable levels of the total phenolic and flavonoid contents to colored cultivars. Tornado, a potato cultivar with white flesh, had the maximum total phenolic contents, phenolic acids, chlorogenic acid, and p-coumaric acid (Vaitkevičienė *et al.,* 2020). Thus, it is assumable that the anthocyanins were insignificant to the flavonoid contents compared with other flavonoids.

Potato cultivars with purple and red flesh differed in anthocyanin content. Earlier studies reported differences in the total anthocyanin content in the potato cultivars with colored tubers (Jansen and Flamme, 2006; Valcarcel *et al.,* 2015). However, the differences in the anthocyanin and other phenolic concentrations may relate to potato genotypes and abiotic and biotic factors, such

as environmental and climate conditions, agrotechnical processes, ripeness, pathogen infection, thermal stress, and injuries. Warm locations and organic farming contribute to increasing the phenolic acid contents in potato tubers (Lombardo *et al.,* 2013). But, according to Hamouz *et al.* (1999), colder and more humid growing regions relate to a higher accumulation of the total phenolic content in potato tubers. Polyphenols relate to plant reactions from stress. Pathogen infection also enhances the concentration of phenolic phytochemicals (Akyol *et al.,* 2016).

Researchers from different countries determined the total content of phytochemicals, such as phenolic acids, flavonoids, anthocyanins, and carotenoids in potato tubers of local and widespread varieties. Unfortunately, these data are difficult to compare due to differences in the methods of determining, sample preparation, and presentation of the data obtained. Hence, only a relative assessment is possible. However, it is probable to identify general trends associated with accumulating phenols and flavonoids in different potato varieties.

Storage conditions and processing also play an essential role in phenolic contents in potatoes. The temperature and storage time are the chief factors influencing the total phenolic content, which tends to increase during long storage (Madiwale *et al.,* 2011). The maximum losses of these compounds were notable after the final production processes, i.e., pre-frying, frying, and drying. Chip production led to the lowest losses of anthocyanins (Rytel *et al.,* 2021). Observations also revealed that microwave and fried potatoes presented different phenolic profiles versus raw potatoes (Silveira *et al.,* 2017). The maturity level also significantly affected the potato's total anthocyanins and polyphenols content. Early and medium-early potato cultivars showed a chlorogenic acid content increase during maturation, while in other cultivars, chlorogenic acid decreased due to higher maturity (Franková *et al.,* 2022).

Even though levels of phenolic compounds in potatoes have many factors influencing these, some past studies have demonstrated that the potato genotype has more effect on the total phenolic content than the environmental factors (Lombardo *et al.,* 2013). However, some results indicated that potato tubers grown under different production systems, like organic farming and integrated production, irrespective of locations and cultivars, showed significant differences in the antioxidant compounds' concentration, such as ascorbic acid, citric acid, total phenolics, and total flavonoids. Growing potatoes under organic farming showed a linkage with moderate stress conditions. Production of phenolic compounds under organic farming was 15%, of flavonoids 45%, and of ascorbic acid 8.5% higher than under integrated production. Potato tubers from the organic system were also better by 13.9% antioxidant capacity measured by the FRAP method (Keutgen *et al.,* 2019).

According to past studies, organically and biodynamically produced potatoes were significantly richer in phenolic acids, flavonoids, and anthocyanins than the traditional production system (Kazimierczak *et al.,* 2019; Vaitkevičienė *et al.,* 2020). Therefore, further research is necessary for the confirmation of these results. Growing conditions and treatment significantly influenced phytonutrient content in potatoes and other Solanaceae species, such as growing tomatoes in fly ash blended soils, which affected phenolic profile and antioxidant and antibacterial activities (Dominic et al., 2022).

CONCLUSIONS

In this study, selecting 15 potato genotypes depended on economic traits, i.e., color, shape, and tuber yield. Consequently, the total phenolic and flavonoid contents had weak correlations with the color of potato tubers. Potato cultivars with white and yellow skin had relatively high levels of total phenolic and flavonoid contents in the skin and flesh. Potato cultivars with high antioxidant compounds may serve as functional food agents. These promising potato genotypes (Vympel, Monakh, Udacha, and Golubizna) can also benefit the breeding program for developing new cultivars with high antioxidant properties. The content

of phytonutrients in potatoes, just like other crops, can incur influences from many factors, such as cultivation conditions, weather, fertilizers, and chemicals. Therefore, the levels of these substances significantly vary.

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REFERENCES

Ainsworth EA, Gillespie KM (2007). Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin-Ciocalteu reagent. *Nat. Protoc* 2(4): 875–877.

Akyol H, Riciputi Y, Capanoglu E, Fiorenza Caboni M, Verardo V (2016). Phenolic compounds in the potato and its byproducts: An overview. *Int. J. Mol. Sci*. 17(6): 835.

Amado I, Franco D, Sánchez M, Zapata C, Vázquez J (2014). Optimisation of antioxidant extraction from *Solanum tuberosum* potato peel waste by surface response methodology. *Food Chem*. 165: 290–299.

Beals KA (2019). Potatoes, nutrition and health. *Am. J. Potato Res.* 96: 102–110.

Camire ME, Kubow S, Donnelly DJ (2009). Potatoes and human health. *Crit. Rev. Food Sci. Nutr*. 49: 823–840.

Cebulak T, Krochmal-Marczak B, Stryjecka M, Krzysztofik B, Sawicka B, Danilčenko H, Jarienè E (2023). Phenolic acid content and antioxidant properties of edible potato (*Solanum tuberosum* L.) with various tuber flesh colours. *Foods* 12: 100.

Choi MK, Park SJ, Eom SH, Kang MH (2013). Anti-diabetic and hypolipidemic effects of purple-fleshed potato in streptozotocin-induced diabetic rats. *Food Sci. Biotechnol*. 22: 1–6.

De-Masi L, Bontempo P, Rigano D, Stiuso P, Carafa V, Nebbioso A, Piacente S, Montoro P, Aversano R, D'Amelia V (2020). Comparative phytochemical characterization, genetic profile, and antiproliferative activity of polyphenol-rich extracts from pigmented tubers of different *Solanum tuberosum* varieties. *Molecules* 25: 233.

Dominic S, Hussain AI, Saleem MH, Alshaya H, Jan BL, Ali S, Wang X (2022). Variation in the primary and secondary metabolites, antioxidant and antibacterial potentials of tomatoes, grown in soil blended with different concentration of fly ash. *Plants* 11: 551.

Ezekiel R, Singh N, Sharma S, Kaur A (2013). Beneficial phytochemicals in potato - A review. *Food Res. Int*. 50: 487–496.

Franková H, Musilová J, Árvay J, Harangozo Ľ, Šnirc M, Vollmannová A, Lidiková J, Hegedűsová A, Jaško E (2022). Variability of bioactive substances in potatoes (*Solanum tuberosum* L.) depending on variety and maturity. *Agronomy* 12: 1454.

Furrer AN, Chegeni M, Ferruzzi MG (2018). Impact of potato processing on nutrients, phytochemicals, and human health. *Crit. Rev. Food Sci. Nutr*. 58: 146–168.

Garg D, Shaikh A, Marar T (2012). In-vitro antioxidant activity and phytochemical analysis in extracts of *Hibiscus rosa-sinensis* stem and leaves. *Free Radic. Antioxid*. 2(3): 41–46.

Gins EM, Egorova AS, Sivolapova AB, Semenov AZH Apshev KhKh, Meleshin AA, Moskalev EA, Polivanova OB, Belov GL, Goryunova SV (2022). Pollen fertility assessment through acetocarmine staining and *in vitro* germination in *Solanum tuberosum* L. *SABRAO J. Breed. Genet.* 54(5): 1037-1048. http://doi.org/10.54910/sabrao2022.54.5.7.

Hamouz K, Lachman J, Pazderů K, Tomášek J, Hejtmánková K, Pivec V (2011). Differences in anthocyanin content and antioxidant activity of potato tubers with different flesh colour. *Plant Soil Environ*. 57(10): 478–485.

Hamouz K, Lachman J, Voka´l B, Pivec V (1999). Influence of environmental conditions and type of cultivation on the polyphenolic and ascorbic acid content in potato tubers. *Rostl. Vyroba*. 45: 293–298.

Han KH, Shimada KI, Sekikawa M, Fukushima M (2007). Anthocyanin-rich red potato flakes affect serum lipid peroxidation and hepatic SOD mRNA level in rats. *Biosci. Biotechnol. Biochem*. 71: 1356–1359.

Haq IU, Razzaq H, Haq MA, Saeed A, Hameed M, Asif M (2021). Morphophysiological characterization of potato (*Solanum tuberosum* L.) genotypes prevailing in the core area of Punjab, Pakistan. *SABRAO J. Breed. Genet.* 53(4): 561-574. https://doi.org/10.54910/sabrao2021.53.4.2

Jansen G, Flamme W (2006). Coloured potatoes (*Solanum tuberosum* L.) – anthocyanin

content and tuber quality. *Genet. Resour. Crop Evol*. 53: 1321–1331.

Jiang Z, Chen C, Wang J, Xie W, Wang M, Li X, Zhang X (2016). Purple potato (*Solanum tuberosum* L.) anthocyanins attenuate alcohol-induced hepatic injury by enhancing antioxidant defense. *J. Nat. Med.* 70: 45–53.

Kaspar KL, Park JS, Brown CR, Mathison BD, Navarre DA, Chew BP (2011). Pigmented potato consumption alters oxidative stress and inflammatory damage in men. *J. Nutr*. 141: 108–111.

Kazimierczak R, Średnicka-Tober D, Hallmann E, Kopczyńska K, Zarzyńska K (2019). The impact of organic vs. conventional agricultural practices on selected quality features of eight potato cultivars. *Agronomy* 9: 799.

Keutgen AJ, Wszelaczyńska E, Pobereżny J, Przewodowska A, Przewodowski W, Milczarek D, Tatarowska B, Flis B, Keutgen N (2019). Antioxidant properties of potato tubers (*Solanum tuberosum* L.) as a consequence of genetic potential and growing conditions. *PLoS One* 14(9): e0222976.

Kim J, Soh SY, Bae H, Nam SY (2019). Antioxidant and phenolic contents in potatoes (*Solanum tuberosum* L.) and micropropagated potatoes. *Appl. Biol. Chem.* 62: 17.

Lachman J, Hamouz K, Orsa´k M, Pivec V, Dvor˘a´k P (2008). The influence of flesh colour and growing locality on polyphenolic content and antioxidant activity in potatoes. *Sci. Hortic*. 117: 109–114.

Lee SH, Oh SH, Hwang IG, Kim HY, Woo KS, Woo SH, Kim HS, Lee J, Jeong HS (2016). Antioxidant contents and antioxidant activities of white and colored potatoes (*Solanum tuberosum* L.). *Prev. Nutr. Food Sci*. 21(2): 110–116.

Lombardo S, Pandino G, Mauromicale G (2013). The influence of growing environment on the antioxidant and mineral content of "early" crop potato. *J. Food Compos. Anal*. 32: 28–35.

Madiwale GP, Reddivari L, Holm DG, Vanamala J (2011). Storage elevates phenolic content and antioxidant activity but suppresses antiproliferative and pro-apoptotic properties of colored-flesh potatoes against human colon cancer cell lines. *J. Agric. Food Chem*. 59(15): 8155–8166.

Oertel A, Matros A, Hartmann A, Arapitsas P, Dehmer KJ, Martens S, Mock HP (2017). Metabolite profiling of red and blue potatoes revealed cultivar and tissue specific patterns for anthocyanins and other polyphenols. *Planta* 246(2): 281–297.

Rasheed H, Ahmad D, Bao J (2022). Genetic diversity and health properties of polyphenols in potato*. Antioxidants (Basel)*. 11(4): 603.

Reddivari L, Hale A, Miller J (2007a). Determination of phenolic content, composition and their contribution to antioxidant activity in specialty potato selections. *Am. J. Potato Res*. 84(4): 275–282.

Reddivari L, Vanamala J, Chintharlapalli S, Safe SH, Miller JC (2007b). Anthocyanin fraction from potato extracts is cytotoxic to prostate cancer cells through activation of caspase dependent and caspase-independent pathways. *Carcinogenesis* 28(10): 2227–2235.

Rytel E, Tajner-Czopek A, Kita A, Tkaczyńska A, Kucharska AZ, Sokół-Łętowska A (2021). The influence of the production process on the anthocyanin content and composition in dried potato cubes, chips, and French fries made from red-fleshed potatoes. *Appl. Sci.* 11: 1104.

Silveira AC, Falagán N, Aguayo E, Vilaró F, Escalona WH (2017). Compositional changes on colored and light-yellow-fleshed potatoes subjected to two cooking processes. *CyTA-J. Food*. 15:241–248.

Singh B, Singh J, Singh JP, Kaur A, Singh N (2020). Phenolic compounds in potato (*Solanum tuberosum* L.) peel and their health promoting activities*. Int. J. Food Sci. Technol*. 55(6): 2273–2281.

Singh N, Rajini PS (2008). Antioxidant-mediated protective effect of potato peels extract in erythrocytes against oxidative damage. *Chem.-Biol. Interact*. 173: 97–104.

Stushnoff C, Holm D, Thompson MD, Jiang W, Thompson HJ, Joyce NI, Wilson P (2008). Antioxidant properties of cultivars and selections from the Colorado potato breeding program. *Am. J. Potato Res*. 85(4): 267–276.

Thompson MD, Thompson HJ, McGinley JN, Neil ES, Rush DK, Holm DG, Stushnoff C (2009). Functional food characteristics of potato cultivars (*Solanum tuberosum* L.): Photochemical composition and inhibition of 1-methyl-1- nitrosourea induced breast cancer in rats. *J. Food Compos. Anal*. 22: 571–576.

Vaitkevičienė N, Kulaitienė J, Jarienė E, Levickienė D, Danillčenko H, Średnicka-Tober D, Rembiałkowska E, Hallmann E (2020). Characterization of bioactive compounds in colored potato (*Solanum Tuberosum* L.)

cultivars grown with conventional, organic, and biodynamic methods. *Sustainability* 12: 2701.

Valcarcel J, Reilly K, Gaffney M, O'Brien NM (2015). Antioxidant activity, total phenolic and total flavonoid content in sixty varieties of potato (*Solanum tuberosum* L.) grown in Ireland. *Potato Res*. 58: 221–244.

Vinson JA, Demkosky CA, Navarre DA, Smyda MA (2012). High-antioxidant potatoes: Acute in vivo antioxidant source and hypotensive agent in humans after supplementation to hypertensive subjects. *J. Agric. Food Chem*. 60(27): 6749–6754.

Visvanathan R, Jayathilake C, Chaminda Jayawardana B, Liyanage R (2016). Health-beneficial properties of potato and compounds of interest. *J. Sci. Food Agric*. 96(15): 4850–4860.

Yin L, Chen T, Li Y, Fu S, Li L, Xu M, Niu Y (2016). A comparative study on total anthocyanin content, composition of anthocyanidin, total phenolic content and antioxidant activity of pigmented potato peel and flesh. *Food Sci. Technol. Res.* 22: 219–226.