

Yield parameters, antioxidant activity, polyphenol and total soluble solids content of beetroot cultivars with different flesh colours

Miroslav Šlosár^{1,*}, Tomáš Kopta², Ondrej Hegedűs³, Alžbeta Hegedűsová¹, Ivana Mezeyová¹, Mária Timoracká⁴, Ján Mezey⁵

¹ Department of Vegetable Production, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

² Department of Vegetable Growing and Floriculture, Faculty of Horticulture, Mendel University in Brno, Lednice, Czech Republic

³ Department of Chemistry, Faculty of Education, Janos Selye University in Komárno, Komárno, Slovak Republic

⁴ Department of Chemistry, Faculty of Biotechnology and Food Sciences, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

⁵ Department of Fruit Growing, Viticulture and Enology, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

ABSTRACT

This study aimed to evaluate yield parameters, antioxidant activity (AOA), total polyphenol content (TPC) and total soluble solids (TSS) in beetroot cultivars with different flesh colours. Field experiments were established at the Slovak University of Agriculture in Nitra in 2016 and 2017. Within the study, 16 beetroot cultivars were tested, including 11 red-fleshed ('Boltardy', 'Boro' F₁, 'Crosby Egyptian', 'Cylindra', 'Detroit Globe', 'Detroit 2', 'Egyptian Turnip Rooted', 'Opolski', 'Pablo' F₁, 'Renova' and 'Taunus' F₁), 2 yellow-fleshed ('Boldor' F₁ and 'Golden'), 2 white-flesh cultivars ('Albino' and 'White Detroit') and 1 red-white fleshed cultivar ('Chioggia'). All beetroot cultivars with red flesh colour showed higher AOA and TPC than different-coloured beetroot cultivars. The highest root yield was found in the white-fleshed beetroot cultivar 'Albino' (37.80–41.91 t · ha⁻¹). The highest root weight was found in the white-fleshed beetroot cultivar 'White Detroit' (362.4–412.1 g). The highest AOA (819.19–972.50 mg TEAC · kg⁻¹ d.w.) and TPC (2,387.70–2,731.00 mg · kg⁻¹ d.w.) were found in the red-fleshed beetroot cultivar 'Pablo' F₁. Different-coloured cultivars of beetroot were characterised by a lower content of TSS (6.4–8.8 °BRIX) than cultivars with typical, red flesh colour (7.8–10.8 °BRIX). Results clearly indicate that cultivar, or flesh colour, is showed as a significant factor influencing the quality of beetroot. Knowing of yield potential and quality of beetroot cultivars is important for growers as well as consumers. Results of this study indicate that white-fleshed cultivars of beetroot are characterised by high yield potential but lower quality, including lower AOA, TPC and TSS.

Keywords: antioxidant activity, beetroot, cultivar, polyphenols, total soluble solids, yield

Abbreviations:

AOA, antioxidant activity; DPPH, 2,2-diphenyl-1-picrylhydrazyl; d.w., dry weight; TPC, total polyphenol content; TSS, total soluble solids.

*Corresponding author.
e-mail: miroslav.slosar@uniag.sk (Miroslav Šlosár).

INTRODUCTION

The beetroot (*Beta vulgaris* L. var. *vulgaris*) is a biennial vegetable species from the Amaranthaceae family (Székely et al., 2014). The beetroot (or red beet) is native to the Mediterranean area, and it is originated from the wild ancestor of *Beta vulgaris* L. var. *maritima*. It was already cultivated and consumed by the Greeks and Romans in the 2nd–3rd century (Jasmitha et al., 2018). According to the statistical report of Meravá (2019), the growing area and production of beetroot in the Slovak Republic showed a variable trend in the period 2012–2018. Within the mentioned period, the growing area of beetroot was ranged from 22 (2013) to 87 ha (2017); the total beetroot production was varied from 421 (2013) to 1,242 tonnes (2015). The beetroot can be eaten raw, baked, boiled, used for juice extraction, or pickled (Babarykin et al., 2019). Data in the statistical report of Meravá (2019) show increased interest about processed beetroot in the Slovak Republic. The consumption of processed beetroot significantly increased from 410 (2012) to 1,137 tones (2018).

Jasmitha et al. (2018) ranked beetroot among 10 vegetable species with respect to the highest antioxidant activity (AOA). Several phytonutrients, abundant in beetroot are characterised by antioxidant, antitumour and anti-inflammatory action (Clifford et al., 2015; Nguyen et al., 2018). They can act as an antidepressant (Invally et al., 2017), antimicrobial, antifungal (Kumar and Brooks, 2018), diuretic (Coles and Clifton, 2012), expectorant (Chawla et al., 2016) or carminative (Lim, 2016). Babagil et al. (2018) reported that beetroot consumption may be useful for the reduction of blood glucose level and hypertension. In addition, bioactive substances abundant in beetroot have great importance for cardiovascular diseases by lowering the level of homocysteine (Mirmiran et al., 2020). The most important bioactive substances in beetroot are mainly polyphenols and water-soluble betalains (Chhikara et al., 2019), which are responsible for the high antioxidant effect and radical scavenging capacity of beetroot (Guiné et al., 2018).

Polyphenols have a wide range of complex structures. Depending upon the strength of the phenolic ring, polyphenols can be classified into many classes; however, phenolic acids, flavonoids, phenolic alcohols and lignans can be identified as the main polyphenol classes (Abbas et al., 2017). Polyphenols belong to important health-promoting micronutrients in the human diet. The health effects of polyphenols are depending on their consumed amount and bioavailability (Manach et al., 2004). It was shown that the increased consumption of polyphenol-rich food sources helps to decrease the incidence of many dangerous diseases, for example, colorectal (Alam et al., 2018), colon cancer (Mattioli et al., 2019), diabetes (Wang et al., 2015), liver (Abenavoli et al., 2017), or cardiovascular diseases (McSweeney and Seetharaman, 2015). According to Wiczkovski et al. (2016), the main group of polyphenols

abundant in beetroot are phenolic acids (chlorogenic, *trans*-cinnamic, ferulic, isoferulic, caffeic, paracoumaric, protocatechuic, sinapic, syringic, etc.) and flavonoids (apigenin, epicatechin, kaempferol, quercetin, luteolin, orientin and vitexin). The authors found that the predominant phenolic acid was isoferulic acid, while in the group of flavonoids, epicatechin was identified as the main compound.

It is possible to find many cultivars of beetroot on the seed market, including cultivars with nontypical flesh colour for beetroot (white, yellow, etc.). According to the EU database of registered plant varieties, there are 142 different cultivars of beetroot (European Commission, 2020). In this study, yield potential and qualitative composition of different-coloured cultivars of beetroot were tested, focusing on its AOA, phenolic and total soluble solids (TSS) content. It was hypothesised that a difference in yield and analytical parameters will be found between beetroot cultivars. It is a very important factor for growers and consumers to know the yield potential and qualitative composition of beetroot cultivars, including those with typical and unique flesh colour.

MATERIALS AND METHODS

Plant material and experiment realisation

The two-year vegetation field experiment was established in the Botanical Garden of the Slovak University of Agriculture in Nitra in 2016 and 2017 (Nitra, Slovak Republic, 48°18' N, 18°05' E, 144 m a. s. l.). The climate in the experimental area is characterised by warm and dry summer and slightly warm, dry or very dry winter. The basic climatic characteristics of the experimental area in individual experimental years are mentioned in Table 1. The long-term average (1961–2010) was used for the evaluation of air temperature and precipitation within the experimental period (May–August) in 2016 and 2017. Significant differences in precipitation sums in the vegetation period were found between experimental years. The year 2017 can be marked as hotter and drier compared to the year 2016.

Table 1. Characteristics of the experiment area in 2016 and 2017 (Nitra, Slovak Republic).

Month	2016		2017	
	P (mm)	T (°C)	P (mm)	T (°C)
May	91 VW	15.0 N	14 ED	16.6 H
June	14 ED	20.3 VH	26 VD	21.2 EH
July	135 EW	21.4 H	60 N	21.7 H
August	35 D	19.5 N	23 VD	22.4 EH
Total	265	-	123	-
Mean	-	19.1	-	20.5

Explanatory notes: T – temperature: N – normal; H – hot; VH – very hot; EH – extremely hot; P – precipitation: N – normal; VW – very wet; EW – extremely wet; D – dry; VD – very dry; ED – extremely dry.

Table 2. Agrochemical characteristics of the soil before the experiment establishment.

Year	pH	Nutrients (mg · kg ⁻¹ of soil)						% of humus
		Nmin	P	K	S	Ca	Mg	
2016	7.05 N	13.0 M	198.8 VH	487.5 VH	26.3 M	6,100 H	816 VH	4.17 H
2017	7.16 N	10.1 M	147.5 H	477.5 VH	91.3 H	5,850 H	762.6 VH	3.75 G

Explanatory notes: Nmin – mineral (inorganic) nitrogen; N – neutral soil pH; G – good content; M – medium content; H – high content; VH – very high content.

Table 3. Characteristics of tested beetroot cultivars.

Cultivar	Root shape	Flesh colour	Ring prominence
Boltardy	Circular	Red	Weak
Boro F ₁	Circular	Red	Very weak
Crosby Egyptian	Transverse narrow elliptic	Red	Weak
Cylindra	Narrow oblong	Red	Very weak
Detroit 2	Transverse medium elliptic	Red	Weak
Detroit Globe	Transverse medium elliptic	Red	Medium
Egyptian Turnip Rooted	Transverse narrow elliptic	Red	Weak
Opolski	Narrow oblong	Red	Weak
Pablo F ₁	Transverse medium elliptic	Red	Very weak
Renova	Very narrow obovate	Red	Very weak
Taunus F ₁	Obovate	Red	Weak
Boldor F ₁	Circular	Yellow	Weak
Golden	Transverse medium elliptic	Yellow	Weak
Chioggia	Transverse medium elliptic	Red-white	Very strong
Albino	Circular	White	Very weak
White Detroit	Circular	White	Weak

According to Petříková and Hlušek (2010), an irrigation amount of 550 mm is required during the vegetation period of beetroot. The water filling to the recommended level was done by sprinkler irrigation.

Field experiments were established on the medium-heavy soil, classified as Fluvisol, with pH 7.14–7.18. The basic agrochemical characteristics of soil in the experimental area are described in Table 2. Based on soil analyses, any fertilisers were applied.

Within this study, 16 beetroot cultivars were tested, including 11 cultivars with typical red colour ('Boltardy', 'Boro' F₁, 'Crosby Egyptian', 'Cylindra', 'Detroit Globe', 'Detroit 2', 'Egyptian Turnip Rooted', 'Opolski', 'Pablo' F₁, 'Renova' and 'Taunus' F₁), 2 yellow-fleshed ('Boldor' F₁, 'Golden'), 2 white-fleshed ('Albino', 'White Detroit') cultivars and 1 cultivar with combined white-purple colour ('Chioggia'). Seeds of individual beetroot cultivars were selected and bought according to their availability on the seed market. The basic characteristics of all beetroot cultivars, evaluated according to the descriptor UPOV (2008), are described in Table 3.

The sowing of beetroot seeds was realised on 19 May 2016 and 25 May 2017. Each beetroot cultivar was sowed into three rows (repetition) with a length of 3 m. The used spacing was 0.30 × 0.10 m. The harvest of beetroot was realised on 9 August 2016 and 15 August 2017. The average sample of beetroot, used for analyses, was prepared from 10 roots. Within sample preparation,

roots were quartered and opposite parts were used for qualitative analyses.

Reagents and chemicals

The following reagents and chemicals were used for qualitative analyses of beetroot: (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox; 97%; Acros Organics™, Denmark), 2,2-diphenyl-1-picrylhydrazyl (DPPH; ≤100%; Sigma Aldrich, USA), Folin–Ciocalteu reagent (Merck, Germany), gallic acid (GA; Sigma Aldrich, USA) and sodium carbonate (solution 20% w/w; Merck, Germany).

Determination of AOA measured by DPPH method

The AOA of beetroot cultivars was analysed in the dry matter by the method of Hegedűs et al. (2019) using DPPH scavenging activity calculated as inhibition of DPPH radicals in mg · kg⁻¹ Trolox equivalents (TEAC).

The lyophilised beetroot sample was homogenised 1 min and 10 g of mild, material was sequentially mixed with 40 ml of water-methanol solution (70%). Then, 20 g of the prepared mixture was mixed with 30 ml of methanol (96%). The mixture was stored at room temperature for 20 h, and it was sequentially extracted 4 h in the orbital shaker. Finally, the mixture was filtered. From each sample extract, 0.2 ml was pipetted and mixed with 1.8 ml of methanol (70%) and 4 ml of DPPH

solution ($25 \text{ mg} \cdot \text{l}^{-1}$). Simultaneously, 2 ml of methanol and 4 ml of DPPH solution were mixed and used as a reference sample (blind experiment). The absorbance of all beetroot samples was measured after 30 min in wavelength of 517 nm (spectrophotometer Jenway 6301, Bibby Scientific Ltd., UK).

Determination of total polyphenol content

The total polyphenol content (TPC) in beetroot was determined photometrically (spectrophotometer Shimadzu UV/VIS-1240) in a lyophilised sample by the method of Lachman et al. (2005) and expressed as milligram of gallic acid equivalent (GAE) per kilogram of dry weight (d.w.). The GA is usually used as a standard unit for phenolic content analysis because of the wide spectrum of phenolic compounds. The TPC was determined by using Folin-Ciocalteu phenol reagent, which was added to a volumetric flask containing 100 ml of extract. The prepared mixture was mixed. After 3 min, 5 ml of sodium carbonate solution (20%) was sequentially added to the mixture. The mixture was adjusted to 50 ml by adding distilled water. After 2 h, samples were centrifuged for 10 min, and sample absorbance was measured at a wavelength of 765 nm against blank. The polyphenol content was sequentially calculated from a standard curve plotted with a known concentration of GA.

Determination of TSS content

The content of TSS in beetroot was analysed by using the refractometric method according to Hegedúsová et al. (2018). The juice from the prepared homogenised sample of beetroot was squeezed on the dry block of a digital hand-held refractometer (Kern ORD 45BM, Balingen, Germany). The value of soluble solids was directly read. The measurement was performed at room temperature.

Statistical analyses

Statistical analyses were performed by using Statgraphic Centurion XVII (Statgraphics Technologies, Inc., The Plains, Virginia, USA). Obtained results were evaluated by analysis of variance (ANOVA), and average values were tested by the LSD test performed at the significance level of 95% ($p < 0.05$).

RESULTS AND DISCUSSION

Yield per hectare

The statistical analysis of obtained results showed significant differences in the root yield among tested beetroot cultivars and experimental years (Figure 1). The yield of beetroot was ranged from 20.74 ('Cylindra', 2017) to 41.91 $\text{t} \cdot \text{ha}^{-1}$ ('Albino', 2016). Generally, white-

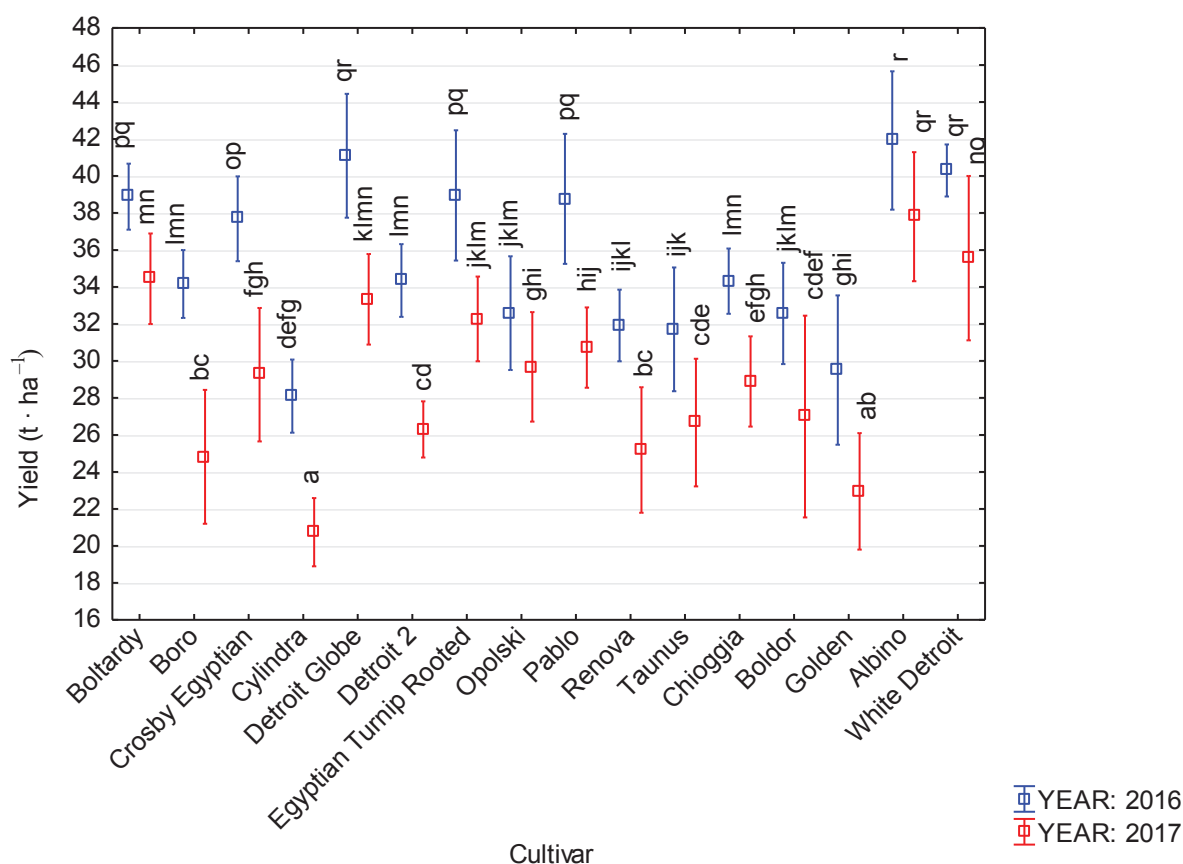


Figure 1. Yield of beetroot by LSD test (error bars represent SD; different letters among cultivars and years show statistically significant differences at the level $p < 0.05$).

Table 4. Effect of the experimental treatments on the mean yield and qualitative parameters of all beetroot cultivars.

Source of variance	Yield	AW	AOA	TPC	TSS
Cultivar	***	***	***	***	***
Year	***	***	***	***	***
Cultivar × Year	*	*	***	***	NS

AOA, antioxidant activity; AW, average weight; NS, non-significant; TPC, total polyphenol content; TSS, total soluble solids.

Differences depending on cultivar, year and interactions cultivar × yield by LSD test (ANOVA, STATGRAPHIC Centurion XVII).

NS or significant at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***), respectively.

fleshed beetroot cultivars were characterised by the highest yield potential (35.56–41.91 t · ha⁻¹). The root yield in typical, red-fleshed cultivars of beetroot was ranged from 20.74 (‘Cylindra’, 2017) to 41.09 t · ha⁻¹ (‘Detroit Globe’, 2016). The beetroot yield in yellow-fleshed cultivars reached 22.95 (‘Golden’, 2017) and 32.57 t · ha⁻¹ (‘Boldor’ F₁, 2016). The root yield of beetroot cultivar with combined red-white colour (‘Chioggia’) was 28.89 (2017) and 34.31 (2016) t · ha⁻¹.

The statistically significant effect of the experimental year on the root yield was found among most beetroot cultivars (Table 4). In white beetroot cultivars (Albino, White Detroit), differences in root yield among experimental years were evaluated as statistically non-significant (NS). Thus, these beetroot cultivars can be characterised as plastic cultivars in relation to changing climate conditions.

Within the study from India, Patel et al. (2017) tested the effect of plant spacing on the yield of beetroot. The yield of beetroot in the variant with spacing 0.30 × 0.15 m was ranged from 24.34 to 31.75 t · ha⁻¹, depending on the cultivar. In the Ukrainian study of Vdovenko et al. (2018), the yield of beetroot varied from 33.9 to 37.3 t · ha⁻¹. Values of beetroot yield in the mentioned studies are corresponding with the results of our study.

Compared to obtained results, Wruss et al. (2015) found the significant variability of beetroot yield in the range from 9.32 to 32.5 t · ha⁻¹, depending on the cultivar. Most of the used beetroot cultivars were shown by lower root yield compared to cultivars tested in our study. The lower yield of beetroot was also reached by Felczyński and Elkner (2008) in Poland where its values were ranged from 13.1 to 25.4 t · ha⁻¹, depending on the cultivar and experimental year. Within another Polish experiment, Szopińska and Gawęda (2013) tested the effect of the different growing system (conventional, integrated, organic) on the yield potential of beetroot (‘Regulski Cylinder’), which was also lower (19.86–25.70 t · ha⁻¹) in comparison with our experimental results.

Compared to the previously mentioned results, a significantly higher yield of beetroot was achieved by Irving (2012) in the experiment in Australia. Depending on the cultivar and planting date, root yield was ranged from 29 to 49 t · ha⁻¹. Compared to the results of our

study, the author found a significantly higher yield of beetroot in the cultivars ‘Pablo’ F₁ (40–47 t · ha⁻¹) and ‘Boro’ F₁ (39–45 t · ha⁻¹).

Obtained results revealed and confirmed the statistically significant effect of cultivar on the yield of beetroot. Except for cultivar, beetroot yield can be affected by other factors, for example, different growing system (Szopińska and Gawęda, 2013), irrigation and soil salinity (da Silva et al., 2016), fertilisation strategy (Agic et al., 2016), or changing climate conditions during vegetation period (Nizioł-Lukaszewska and Gawęda, 2014).

Figure 2 shows a 3D surface graph with average yields of all cultivars in relation to root shape (with two main shape types) and flesh colour. The highest yield is achieved by white cultivar. In the case of red cultivars, the highest yield was marked in those with circular or elliptic shape instead of oblong or ovate shape.

Average root weight

The average weight (AW) of beetroot was ranged from 187.8 (‘Golden’, 2017) to 412.1 g (‘White Detroit’, 2016). Statistically significant differences of AW were shown among tested beetroot cultivars and years (Figure 3). The statistically significant effect of the experimental year on the root weight was found among most beetroot cultivars (Table 4). In the red-fleshed cultivar (‘Opolski’), the difference of AW was found as statistically NS. Thus, this beetroot cultivar can be characterised as a plastic cultivar in relation to changing climate conditions.

Similar results of root weight were presented in several studies with beetroot. Within the Austrian experiment (Wruss et al., 2015), the average root weight of seven beetroot cultivars ranged from 214 to 366 g. Székely et al. (2014) found root weight variability of beetroot, depending on its cultivar, from 298.5 to 395.5 g in Hungary. The significant variability of root weight, depending on the beetroot cultivar, was presented by Nizioł-Lukaszewska and Gawęda (2014) in the study realised in Poland (83.7–336.7 g). The authors found a slightly higher value of AW in the beetroot cultivar ‘Boro’ F₁ (336.7) in comparison with the same cultivar in our study.

On the other hand, significantly lower root weight of beetroot was found in experiments in Poland (149.4–202.4 g; Szopińska and Gawęda, 2013), Ukraine (170.4–180.2 g; Vdovenko et al., 2018) or Brazil (161.6–180.7 g; da Silva et al., 2016).

Antioxidant activity

The statistical analysis of experimental results showed statistically significant differences of AOA among tested beetroot cultivars (Table 5). Values of AOA varied from 314.73 (‘White Detroit’, 2016) to 972.50 mg TEAC · kg⁻¹ d.w. (‘Pablo’ F₁, 2017). Generally, red-fleshed beetroot cultivars were characterised by significantly higher AOA (645.88–972.50 mg TEAC · kg⁻¹ d.w.) than beetroot cultivars with non-typical flesh colour (314.73–513.60 mg TEAC · kg⁻¹ d.w.). The statistically significant

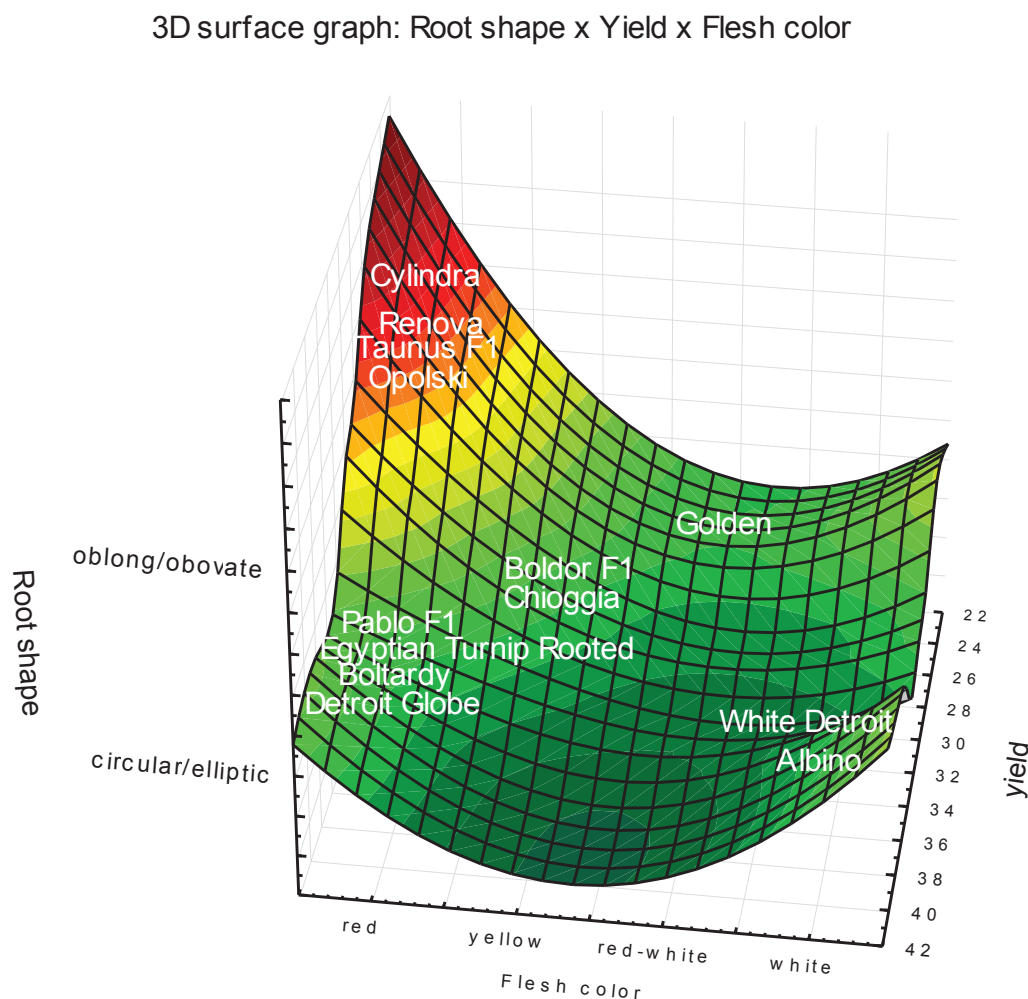


Figure 2. 3D surface graph with average yields of all cultivars in relation to root shape (with two main shape types) and flesh colour.

effect of the experimental year on the AOA of beetroot was also found (Table 4).

Compared to obtained results, Guldiken et al. (2016) found higher AOA of beetroot ($1,370 \text{ mg TEAC} \cdot \text{kg}^{-1} \text{ d.w.}$). Kovarovič et al. (2017) tested the effect of cultivar on the AOA of beetroot, determined by the DPPH method. The AOA of red-fleshed cultivars (20.70–21.83% inhibition of DPPH) was statistically significantly higher compared to the red-white cultivar of beetroot (8.37%), as it was shown by results obtained in our study. Within the study of Wruss et al. (2015), the significant variability of AOA in relation to beetroot cultivars was found and confirmed by using two different methods of AOA determination (ORAC - oxygen radical absorbance capacity, and FRAP - Ferric reducing antioxidant power). The difference between beetroot cultivars with the lowest and highest AOA content was approximately double in both used analysis methods. The significant effect of cultivar on the AOA of beetroot was also shown in the study of Nizioł-Lukaszewska and Gawęda (2014) who found the variability of its values from 25.60% to 37.99% DPPH. Significant variability of AOA in relation to beetroot cultivar was also found and

presented by Székely et al. (2014) or Czapski et al. (2009). Obtained results revealed and confirmed the statistically significant effect of cultivar on the AOA of beetroot. Except for cultivar, AOA of beetroot can be affected by other factors, for example, fertilisation strategy (Babagil et al., 2018), growing locality (Kavalcová et al., 2015), or changing climate conditions during the vegetation period (Nizioł-Lukaszewska and Gawęda, 2014).

Obtained results showed the significant effect of flesh colour on the AOA of beetroot, which was decreased in the following order of flesh colour: red > yellow > red-white > white. Results indicate that beetroot cultivars with darker flesh colour are characterised by higher AOA because of polyphenol content. A similar trend was also shown in the experiments with other crops, for example, potato (Gupta et al., 2015), sweet potato (Ji et al., 2015), or carrot (Scarano et al., 2018).

Experimental results revealed a very strong correlation between AOA and TPC in tested beetroot cultivars (Figure 4). The increasing TPC content was expressed by higher AOA values in individual beetroot cultivars. This fact was also shown in several studies with beetroot (Koubaier et al. 2014; Kavalcová et al.,

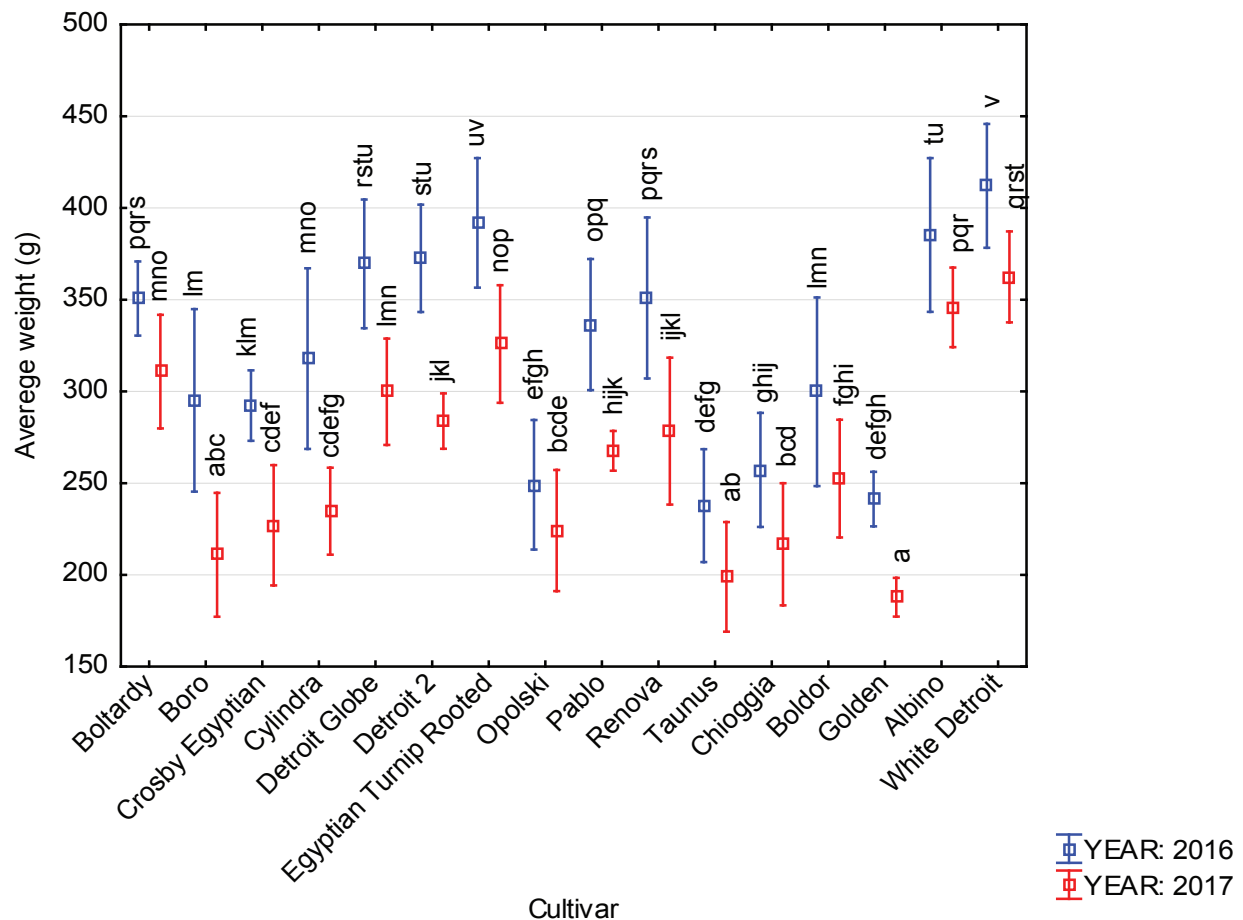


Figure 3. The average weight of beetroot by LSD test (error bars represent SD; different letters among cultivars and years show statistically significant differences at the level $p < 0.05$).

Table 5. Antioxidant activity of beetroot cultivars (mg TEAC · kg⁻¹ d.w.).

Cultivar	2016	2017
Boltardy	759.33 ± 15.48 kl	897.02 ± 6.62 q
Boro F ₁	756.27 ± 16.48 kl	864.30 ± 5.38 p
Crosby Egyptian	765.23 ± 20.44 l	886.35 ± 6.07 q
Cyindra	682.30 ± 6.55 h	792.04 ± 8.04 m
Detroit Globe	768.60 ± 11.49 l	940.32 ± 16.84 s
Detroit 2	645.88 ± 3.80 g	745.12 ± 5.16 jk
Egyptian Turnip Rooted	718.73 ± 4.83 i	810.34 ± 7.64 mn
Opolski	724.46 ± 18.66 i	834.20 ± 5.51 o
Pablo F ₁	819.19 ± 19.23 no	972.50 ± 5.95 r
Renova	685.16 ± 15.63 h	820.38 ± 6.91 no
Taunus F ₁	735.05 ± 32.09 ij	864.10 ± 4.27 p
Chioggia	336.33 ± 3.39 b	437.20 ± 6.30 d
Boldor F ₁	411.41 ± 12.63 c	513.60 ± 4.28 f
Golden	435.57 ± 8.38 d	494.49 ± 5.32 e
Albino	328.30 ± 8.22 ab	437.23 ± 7.44 d
White Detroit	314.73 ± 13.09 a	421.24 ± 4.51 cd

Different letters among cultivars and years show statistically significant differences at the level $p < 0.05$.

2015; Kovarovič et al., 2017), carrot (Yoo et al., 2020; Scarano et al., 2018), red cabbage (Leja et al., 2010), potatoes (Šulc et al., 2008), or sweet potatoes (Salawu et al., 2015).

Total polyphenols

The statistically significant differences of TPC among tested beetroot cultivars were found (Table 6). Values of TPC were ranged from 717.27 ('White Detroit', 2016) to 2,731.00 mg GAE · kg⁻¹ d.w. ('Pablo' F₁, 2017). The highest TPC was found in red-fleshed cultivars (1,537.64–2,731.00 mg GAE · kg⁻¹ d.w.), followed by beetroot cultivars with yellow (995.45–1,183.72 mg GAE · kg⁻¹ d.w.), red-white (756.93–941.41 mg GAE · kg⁻¹ d.w.) and white (717.27–933.17 mg GAE · kg⁻¹ d.w.) colour of root flesh. The statistically significant effect of the experimental year on the TPC in beetroot was also found (Table 4).

Koubaier et al. (2014) found extraordinary, statistically high-significant differences of TPC in beetroot (700–6,600 mg GAE · kg⁻¹ d.w.). Within the study of Guldiken et al. (2016), TPC in beetroot was 2,550 mg GAE · kg⁻¹ d.w. This value is comparable to

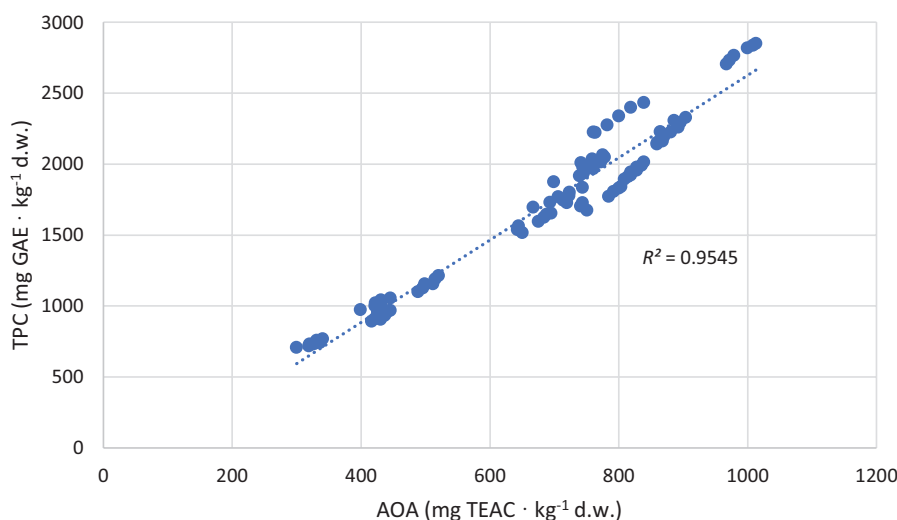


Figure 4. Correlation of antioxidant activity and total polyphenol content in red beet.

Table 6. Total polyphenol content in beetroot cultivars (mg GAE · kg⁻¹ d.w.).

Cultivar	2016	2017
Boltardy	2,023.35 ± 44.29 n	2,298.58 ± 24.91 q
Boro F ₁	1,969.86 ± 49.96 lm	2,162.97 ± 26.42 o
Crosby Egyptian	2,031.63 ± 21.19 n	2,262.05 ± 41.32 pq
Cylindra	1,619.93 ± 24.75 g	1,800.99 ± 29.04 j
Detroit Globe	2,238.81 ± 30.68 p	2,833.04 ± 15.60 t
Detroit 2	1,537.64 ± 22.90 f	1,699.60 ± 25.84 hi
Egyptian Turnip Rooted	1,747.24 ± 24.65 i	1,883.62 ± 41.68 k
Opolski	1,799.62 ± 32.39 j	1,985.29 ± 28.71 mn
Pablo F ₁	2,387.70 ± 48.75 r	2,731.00 ± 30.38 s
Renova	1,690.57 ± 38.11 h	1,942.62 ± 33.13 lm
Taunus F ₁	1,923.52 ± 47.32 kl	2,178.10 ± 42.11 o
Chioggia	756.93 ± 8.96 a	941.41 ± 19.23 b
Boldor F ₁	995.45 ± 23.62 c	1,183.72 ± 30.02 e
Golden	1,035.27 ± 22.04 c	1,125.55 ± 27.21 d
Albino	734.60 ± 5.84 a	933.17 ± 31.84 b
White Detroit	717.27 ± 12.10 a	918.19 ± 34.24 b

Different letters among cultivars and years show statistically significant differences at the level $p < 0.05$.

the polyphenol-richest cultivars of beetroot tested in our study. Kavalcová et al. (2015) tested the effect of growing locality and cultivar on the TPC in beetroot in the Slovak Republic with values ranged from 820.10 to 1,280.56 mg GAE · kg⁻¹ d.w. In the red-fleshed beetroot cultivar ‘Renova’, significantly lower TPC was found (820.10–1,280.56 mg GAE · kg⁻¹ d.w.) compared to our study. In the study of Kovarovič et al. (2017) in the Slovak Republic, TPC in beetroot was ranged from 368.75 to 887.75 mg GAE · kg⁻¹ d.w., depending on cultivar. Values of TPC in beetroot cultivars ‘Cylindra’ (887.75 mg GAE · kg⁻¹ d.w.), ‘Crosby Egyptian’ (882.40 mg GAE · kg⁻¹ d.w.) and ‘Chioggia’ (373.80 mg GAE · kg⁻¹ d.w.) were significantly lower compared to results of our study for the same tested

cultivars. Within the study of Ninfali et al. (2013), the lower TPC in beetroot cultivars, except one cultivar, was determined (720–1,726 mg GAE · kg⁻¹ d.w.) in comparison with our study. The lower TPC in beetroot was also shown by Wootton-Beard et al. (2011) and Číž et al. (2010). Its values were ranged from 617.8 to 1,450.3 mg GAE · kg⁻¹ d.w. in the mentioned studies. On the contrary, significantly higher TPC in beetroot (3,764 mg GAE · kg⁻¹ d.w.), in comparison with our study, was found by Čanadanovič-Brunet et al. (2011). The significant variability of TPC in beetroot, depending on its cultivar, was also shown by Wruss et al. (2015), Székely et al. (2014), Czapski et al. (2009), or Felczyński and Elkner (2008).

Obtained results revealed and confirmed the statistically significant effect of cultivar on the TPC in beetroot. Except for cultivar, TPC of beetroot can be affected by other factors, for example, growing system (Heimler et al., 2017; Kazimierczak et al., 2014), fertilisation strategy (Babagil et al., 2018), growing locality (Kavalcová et al., 2015), or water stress (Stagnari et al., 2014).

Total soluble solids

According to Cejpek (2012), the estimation method of TSS is used for testing sugar content in fruit and vegetable juices or other food products and the total concentration of monosaccharides and disaccharides in any solutions. Hegedúsová et al. (2018) defined TSS as additive quantity, which expresses the content of dissolved substances, mainly sugars, in vegetable or fruit extracts. As the unit of TSS, Brix degrees (BRIX) are used.

The obtained results showed statistically significant differences in TSS among tested beetroot cultivars (Table 7). Values of TSS were varied from 7.1 (‘Chioggia’, 2016) to 10.8 °BRIX (‘Detroit 2’, 2016). The TSS of beetroot cultivars was decreased in the following order of flesh colour: red (8.1–10.8 °BRIX) > white (7.8–8.8

Table 7. Total soluble solids in beetroot cultivars (°BRIX).

Cultivar	2016	2017
Boltardy	8.6 ± 0.2 hi	9.4 ± 0.2 nop
Boro F ₁	9.2 ± 0.3 mno	10.2 ± 0.1 r
Crosby Egyptian	9.9 ± 0.2 qr	10.5 ± 0.2 s
Cylindra	9.2 ± 0.2 mno	9.9 ± 0.2 qr
Detroit Globe	8.5 ± 0.1 gh	9.2 ± 0.2 lmn
Detroit 2	10.1 ± 0.2 r	10.8 ± 0.1 s
Egyptian Turnip Rooted	8.7 ± 0.2 hij	9.5 ± 0.1 op
Opolski	8.3 ± 0.1 fg	9.1 ± 0.2 klm
Pablo F ₁	7.8 ± 0.1 d	8.8 ± 0.1 ijk
Renova	8.1 ± 0.2 ef	8.9 ± 0.2 jkl
Taunus F ₁	8.9 ± 0.3 ijk	9.7 ± 0.2 pq
Chioggia	6.4 ± 0.2 a	7.7 ± 0.2 d
Boldor F ₁	6.8 ± 0.2 b	7.9 ± 0.3 de
Golden	7.1 ± 0.3 c	8.2 ± 0.1 f
Albino	7.8 ± 0.2 d	8.5 ± 0.20 gh
White Detroit	7.8 ± 0.2 d	8.8 ± 0.2 hij

Different letters among cultivars and years show statistically significant differences at the level $p < 0.05$.

°BRIX) > yellow (6.8–8.2 °BRIX) > red-white (6.4–7.7 °BRIX). The statistically NS effect of the experimental year on the TSS in beetroot was found (Table 4).

Székely et al. (2014) found similar content of TSS in beetroot in a Hungarian experiment (6.0–10.7 °BRIX). In the cultivar ‘Cylindra’, higher TSS content was found (10.7 °BRIX) compared to the same cultivar in our study. On the other hand, Stagnari et al. (2014) determined significantly higher TSS content in beetroot (13.9 °BRIX) compared to our study. The significantly higher content of TSS (14.2–21.5 °BRIX) in beetroot was also shown in the Australian study of Irving (2012). Values of TSS in cultivars ‘Pablo’ F₁ (15.5–18.4 °BRIX) and ‘Boro’ F₁ (15.1–18.3 °BRIX) were significantly higher than values of the same cultivars tested in our study.

The significant variability of TSS or sugar content, depending on the beetroot cultivar, was also shown by Wruss et al. (2015) or Nizioł-Łukaszewska and Gawęda (2014). Besides cultivar, TSS in beetroot can be also affected by the growing system (Szopińska and Gawęda, 2013) or water stress (Stagnari et al., 2014).

CONCLUSIONS

Results of this study emphasise the large variation of quantitative and qualitative parameters in beetroot cultivars. White cultivars of beetroot (‘Albino’, ‘White Detroit’) were characterised by higher yield, but lower AOA, content of polyphenols and TSS. Tested white cultivars can be also characterised as plastic cultivars in relation to changing climate conditions because statistically NS differences of root yield among experimental years were found in these cultivars. Results of this study showed that most red-coloured cultivars of beetroot were showed by a promising mixture of

good yield potential and higher antioxidant potential and content of TSS. These data are helpful for beetroot growers and consumers. Nowadays, the consumption of fresh vegetable-fruit juices and increased interest about human health are relatively popular and beetroots are often used for its preparation. From the aspect of yield potential in combination with the possible use of roots for production of beetroot juices, the following beetroot cultivars can be surely recommended: ‘Pablo’ F₁, ‘Detroit Globe’, ‘Boltardy’ or ‘Crosby Egyptian’. Beetroot cultivars with yellow (‘Golden’, ‘Boldor’ F₁) or red-white (‘Chioggia’) flesh colour were characterised by good yield potential, but lower antioxidant potential. Because of their interesting flesh colour, it should be used in modern gastronomy.

FUNDING

This article was supported by a grant from the Educational Grant Agency (KEGA 018SPU-4/2020) of the Ministry of Education, Science, Research and Sport of the Slovak Republic.

AUTHOR CONTRIBUTIONS

M.Š. performed conceptualisation, methodology and funding acquisition. O.H., A.H., M.T., J.M. and I.M. performed laboratory analyses. M.Š., I.M. and T.K. equally contributed to manuscript writing and editing. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

- ABBAS, M., SAEED, F., ANJUM, F. M., AFZAAL, M., TUFAIL, T., BASHIR, M. S., ISHTIAQ, A., HUSSAIN, S., AND SULERIA, H. A. R. (2017). Natural polyphenols: an overview. *International Journal of Food Properties*, 20(8), 1689–1699, doi: 10.1080/10942912.2016.1220393.
- ABENAVOLI, L., MILIC, N., LUZZA, F., BOCCUTO, L., AND DE LORENZO, A. (2017). Polyphenols treatment in patients with nonalcoholic fatty liver disease. *Journal of Translational Internal Medicine*, 5(3), 144–147, doi: 10.1515/jtim-2017-0027.
- AGIC, R., ZDRAVKOVSKA, M., POPSIMONOVA, G., DIMOVSKA, D., BOGEVSKA, Z., AND DAVITKOVSKA, M. (2016). Yield and quality of beetroot (*Beta vulgaris* ssp. *esculenta* L.) as a result of microbial fertilizers. *Contemporary Agriculture*, 67(1), 40–44, doi: 10.2478/contagri-2018-0006.
- ALAM, N., ALMOYAD, M., AND HUQ, F. (2018). Polyphenols in colorectal cancer: Current state of knowledge including clinical trials and molecular mechanism of action. *BioMed Research International*, 2018, 4154185, doi: 10.1155/2018/4154185.

- BABAGIL, A., TASGIN, E., NADAROGLU, H., AND KAYMAK, H. C. (2018). Antioxidant and antiradical activity of beetroot (*Beta vulgaris* L. var. *conditiva* Alef.) grown using different fertilizers. *Journal of Chemistry*, 2018, 7101605, doi: 10.1155/2018/7101605.
- BABARYKIN, D., SMIRNOVA, G., PUNDINSH, I., VASILJEVA, S., KRUMINA, G., AND AGEJCHENKO V (2019). Red beet (*Beta vulgaris*) impact on human health. *Journal of Biosciences and Medicines*, 7(3), 61–79. doi: 10.4236/jbm.2019.73007.
- ČANADANOVIĆ-BRUNET, J. M., SAVATOVIĆ, S., ČETKOVIĆ, G., VULIĆ, J. J., MARKOV, M., AND CVETKOVIĆ, D. (2011). Antioxidant and antimicrobial activities of beet root pomace extracts. *Journal Food Science*, 29(6), 575–585, doi: 10.17221/210/2010-CJFS.
- CEJPEK, K. (2012). *Analysis of food and natural products: Determination of carbohydrates in foodstuffs*. Prague, Czech Republic: Institute of Chemical Technology.
- CHAWLA, H., PARLE, M., AND SHARMA, K. (2016). Beetroot: A health promoting functional food. *Inventi Impact: Nutraceuticals*, 2016(1), 8–12.
- CHHIKARA, N., KUSHWAHA, K., SHARMA, P., GAT, Y., AND PANGHAL, A. (2019). Bioactive compounds of beetroot and utilization in food processing industry: A critical review. *Food Chemistry*, 272, 192–200, doi: 10.1016/j.foodchem.2018.08.022.
- ČÍŽ, M., ČÍŽOVÁ, H., DENEV, P., KRACHTOVÁ, M., SLAVOV, A., AND LOJEK, A. (2010). Different methods for control and comparison of the antioxidant properties of vegetables. *Food Control*, 21(4), 518–521, doi: 10.1016/j.foodcont.2009.07.017.
- CLIFFORD, T., HOWATSON, G., WEST, D. J., AND STEVENSON, E. J. (2015). The potential benefits of red beetroot supplementation in health and disease. *Nutrients*, 7, 2801–2822, doi: 10.3390/nu7042801.
- COLES, L. T., AND CLIFTON, P. M. (2012). Effect of beetroot juice on lowering blood pressure in free-living, disease-free adults: a randomized, placebo-controlled trial. *Nutrition Journal*, 11, 106, doi: 10.1186/1475-2891-11-106.
- CZAPSKI, J., MIKOŁAJCZYK, K., AND KACZMAREK, M. (2009). Relationship between antioxidant capacity of red beet juice and contents of its betalain pigments. *Polish Journal of Food and Nutrition Science*, 59(2), 119–122.
- DA SILVA, A. O., DE F. E SILVA, Ê. F., AND KLAR, A. E. (2016). Yield of beet cultivars under fertigation management and salinity control in a protected environment. *Chilean Journal of Agricultural Research*, 76(4), 463–470, doi: 10.4067/S0718-58392016000400010.
- EUROPEAN COMMISSION. (2020). *Common catalogue of varieties of vegetable species*. Retrieved from https://ec.europa.eu/food/sites/food/files/plant/docs/plant_variety_catalogues_vegetable-species.pdf.
- FELCZYŃSKI, K., AND ELKNER, K. (2008). Effect of long-term organic and mineral fertilization on the yield and quality of red beet (*Beta vulgaris* L.). *Vegetable Crops Research Bulletin*, 68(1), 111–125. doi: 10.2478/v10032-008-0010-7.
- GUINÉ, R. P. F., GONÇALVES, F., LERAT, C., IDRISSE, T. E., RODRIGI, E., CORREIA, P. M. R., AND GONÇALVES, J. C. (2018). Extraction of phenolic compounds with antioxidant activity from beetroot (*Beta vulgaris* L.). *Current Nutrition & Food Science*, 14(4), 350–357, doi: 10.2174/1573401313666170609102336.
- GULDIKEN, B., TOYDEMİR, G., MEMIS, K. N., OKUR, S., BOYACIOĞLU, D., AND CAPANOĞLU, E. (2016). Home-processed red beetroot (*Beta vulgaris* L.) products: Changes in antioxidant properties and bioaccessibility. *International Journal of Molecular Sciences*, 17(6), 858, doi: 10.3390/ijms17060858.
- GUPTA, V. K., TUOHY, M. G., O'DONOVAN, A., AND LOHANI, M. (2015). *Biotechnology of bioactive compounds: Sources and applications*. Hoboken, NJ: John Wiley & Sons.
- HEGEDŰS, O., HEGEDŰSOVÁ, A., SZARKA, K., ŠLOSÁR, M., AND MAŤOVÁ, A. (2019). Antioxidant activity determination of horticultural crops. Paper presented at 19th International Multidisciplinary Scientific GeoConference SGEM 2019, Vol. 19, Albena, Bulgaria, 543–555.
- HEGEDŰSOVÁ, A., ŠLOSÁR, M., MEZEYOVÁ, I., HEGEDŰS, O., ANDREJIOVÁ, A., AND SZARKA, K. (2018). *Methods for estimation of selected biologically active substances*. Nitra, Slovak Republic: Slovak University of Agriculture.
- HEIMLER, D., ROMANI, A., AND IERI, F. (2017). Plant polyphenol content, soil fertilization and agricultural management: A review. *European Food Research and Technology*, 243, 1107–1115, doi: 10.1007/s00217-016-2826-6.
- INVALLY, M., KAUR, G., AND BUTTA, H. S. (2017). Evaluation of the antidepressant activity of *Beta vulgaris* alone and in combination with fluoxetine in mice. *Journal of Pharmacology and Toxicology*, 12(1), 33–41, doi: 10.3923/jpt.2017.33.4.
- IRVING, D. (2012). *Beetroot stand management*. Sydney, Australia: Horticulture Australia Ltd.
- JASMITHA, S. K., AHOK, S., AND KARUNAKAR, H. (2018). A review on *Beta vulgaris* (beet root). *International Journal of Pharma and Chemical Research*, 4(2), 136–141.
- Ji, H., ZHANG, H., LI, H., AND LI, Y. (2015). Analysis on the nutrition composition and antioxidant activity of different types of sweet potato cultivars. *Food and Nutrition Sciences*, 6(1), 161–167, doi: 10.4236/fns.2015.61017.
- KAVALCOVÁ, P., BYSTRICKÁ, J., TOMÁŠ, J., KAROVIČOVÁ, J., KOVAROVIČ, J., AND LENKOVÁ, M. (2015). The content of total polyphenols and antioxidant activity in red beetroot. *Potravinárstvo*, 9(1), 77–83, doi: 10.5219/441.
- KAZIMIERCZAK, R., HALLMANN, E., LIPOWSKI, J., DRELA, N., KOWALIK, A., PUSSA, T., MATT, D., LUIK, A.,

- GOZDOWSKI, D., AND REMBIA, X. K. E. (2014). Beetroot (*Beta vulgaris* L.) and naturally fermented beetroot juices from organic and conventional production: metabolomics, antioxidant levels and anti-cancer activity. *Journal of the Science of Food and Agriculture*, 94(13), 2618–2629, doi: 10.1002/jsfa.6722.
- KOUBAIE, H. B. H., SNOUSI, A., ESSAIDI, I., CHAABOUNI, M. M., THONART, P., AND BOUZOUITA, N. (2014). Betalain and phenolic compositions, antioxidant activity of Tunisian red beet (*Beta vulgaris* L. *conditiva*) roots and stems extracts. *International Journal of Food Properties*, 17(9), 1934–1945, doi: 10.1080/10942912.2013.772196.
- KOVAROVIČ, J., BYSTRICKÁ, J., TOMÁŠ, J., AND LENKOVÁ, M. (2017). The influence of variety on the content of bioactive compounds in beetroot (*Beta vulgaris* L.). *Potravinárstvo Slovak Journal of Food Sciences*, 11(1), 106–112, doi: 10.5219/702.
- KUMAR, S., AND BROOKS, M. S. L. (2018). Use of red beet (*Beta vulgaris* L.) for antimicrobial applications – A critical review. *Food and Bioprocess Technology*, 11(1), 17–42, doi: 10.1007/s11947-017-1942-z.
- LACHMAN, J., HAVRLAND, B., HEJTMÁNKOVÁ, A., FERNÁNDEZ, E. C., AND PIVEC, V. (2005). Content of polyphenolic antioxidants and phenol carboxylic acids in selected parts of yacon. *Scientia Agriculturae Bohemica*, 36(2), 49–54.
- LEJA, M., KAMIŃSKA, I., AND KOLTON, A. (2010). Phenolic compounds as the major antioxidants in red cabbage. *Folia Horticulturae*, 22(1), 19–24, doi: 10.2478/fhort-2013-0146.
- LIM, T. K. (2016). *Edible medicinal and non-medicinal plants*. New York City, NY: Springer.
- MANACH, C., SCALBERT, A., MORAND, C., RÉMÉSY, C., AND JIMÉNEZ, L. (2004). Polyphenols: food sources and bioavailability. *The American Journal of Clinical Nutrition*, 79(5), 727–747, doi: 10.1093/ajcn/79.5.727.
- MATTIOLI, A. V., FARINETTI, A., AND GELMINI, R. (2019). Polyphenols, Mediterranean diet, and colon cancer. *Supportive Care in Cancer*, 27, 4035–4036, doi: 10.1007/s00520-019-04835-9.
- MCSWEENEY, M., AND SEETHARAMAN, K. (2015). State of polyphenols in the drying process of fruits and vegetables. *Critical Reviews in Food Science and Nutrition*, 55(5), 660–669, doi: 10.1080/10408398.2012.670673.
- MERAVÁ, E. (2019). *Fruits and vegetables* (in Slovak). Bratislava, Slovak Republic: Research Institute of Agriculture and Food Economics.
- MIRMIRAN, P., HOUSHIALSADAT, Z., GAEINI, Z., BAHADORAN, Z., AND AZIZI, F. (2020). Functional properties of beetroot (*Beta vulgaris*) in management of cardio-metabolic diseases. *Nutrition & Metabolism*, 17, 3, doi: 10.1186/s12986-019-0421-0.
- NGUYEN, H., NGUYEN, M., CHANDRAN, V., NGUYEN, Q. H., NGUYEN, K. T., NGUYEN, C., BUI CHI, T., NGUYEN, V., LAM, F., AND DANG, H. (2018). Phytochemical, cardiovascular effect, antioxidant, antiinflammation and anti-tumor properties by *Beta vulgaris* (beet) root juice. *Journal of Translation Science*, 5, doi: 10.15761/JTS.1000293.
- NINFALI, P., AND ANGELINO, D. (2013). Nutritional and functional potential of *Beta vulgaris* *cicla* and *rubra*. *Fitoterapia*, 89, 188–199, doi: 10.1016/j.fitote.2013.06.004.
- NIZIOL-ŁUKASZEWSKA, Z., AND GAWĘDA, M. (2014). Changes in quality of selected red beet (*Beta vulgaris* L.) cultivars during the growing season. *Folia Horticulturae*, 26(2), 139–146, doi: 10.1515/fhort-2015-0005.
- PATEL, H. T., SHARMA, M. K., JOSHI, P. C., CHAUDHARI, A. H., AND DAVE, P. P. (2017). Production and profitability of beetroot (*Beta vulgaris* L.) cultivars to date of planting and spacing under north Gujarat conditions. *International Journal of Chemical Studies*, 5(5), 1505–1510.
- PETŘÍKOVÁ, K., AND HLUŠEK, J. (2010). *Vegetables* (in Czech). Praha, Czech Republic: ProfiPress.
- SALAWU, S. O., UDI, E., AKINDAHUNSI, A. A., BOLIGON, A. A., ATHAYDE, M. L. (2015). Antioxidant potential, phenolic profile and nutrient composition of flesh and peels from Nigerian white and purple skinned sweet potato (*Ipomoea batatas* L.). *Asian Journal of Plant Science and Research*, 5(5), 14–23.
- SCARANO, A., GERARDI, C., D'AMICO, L., ACCOGLI, R., AND SANTINO, A. (2018). Phytochemical analysis and antioxidant properties in colored Tiggiano carrots. *Agriculture*, 8(7), 102, doi: 10.3390/agriculture8070102.
- STAGNARI, F., GALIENI, A., SPECA, S., AND PISANTE, M. (2014). Water stress effects on growth, yield and quality traits of red beet. *Scientia Horticulturae*, 165(1), 13–22, doi: 10.1016/j.scienta.2013.10.026.
- ŠULC, M., LACHMAN, J., HAMOUZ, K., AND DVOŘÁK, P. (2008). Impact of phenolic content on antioxidant activity in yellow and purple-fleshed potatoes grown in the Czech Republic. *Biological Agriculture & Horticulture*, 26(1), 45–54, doi: 10.1080/01448765.2008.9755068.
- SZÉKELY, D., SZALÓKI-DORKÓ, L., STÉGER-MATÉ, M., SZABÓ-NÓTI, B., IVANICS, J., AND MONSPART-SÉNYI, J. (2014). Distribution of antioxidant components in roots of different red beets (*Beta vulgaris* L.) cultivars. *Acta Alimentaria*, 43(Suppl.), 164–171, doi: 10.1556/AAlim.43.2014.Suppl.23.
- SZOPIŃSKA, A. A., AND GAWĘDA, M. (2013). Comparison of yield and quality of red beet roots cultivated using conventional, integrated and organic method. *Journal of Horticultural Research*, 21(1), 107–114, doi: 10.2478/johr-2013-0015.
- UPOV (2008). *Beetroot: Guidelines for the conduct of tests for distinctness, uniformity and stability*. Retrieved from <https://www.upov.int/edocs/tgdocs/en/tg060.pdf>.

- VDOVENKO, S. A., PALAMARCHUK, I. I., PANTSUREVA, H. V., ALEXEYEV, O. O., AND VDOVENKO, L. O. (2018). Energy efficient growing of red beet in the conditions of central forest steppe of Ukraine. *Ukrainian Journal of Ecology*, 8(4), 34–40.
- WANG, S., MOUSTAID-MOUSSA, N., CHEN, L., MO, H., SHASTRI, A., SU, R., BAPAT, P., KWUN, I. S., AND SHEN, C. L. (2015). Novel insights of dietary polyphenols and obesity. *Journal of Nutritional Biochemistry*, 25(1), 1–18, doi: 10.1016/j.jnutbio.2013.09.001.
- WICZKOWSKI, W., PLATOSZ, N., AND SAWICKI, T. (2016). Comparison of free and bound polyphenols profile in a raw and fermented red beetroot. Paper presented at the 15th International Conference on Food Processing & Technology, Rome, Italy, 100.
- WOOTTON-BEARD, P. C., AND RYAN, L. (2011). A beetroot juice shot is a significant and convenient source of bioaccessible antioxidants. *Journal of Functional Foods*, 3(4), 329–334, doi: 10.1016/j.jff.2011.05.007.
- WRUSS, J., WALDENBERGER, G., HUEMER, S., UYGUN, P., LANZERSTORFER, P., MÜLLER, U., HÖGLINGER, O., AND WEGHUBER, J. (2015). Compositional characteristics of commercial beetroot products and beetroot juice prepared from seven beetroot varieties grown in Upper Austria. *Journal of Food Composition and Analysis*, 42, 46–55, doi: 10.1016/j.jfca.2015.03.005.
- YOO, K. S., BANG, H., PIKE, L., PATIL, B. S., AND LEE, E. J. (2020). Comparing carotene, anthocyanins, and terpenoid concentrations in selected carrot lines of different colors. *Horticulture, Environment, and Biotechnology*, 61, doi: 10.1007/s13580-019-00225-6.

Received: August 31, 2020; accepted: November 17, 2020