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Nutritional value, bioactive components and antioxidant activity of *Schisandra chinensis* (Turcz.) Baill. leaves

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As a part of the ongoing interest in the nutritional and antioxidative properties of a little-known East Asian plant species, the aim of the study was to determine the contents of macronutrients and selected elements, profiles of fatty and amino acids, the content of phenolic compounds, β-carotene, vitamin A and E, and antioxidant activity of *Schisandra chinensis* (Turcz.) Baill. edible leaves. *Schisandra chinensis* leaves contained a small amount of lipids – 4.36 % and 12.38 % of proteins. Sugars (fructose, maltose, sucrose, and lactose) were detected only in trace amounts (<0.5 g/kg). The β-carotene content was 17.70 mg/kg. The fatty acid profile of leaves was represented by palmitic C16:0 (44.6 g/100 g of oil), linoleic C18:2 *9c12c* (17.9 g/100 g of oil), and α-linolenic C18:3 (*9c12c15c* 10.6 g/100 g of oil) acids. Nine out of 18 amino acids detected in leaves were essential amino acids (68.80 g/kg of dry matter leaves). Glutamic acid was found to be the major component of non-essential amino acids (25 g/kg of dry matter), followed by aspartic acid (16.2 g/kg of dry matter) and leucine (14.2 g/kg of dry matter). The element composition of leaves demonstrated the presence of: macroelements (K, P, S, Ca, Mg, Na), microelements (Zn, Fe, Cu, Mn, Cr, Se), and metals (Al, As, Cd, Ni, Hg, Pb). Potassium was the most abundant element in *Schisandra chinensis* leaves (10209 mg/kg of dry matter of leaves), followed by Ca, P, and Mg. The spectrophotometric assays enabled detecting phenolic compounds from three categories: polyphenols (44.32 mg galic acid equivalents/g of dry matter of leaves), total flavonoids (29.16 mg quercetin equivalents/g of dry matter of leaves) and phenolic acids (6.12 mg caffeic acid equivalents/g of dry matter of leaves) in *Schisandra chinensis* leaves. The antioxidant activity of *S. chinensis* leaves, as determined

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by DPPH•, was at the level of 9.19 mg TEAC/g of dry matter of leaves, and 214 mg TEAC/g of dry matter of leaves (as determind by molybdenum reducing antioxidant power). The composition of *Schisandra chinensis* leaves suggest it to become an inexpensive novel plant source of functional foods, supplements, and as new ingredient in human diet.

Keywords: *Schisandra chinensis*, leaves, chemical composition

Introduction

Ample studies have shown that non-traditional, little-known, and underutilized edible leaves of plant species, also offer some nutritional value; being a good source of macroelements, minerals, polyphenols, with impressive antioxidant activity, thus gained interest as potential functional foods (Monka et al., 2014; Ivanišová et al., 2017a; Horčinová Sedláčková et al., 2018, 2019; Klymenko et al., 2017, 2019; Vinogradova et al., 2020; Grygorieva et al., 2017, 2018a, 2018b, 2018c, 2020a, 2020b). However, to the best of authors' knowledge, the data about nutrient composition and therapeutic properties of different morphological parts of plants is highly limited.

Schisandra chinensis (Turcz.) Baill. fruits proved to be a rich source of carbohydrates, vitamins, phytosterols, organic acids (Hancke et al., 1999; Wu et al., 2011; Tong et al., 2012; Ekiert et al., 2013; Szopa and Ekiert, 2014). The main bioactive components determined in fruits are lignans ("schisandra lignans"), which are also present in *Schisandra chinensis* leaves, but in lower amounts (Ekiert et al., 2013). Study of *Schisandra chinensis* leaves performed by Xia et al. (2015) allowed detection of 16,17-Seco-pre-schisanartanes (C_{29}), known as new triterpenoid from plant species of the family Schisandraceae. *Schisandra chinensis* leaves are known to be used in infusions or as spices (Ciorchină et al., 2011). The essential oil of *S. chinensis* also possess valuable properties (Merdzhanov et al., 2016).

The health beneficial properties of *Schisandra chinensis* fruits primarily refer to Traditional Chinese Medicine. Previous studies showed that *Schisandra chinensis* fruits possess hepatoprotective (Panossian and Wikman, 2008), anti-inflammatory (Hu et al., 2014), anticancer (Hwang et al., 2011) immunostimulant (Chen et al., 2012a; Zhao et al., 2013), anti-obesity (Park et al., 2012), antiviral (Xu et al., 2015), antibacterial (Chen et al., 2011; Hakala et al., 2015; Tvrdá et al., 2020), adaptogenic, ergogenic activity (Jeong et al., 2013; Sa et al., 2015), antioxidant and detoxifying properties (Chiu et al., 2008; Yim et al., 2009; Thandavarayan et al., 2015; Wang et al., 2018). Moreover, *S. chinensis* fruits extracts are used in cosmetic industry (Quirin, 2008; Dweck and Marshall, 2009; Chiu et al., 2011).

Despite the well-studied composition and properties of the fruits of *Schisandra chinensis*, the nutritional value and bioactive components of leaves remains to be studied. Thus, the aim of this study was to determine the contents of macronutrients and selected elements, profiles of fatty and amino acids, the content of phenolic compounds, β-carotene, vitamin A and E, and antioxidantive activity of *Schisandra chinensis* edible leaves.

Material and methodology

Sampling

The *Schisandra chinensis* leaves (Figure 1) were collected in July 2020 from the trees growing in the Botanical Garden (Slovak University of Agriculture in Nitra).

Chemicals and reagnets

All the chemicals and reagnets used were of analytical grade and were purchased from Sigma-Aldrich (Steinheim, Germany), Merck (Darmstadt, Germany), and CentralChem (Slovakia).

Analysis of proximate composition

Dry matter, ash, and protein contents were determined according to CSN-EN 12145 procedures (1997). Total lipid content was determined according to ISO method (ISO 659, 1998).

Analysis of sugars

For the determination of sugars content, 1 g of leaves was vigorously shaken with 10 mL of water/ethanol mixture (4:1) on a vertical shake table (GFL, Germany). After 1 h of the extraction, the mixture was centrifuged at 6000 rpm for 4 min (EBA 21, Hettich, Germany). The supernatant was filtered through filter paper with 0.45 mm pore size (Labicom, Czech Republic) and filled up to 50 mL in a volumetric flask with ultrapure water.

An HPLC analysis of sugars (fructose, maltose, sucrose, lactose) was performed using an Agilent Infinity 1260 instrument (Agilent Technologies, USA) equipped with an ELSD detector. Separation of sugars was conducted on a Prevail Carbohydrates ES column (250 × 4.6 mm). Acetonitrile/water (75 : 25 v/v) was used as the mobile phase. The identification of sugars was made by comparison the relative retention times of sample

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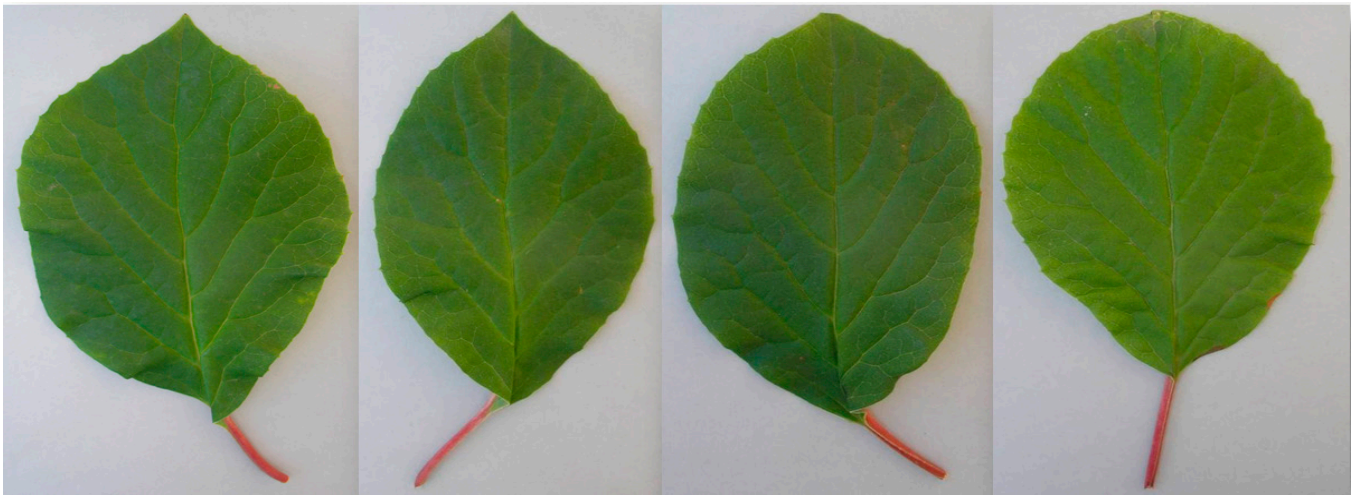

Figure 1 Leaves of *Schisandra chinensis* (Turcz.) Baill.

peaks with standards Sigma-Aldrich (Steinheim, Germany). The contents of sugars were expressed as g/kg of dry leaves.

Beta-carotene carotenoids content

Beta-carotene content was extracted following the method of Sarker and Oba (2019). 1 g of dry leaf sample was ground thoroughly in a mortar and pestle with 10 mL of 80 % acetone. After removing the supernatant in a volumetric flask, the extract was centrifuged at 10 000 × g for 3–4 min. The final volume was brought up to 20 mL. The absorbance was taken at 510 nm and 480 nm using a spectrophotometer (UV-VIS spectrophotometer, Jenway Model 6405, England). Data were expressed as mg beta-carotene per kg of dry leaves. The following formula was used to measure the beta-carotene content:

$$\text{Beta-carotene} = 7.6(\text{Abs. at } 480) - 1.49(\text{Abs. at } 510) \times \text{final volume}/1000$$

Elemental analysis

The contents of macroelements, microelements and trace metals were determined by the inductively coupled plasma optical emission spectroscopy (ICP-OES) according to Divis et al. (2015) by using an ICP-OES instrument (Ultima 2, Horiba Scientific, France). Leaves were prepared for analysis after microwave digestion (Milestone 1200, Milestone, Italy), 0.25 g of sample was decomposed in a mixture of nitric acid (6 mL) (Analytika Praha Ltd, Czech Republic) and hydrochloric acid (2 mL) (Analytika Praha Ltd, Czech Republic). After the decomposition sample was filtered through filter paper (0.45 mm pore size) and filled up to 25 mL in a volumetric flask with pure water.

Determination of amino acids

Amino acid profile was determined by ion-exchange chromatography using an AAA-400 Amino Acid Analyzer (Ingos, Czech Republic) and post-column derivatization with ninhydrin and a VIS detector. Separation was provided on a glass column (length 350 mm, inner diameter 3.7 mm) filled with a strong cation exchanger in the LG ANB sodium cycle (Laboratory of Spolchemie) with average particles size of 12 µM and 8 % porosity. The column was heated within the range of 35–95 °C, with the elution of amino acids at 74 °C. A double-channel VIS detector with the inner cell volume of 5 µL was set to 440 and 570 nm. A solution of ninhydrin was prepared in 75 % v/v methyl cellosolve and in 2 % v/v 4 M acetic buffer (pH 5.5). $SnCl_2$ was used as a reducing agent. Solution of ninhydrin was stored in an inert atmosphere (N_2) without access of light at 4 °C. The flow rate was 0.25 mL/min, and the reactor temperature was 120 °C. Individual amino acids values were expressed as g/kg of dry leaves.

Fatty acid composition

Fatty acid (FA) composition of extracted fat from *Schisandra chinensis* leaves was determined as follows: the samples were prepared according to official methods Ce 2-66 (1997) to convert the oils into fatty acid methyl esters (FAME). The FAME profile was analyzed by gas chromatography (GC-6890-N, Agilent Technologies, Santa Clara, USA) equipped with capillary column DB-23 (60 m × 0.25 mm, film thickness 0.25 µm, Agilent Technologies, Santa Clara, CA, USA) and FID detector (250 °C; constant flow, hydrogen 40 mL/min, air 450 mL/min.). A detailed description of the

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chromatography conditions is presented in the work Szabóová et al. (2020). Standards of a C4–C24 FAME mixture (Supelco, Bellefonte, PA, USA) were applied in order to identify FAME peaks. The evaluation was carried out by the ChemStation 10.1 software.

Spectrophotometric assays of phenolic compounds

Total phenolics content (TPC)

The TPC was determined spectrophotometrically at 700 nm (UV-VIS spectrophotometer, Jenway Model 6405, England) according to Singleton and Rossi (1965) using Folin-Ciocalteu's reagent. Briefly, 0.1 mL of leaves ethanolic extract was diluted with 8.8 mL of distilled water, mixed with 0.1 mL of the Folin-Ciocalteu's reagent and 1 mL of 20 % sodium carbonate. The mixture was kept in darkness for 30 min before measurement of absorbance. Gallic acid (25–300 mg/L; R^2 = 0.998) was used as the standard. The results were expressed as gallic acid equivalents (GAE; mg GAE/g of dry matter of leaves).

Total flavonoids content (TFC)

The TFC was determined spectrophotometrically at 415 nm (UV-VIS spectrophotometer, Jenway Model 6405, England) according to a modified method of Shafii et al. (2017). An aliquot of 0.5 mL of leaves ethanolic extract was mixed with 0.1mL of 10 % ethanolic solution of aluminum chloride, 0.1 mL of 1 M potassium acetate and 4.3 mL of distilled water. The mixture was kept in darkness for 30 min before measurement of absorbance. Quercetin (1–400 mg/L; R^2 = 0.9977) was used as the standard. The results were expressed as mg quercetin equivalents (QE)/g of dry matter of leaves.

Phenolic acid content (TPA)

The TPA was determined spectrophotometrically at 490 nm (UV-VIS spectrophotometer, Jenway Model 6405, England) according to a method described in Farmakopea Polska (1999). A 0.5 mL of sample extract was mixed with 0.5 mL of 0.5 M hydrochloric acid, 0.5 mL Arnova reagent (10 % $NaNO_2$ + 10 % Na2MoO4), 0.5 mL of 1 M sodium hydroxide (w/v) and 0.5 mL of distilled water. Caffeic acid (1–200 mg/L, R^2 = 0.999) was used as a standard. The results were expressed as mg caffeic acid equivalents (CAE)/g of dry matter of leaves.

Determination of antioxidant activity

DPPH• radical scavenging activity

The free radical scavenging activity of leaves extract on DPPH• (2,2-diphenyl-1-picrylhydrazyl) was determined according to Sánches-Moreno et al. (1998). Briefly, 0.4 mL of the extract was mixed with 3.6 mL of DPPH• solution (0.025 g of DPPH• in 100 mL of methanol). The absorbance was measured at 515 nm using a UV-Vis spectrophotometer (Jenway Model 6405, England). Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) (10–100 mg/L; R^2 = 0.989) was used as standard. The results were expressed as mg of Trolox equivalents (TEAC)/g of dry matter of leaves.

Molybdenum reducing antioxidant power (MRAP)

The MRAP of leaves extract was determined according to the method of Prieto et al. (1999) with slight modifications. The mixture of 1 mL of extract, monopotassium phosphate (2.8 mL, 0.1 M), sulfuric acid (6 mL, 1 M), ammonium heptamolybdate (0.4 mL, 0.1 M) and distilled water (0.8 mL) was incubated at 90 °C for 120 min, then rapidly cooled. The absorbance was measured at 700 nm using a UV-Vis spectrophotometer (Jenway Model 6405, England). Trolox (10–1000 mg/L; R^2 = 0.998) was used as the standard. The results were expressed as mg of Trolox equivalents (TEAC)/g of dry matter of leaves.

Statistic analysis

The results were subjected to one-way ANOVA followed by Tukey-Kramer test, when the differences between mean values were considered significant at $p < 0.05$. The variability of all parameters was evaluated by descriptive statistics. The results were presented as means with standard error (SE). The PAST 2.17 software was used.

Results and discussion

The protein content of *Schisandra chinensis* leaves (12.38 %) was higher than in many cultivated fruits, up to 1%. Our results are in agreement with other studies; in generally, leaves are a poor lipid source. *Schisandra chinensis* leaves contained a small amount of lipids – 4.36 %. Sugars (fructose, maltose, sucrose, and lactose) were detected only in trace amounts (< 0.5 g/kg) (Table 1). Monosaccharides are involved in almost all major plant metabolic processes such as synthesis of organic acids, amino acids, polyphenols, pigments, and aromatic compounds (Halford et al., 2011). It has been

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observed that leaves accumulate monosaccharides in plants grown under stress conditions (Wind et al., 2010). Probably, lower levels of these macronutrients in leaves indicate optimal environmental conditions for plant growth.

Table 1 Proximate composition of *Schisandra chinensis* (Turcz.) Baill. leaves

Component	Mean ±SE
Proteins	12.38 ±0.16
Lipids (%)	4.36 ±0.09
Saturated fatty acids (g/100 g oil)	54.40 ±0.16
Monounsaturated fatty acids (g/100 g oil)	11.30 ±0.11
Polyunsaturated fatty acids (g/100 g oil)	28.50 ±1.07
Fructose (g/kg)	<0.5
Maltose (g/kg)	<0.5
Sucrose (g/kg)	<0.5
Lactose (g/kg)	<0.5
Dry matter (%)	92.34 ±2.44
Ash (%)	5.70 ±0.17
Vitamin A (retinyl acetate) (mg/kg)	<0.1
β-carotene (mg/kg)	17.70 ±0.10
Vitamin E (α-tocopherol) (mg/kg)	48.58 ±2.66

Schisandra chinensis leaves proved to be rich in carotenoids, mainly β-carotene (17.7 mg/kg). Substantial share of β-carotene has a great impact on the colour, it is well known that carotenoids are one of the most common natural pigments protecting plants against photo-oxidative reactions. They are also the most effective antioxidants trapping molecular singlet oxygen and peroxyl radicals. At the same time, carotenoids enhance the effect of other antioxidants (Stahl and Sies, 2003).

The content of α-tocopherol in leaves was assayed at the level of 48.58 mg/kg. Vitamin E includes four tocopherols and tocotrienols, which main biochemical function is thought to bind organic peroxyl radicals (Shahidi and Ambigaipalan, 2015). These reactions determine the antioxidant activity of vitamin E, protecting tissue lipids from free radical attack.

The application of gas chromatography enabled determination of 20 fatty acid in lipid fraction extracted from *Schisandra chinensis* leaves belonged to all groups (Mišurcová et al., 2011) (Table 1 and 2); saturated – SFAs (54.4 g/100 g of the oil), monounsaturated – MUFAs (11.3 g/100 g of the oil), and polyunsaturated – PUFAs (28.50 g/100 g of the oil). The FA profile of leaves was represented mainly by palmitic (C16:0) 44.6 g/100 g of oil, linoleic C18:2 *9c12c* 17.9 g/100 g of oil, and α-linolenic C18:3 *9c12c15c* 10.6 g/100 g of oil acids (Table 2). The amount of these three FAs was 76.44 % of the total FAs. The substancial presence of palmitic acid was confirmed in many previous studies; palmitic acid (27.7–60.0 %) dominated in the FA profile of leaf of many species from the Lamiaceae family (Cacan et al., 2018; Kilic, 2018); *Cassia tora* (L.) Roxb. (18.6–38.7 %) (Shukla et al., 2018); *Nicotiana* species (13.0–18.0 %) (Koiwai et al., 1983); *Cistus ladanifer* L. (13.6–17.5 %) (Jerónimo et al., 2020). In most cases, oleic acid is the second compound in the fatty acid profile (12.5 %). According to study of Kumar et al. (2009) oleic acid has insecticidal activity against *Aedesae gyptii* larvae. This FA was also detected in the FA profile of *S. chinensis* leaves (6.8 %).

Table 2 Fatty acid composition (g/100 g of oil) of lipids of *Schisandra chinensis* leaves

Fatty acid	Mean ±SE
SFAs	7.63
C14:0	1.61 ±0.08
C16:0	44.60 ±1.58
C17:0	0.51 ±0.03
C18:0	3.94 ±0.08
C20:0	1.27 ±0.03
C22:0	1.16 ±0.04
C24:0	1.26 ±0.02
MUFAs	11.27
C16:1	3.99 ±0.05
C18:1	6.79 ±0.11
C20:1	0.49 ±0.03
PUFAs	28.49
C18:2	17.90 ±0.63
C18:3	10.59 ±0.48

Note: Saturated fatty acids – SFAs; monounsaturated fatty acids – MUFAs; polyunsaturated fatty acids – PUFAs

Changes in FA composition of different morphological parts of the plants may be affected by abiotic stress such as extreme temperatures below and above zero and moisture deficiency (Gigon et al., 2004; Liu and Huang, 2004; Zhong et al., 2011; Li et al., 2017). Lipids play an important role in metabolic processes of organisms (Cakir, 2004). Also, it is well-known that FAs have antibacterial and antifungal properties (McGaw et al., 2002; Seidel and Taylor, 2004). Many studies indicated that a decreased risk of cardiovascular disease, coronary heart disease, cancer, hypertension, type 2 diabetes, kidney diseases, rheumatoid arthritis, ulcerative colitis, Crohn's disease, and osteoporosis,

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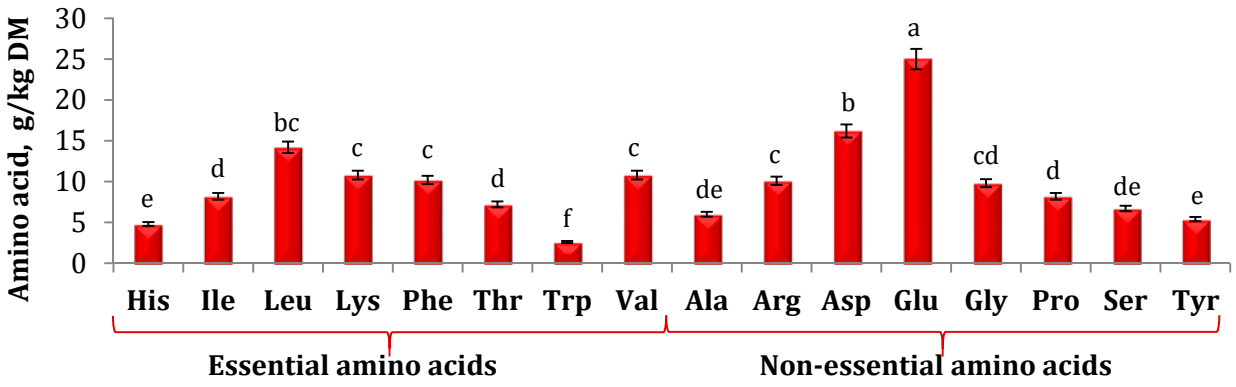

Figure 2 Amino acid composition (g/kg of dry matter; DM) of *Schisandra chinensis* leaves
a, b, c, d, e, f – different superscripts indicate the significant differences at p <0.05

with consumption of PUFAs, especially FAs from n-3 family (De Caterina et al., 2000; Mišurcová et al., 2011; Abedi and Sahari, 2014). Our results indicated that *Schisandra chinensis* leaves may represent a novel potential plant source of FAs important for nutritional reasons.

Eighteen amino acids were detected in *Schisandra chinensis* leaves, nine of them were essential amino acids and nine non-essential ones (Figure 2).

The content of amino acids in leaves was at the level of 156.20 g/kg of dry matter; while content of total essential amino acids was 68.80 g/kg of dry matter (amounted 44.05 %) and 87.40 g/kg of dry matter (55.95 %) for total non-essential amino acids. Glutamic acid was found to be the major component of non-essential amino acids (25 g/kg of dry matter), followed by aspartic acid (16.2 g/kg of dry matter) and leucine (14.2 g/kg of dry matter).

The contents of macroelements (K, P, S, Ca, Mg, Na), microelements (Zn, Fe, Cu, Mn, Cr, Se), and metals (Al, As, Cd, Ni, Hg, Pb) are presented in Table 3. Elements present in plants are responsible for their properties (including toxicity) since they are catalysts of most biochemical processes occurring in plants. Analysis of elements in leaves is an important guide to sustainable plant nutrition. The presence of trace elements and their content in plants are of considerable interest both from the theoretical point of view and of their medical application. In the etiology of many diseases, the imbalance of the content of trace elements in the human body plays an important role for mainatnance of good health (Penauelas et al., 2001; Erdal et al., 2006; Lipa, 2013; Yildirim et al., 2015).

Potassium (K) was the most abundant element in *Schisandra chinensis* leaves (10209 mg/kg of dry weight of leaves), followed by Ca, P, and Mg. It should be highlighted that potassium is an essential mineral, important mainly to maintain body water and to participate in transmitting nerve impulses to muscles, thus consumption of such leaves may have influence in covering daily required amount of this element. Regarding the presence of metals, the content of aluminium (Al; 32.1 mg/kg of dry weight of leaves) dominated among detected metals in *Schisandra chinensis* leaves. For maitanance of human health it is very important to study the contents of heavy metals, like for example Cd, Ni and Al, because some plants may have the tendency to accumulate toxic metals. Also, amounts of metals, especially toxic ones may provide useful information about environmental pollution levels.

Phenolic compounds are known as phytonutrients, secondary metabolites or bioactive compounds (Yoona et al., 2016). Phenolic compounds can prevent excessive free radicals and have positive health benefits such as anti-carcinogenic, anti-inflammatory activities, anti-bacterial, anti-diabetics, prevent neurodegenerative diseases such as Alzheimer's disease, Parkinson's disease, prion disease, and motor neurone disease (Siracusa et al., 2019), decrease the level of blood pressure, improvement of plasma lipid profile and endothelial function (Yoona et al., 2016).

The leaves of many non-traditional plants repersent promising source of antioxidants (Sakanaka et al., 2005; Priya and Nethaji, 2015; Ferlemi and Lamari, 2016; Klymenko et al., 2017; Urbanaviciute et al., 2019; Grygorieva et al., 2020b).

The spectrophotometric assays enabled detecting phenolic compounds belonging to; polyphenols, phenolic acids, and flavonoids, in *Schisandra chinensis* leaves. The content of polyphenols was 44.32 mg

Table 3 Elements composition of *Schisandra chinensis* leaves (mg/kg of dry weight)

Element	mean ±SE
Macroelements	
K	10 209 ±387
P	3 277 ±222
Ca	7 330 ±310
S	987 ±68
Mg	4 012 ±412
Na	28.0 ±0.9
Microelements	
Zn	32.0 ±1.2
Fe	54.0 ±1.2
Cu	9.10 ±0.8
Mn	47.4 ±1.8
Cr	1.20 ±0.06
Se	0.19 ±0.01
Metals	
Al	32.1 ±1.9
As	<0.3
Cd	0.114 ±0.002
Ni	0.49 ±0.02
Hg	0.017 ±0.002
Pb	0.66 ±0.020

GAE/g of dry leaves, total flavonoids – 29.16 mg QE/g of dry leaves and phenolic acids – 6.12 mg CAE/g of dry leaves (Figure 3).

According to study of Mocan et al. (2014), *S. chinensis* leaves contained more polyphenols (62.36 ±1.38 mg/g DM) and flavonoids (35.10 ±1.23 mg/g DM) compering with their fruits (9.20 ±0.43 and 7.65 ±0.95 mg/g d.w., respectively).

According to previously published data, leaves of cultivated and wild plants are a valuable source of polyphenols and flavonoids. Thus, the TPC in *Mangifera indica* L. leaves was at the level of 65 mg/g, *Anacardium occidentale* L. – 58.57 mg/g. Moreover, TPC determined in ethanolic extracts of *Cymbopogm citrates* leaves was 28.30 mg/g, *Carica papaya* L. leaves – 21.80 mg/g (Iyawe and Azih, 2011), *Euphorbia* spp. leaves – 19.10–20.30 mg/g (Gapuz and Besagas, 2018), *Azadirachta indica* Juss leaves 14.43 mg/g (Iyawe and Azih, 2011). According to Thi and Hwang (2014), the polyphenol content of *Aronia mitschurinii* leaves ranges from 139.3 to 250.8 mg GAE/g of DM. However, results of TPC of Shahin et al. (2019) were significantly higher – 765.63 mg GAE/g of dried leaves of *Aronia melanocarpa*. According to Męczarska et al. (2017), the leaves of *Amelanchier alnifolia* had a polyphenol content at the level of 185.23 mg GAE/g DM.

Research of Barreira et al. (2010) and Stankovic et al. (2014), who studied total flavonoid content of leaves of *Castanea sativa* Mill., indicated that the flavonoids content was up to 3-fold higher (73.31–90.39 mg/g) compering with our results of flavonoids of *Schisandra chinensis* leaves. It was proved that methanolic extracts were the richest in flavonoids: TFC was 90.28 mg/g of methanolic extracts of *Ziziphus jujuba* Mill. leaves, while in the ethanolic extract the TFC was only 22.18 mg/g (Al-Saeedi et al., 2016). Grygorieva et al. (2020b) studied the content of phenolic compounds in the leaves of several non-traditional plants. The *Lycium barbarum* leaves distinguished by the highest content of polyphenols and flavonoids (95.84 mg GAE/g and 54.61 mg QE/g, respectively).

The antioxidant activity of *S. chinensis* leaves, as determined by DPPH•, was at the level of 9.19 mg TEAC/g of DW, and 214 mg TEAC/g of DW (as determind by molybdenum reducing antioxidant power – MRAP; Figure 3). For the comparison, the radical scavenging activity (DPPH) of some other plant leaves is lower than assayed for *S. chinensis* leaves: *Aronia mitschurinii* leaves – 6.92 mg TEAC/g of DM; *Cornus mas* – 9 mg

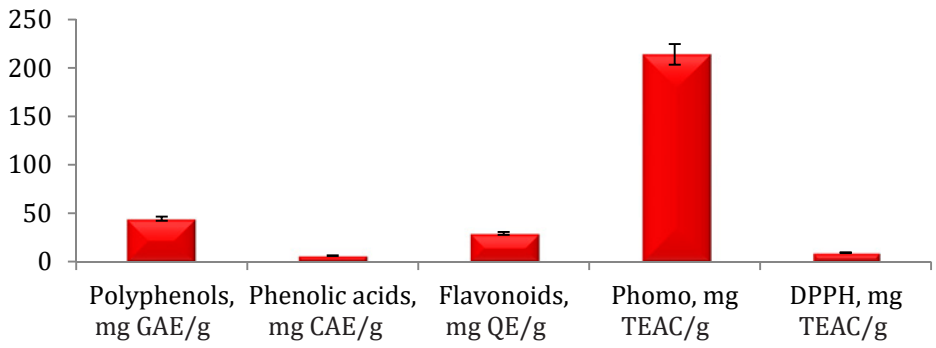

Figure 3 Bioactive compounds and antioxidant potential of *Schisandra chinensis* leaves

TEAC/g of DM. Antioxidant activity determined by molybdenum reducing antioxidant power ranged from 109.43 mg TEAC/g of DM (*A. mitschurinii* leaves) to 322.95 mg TEAC/g of DM (*C. mas* leaves) (Grygorieva et al., 2020b).

Some previous studies were also focused on the composition of *S. chinensis* plant and its products (Tvrdá et al., 2020). The antioxidant capacity of *S. chinensis* essential oil, measured by DPPH test (IC_{50}), was determined as 4.17 mg/mL (Chen et al., 2012b), while the free-radical scavenging activity of the extract was 5.93 mg TEAC/g of DM. According to the MRAP assay, the antioxidant activity of the extract was 140.52 mg TEAC/g of DM. The TPC of the extract was 16.52 mg GAE/g of DM, the TFC was 2.66 mg QE/g of DM and the carotenoids content was 0.15 mg β-carotene/g of DM (Tvrdá et al., 2020). Also, antioxidant activity of *S. chinensis* berries was studied previously by Ivanišová et al. (2017b), who determined DPPH• – 5.85 mg TEAC/g, MRAP – 148.87 mg TEAC/g, and TPC – 15.55 mg GAE/g of berries. Compering these findings with our results for antioxidant properties of *S. chinensis* leaves, it can be concluded that not only *S. chinensis* berries but also leaves posses fairy good antioxidant capacity.

Hamauzu et al. (2006) described that the fruits and leaves of *Schisandra chinensis* are a valuable natural source of caffeoylquinic acid and epicatechin. High levels of antioxidants and antiproliferative compounds make it possible to recommend this species for use in pharmaceutical and therapeutic nutrition, for the prevention and treatment of such human pathologies as cardiovascular disease and cancer.

Since the leaves of *Schisandra chinensis* are an inexpensive natural source of bioactive components, the extract from them can be used for the prevention and treatment of atherosclerosis, hypertrophic heart disease, hypertension, and diabetes.

Conclusions

This study demonstrates that *Schisandra chinensis* leaves may be regarded as a valuable source of minerals: K (10209 mg/kg of dry weight of leaves), Ca, P, Mg, and phenolic compounds (polyphenols – 44.32 mg GAE/g of dry leaves), with fairly good antioxidant activity (DPPH• test – 9.19 mg TEAC/g of dry leaves, and MRAP test – 214 mg TEAC/g of dry leaves). The β-carotene content was 17.7 mg/kg. The fatty acid profile of leaves was represented by palmitic C16:0 (44.6 g/100 g of oil), linoleic C18:2 *9c12c* (17.9 g/100 g of oil), and α-linolenic C18:3 (*9c12c15c* 10.6 g/100 g of oil) acids. Nine out of 18 amino acids detected in leaves were essential amino acids (68.80 g/kg of dry leaves), with significant share of glutamic acid (25 g/kg of dry weight), followed by aspartic acid (16.2 g/kg of dry weight) and leucine (14.2 g/kg of dry weight). The established composition of *Schisandra chinensis* leaves suggest it to become an inexpensive novel plant source of functional foods, supplements, and as a new ingredient in human diet.

Conflicts of Interest

The authors declare no conflict of interest.

Ethical Statement

This article does not contain any studies that would require an ethical statement.

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