

## ASSESSMENT OF FLAVONOIDS AND PHENOLIC COMPOUND ACCUMULATION IN INVASIVE *SOLIDAGO CANADENSIS* L. IN SLOVAKIA

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### ABSTRACT

*Solidago canadensis* L. was introduced to Europe as an ornamental plant from North America in 1645 and began to spread during the XIX-XX centuries. Nowadays the species is considered the most aggressive invasive species. On the other hand, *S. canadensis* is considered to be a medicinal plant. The raw material known as Herba Solidaginis includes herbs of *S. canadensis*, *S. gigantea*, and *S. virgaurea*. These species are known for their diuretic, anti-inflammatory, antimicrobial, antioxidant, antispasmodic properties. The purpose of our study was to analyze the chemical compounds and some biological properties of *S. canadensis*, growing in Slovakia, to evaluate its therapeutic potential. The total phenolic content (TPC) of the extracts from aerial parts of *S. canadensis* was determined by the Folin-Ciocalteu method. The evaluation of total flavonoid content (TFC) was performed by using a spectrophotometric method. The flavonoids content was expressed as rutin equivalents (mg REs) per g DW vegetal product. The phytochemical profile of *S. canadensis* extracts was assessed by liquid chromatography-tandem mass spectrometry (LC-MS/MS). The radical scavenging activity of samples was measured using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method. Reducing power of extracts was determined by the phosphomolybdenum method. Total phenolic contents (TPC) and total flavonoid contents (TFC) of the extracts varied from 204.19 to 293.43 mg GAE.g<sup>-1</sup> DW, and 64.99 – 175.25 g QE.g<sup>-1</sup> DW, respectively; the best results were obtained for ethanol extract. Some phenolic compounds were identified by HPLC with significant amounts of rutin (211.20 µg.mL<sup>-1</sup>), quercetin (122.08 µg.mL<sup>-1</sup>), quercitrin (102.50 µg.mL<sup>-1</sup>) and chlorogenic acid (147.00 µg.mL<sup>-1</sup>). The DPPH values in the inflorescences were higher than in the leaves: the antioxidant activity of leaf extracts was in the range from 5.34 to 17.16 mg TE.g<sup>-1</sup>, for inflorescences, this parameter ranged from 6.09 to 19.87 mg TE.g<sup>-1</sup>. The high total phenolic compounds and flavonoids can be used as a valuable source of phytochemicals in herbal remedies. Our study of *S. canadensis*, growing in Slovakia, shows the promising potential that can be evaluated as an effective antioxidant and antimicrobial agent in herbal medicines.

**Keywords:** *Solidago canadensis*; flavonoid; phenolic compound; antiradical activity

### INTRODUCTION

*Solidago canadensis* L. was introduced to Europe as ornamentals from North America in 1645 and began to spread during the XIX-XX centuries (Lambdon et al., 2008; Vinogradova, Mayorov and Choroov, 2010). The specie is considered as the most aggressive invaders, which is defined by the European and Mediterranean Plant Protection Organization as invasive species having a high potential for spread and posing an important threat to the environment and biodiversity in the region (Invasive Species Compendium, 2015). Abandoned and poorly managed agricultural areas contribute to the rapid spread and high density of goldenrod populations, and it was also recorded as one of the most common weeds in suburbs.

Invasive goldenrod is negatively evaluated because it reduces the abundance of native plants. On the other hand, goldenrod is considered to be medicinal plant. The raw material known as Herba Solidaginis includes herbs of *S. canadensis*, *S. gigantea*, and *S. virgaurea* (Wichtl,

2013). Goldenrod has been traditionally used to treat inflammations of the urinary tract. Preparations from goldenrods have a well-defined diuretic, spasmolytic and hypotensive effect together with anti-inflammatory, bacteriostatic, and analgesic properties (Apáti et al., 2003; Pawlaczyk et al., 2009; Deng et al., 2015). In addition to the above indications, preliminary studies of *Solidago* species have demonstrated that these plants contain a high-molecular-weight polysaccharide-protein complex that has strong cytotoxic activity against prostate cancer cells and an antitussive effect (Ravichandiran and Deepa, 2012; Šutovská et al., 2013). There are also antitumor activities in the saponins fraction of *Solidago* species and antimicrobial, sedative, cytotoxic, and hypotensive effects in the essential oils of *Solidago* species (Kołodziej, Kowalski and Kędzia, 2011; Vinogradova and Kuklina, 2018; Shelepova et al., 2018). The toxicity and contraindications for goldenrods preparations have not been reported, and the available information is based

mainly on studies conducted on the native European goldenrod (*S. virgaurea* L.).

The flavonoids and phenolic acids are one of the most numerous and widespread groups of natural constituents in the plant kingdom. They exhibit biological activities, including antiallergenic, antiviral, anti-inflammatory, and vasodilating actions. Most research in recent years has been devoted to the antioxidant activity of flavonoids and phenolic acids, which is due to their ability to reduce the free radical formation and to scavenge free radicals. As a rule flavonoids and phenolic acids have low toxicity which, combined with high antioxidant capacity, makes these compounds extremely useful as pharmacological agents (Pietta, 2000; Andersen and Markham, 2006). The effect of goldenrod preparations in urinary therapy is highly related to the biological action of flavonoids; they inhibit the enzyme neutral endopeptidase, which is responsible for the interaction of the atrial natriuretic peptide with the glomerulus, and, thus, they regulate the formation of urine via the excretion of sodium ions (Melzig, 2004). However, despite the importance of flavonoids, investigations of these compounds in *Solidago* species are scarce. Studies on *S. canadensis* in China (Wang et al., 2011; Deng et al., 2015), Lithuania (Radusiene et al., 2015) and Hungary (Apati et al., 2002; Apáti et al., 2003; Apáti et al., 2006), *S. virgaurea* and *S. graminifolia* (L.) Elliot in Poland (Roslon et al., 2014;

Thiem et al., 2001) and Romania (Toiu et al., 2019), *S. caucasica* Kem.-Nath. and *S. dahurica* Kitag. in Russia (Goryachkina, Buinov and Fedoseeva, 2012) have been conducted.

### Scientific hypothesis

Worldwide, works are being carried out the estimation of the content and accumulation of phenolic compounds during the growth of *Solidago*. The scientific hypothesis of the present study was to identify and quantify the concentrations of the principal phenolic compounds in widespread invasive *S. canadensis* in Slovakia to determine the importance of *Solidago* raw material as potential sources of phenolic compounds in foods and health-promoting ingredients for humans.

## MATERIAL AND METHODOLOGY

### Plant material

The population nearby Nitra city, Slovakia, has been observed. The population of *Solidago canadensis* (Figure 1) is very dense and occupies a large area. Thus, there is no shortage of this plant as a biological resource. Material has been dried in the shade, at a temperature of 20 – 30 °C. Because of our earlier studies proved the minimal concentration of functional ingredients in stems (Shelepova et al., 2019), only leaves and inflorescences have been taken for analysis.



Figure 1 *Solidago canadensis* L.

### Preparation of extracts

Air-dried plant material was mechanically ground with a laboratory mill to obtain a homogenous powder. All the samples of *S. canadensis* of approximately 0.1 g (weighed with 0.0001 g precision) were extracted in 10 mL of methanol (ME), ethanol (EE), acetone (AE) and aqueous (WE) extracts by ultra-sonication at 25 °C for 50 min. The prepared extracts were passed through a 0.22 µm filter and stored at 4 °C until analysis.

### Quantitative analyses

The total phenolic content (TPC) of the extracts from *S. canadensis* aerial parts were determined by the Folin-Ciocalteu method (Singleton, Orthofer and Lamuela-Raventós, 1999). The content in total phenolics was expressed as mg gallic acid equivalents (GAE).g<sup>-1</sup> dry weight (DW) vegetal product. The experiments were performed in triplicate.

The evaluation of total flavonoid content (TFC) of the extracts from *S. canadensis* aerial parts was performed by using a spectrophotometric method (Shafii et al., 2017). The flavonoids content was expressed as quercetin equivalents (mg QE).g<sup>-1</sup> DW vegetal product.

### HPLC conditions and analysis

The phytochemical profile of *S. canadensis* extracts was assessed by liquid chromatography-tandem mass spectrometry (LC-MS/MS). The equipment was an Agilent 1100 HPLC Series system (Agilent, Santa Clara, CA, USA) equipped with an autosampler, binary gradient pump, degasser, column thermostat (set at 48 °C), and UV detector. The mass spectrometer was an Agilent Ion Trap 1100 SL (LC/MSD Ion Trap VL, Agilent, Santa Clara, CA, USA) equipped with electrospray ionization (ESI) or atmospheric pressure chemical ionization (APCI). The flow rate was 1 mL/min and the injection volume was 5 µL. The separation of compounds was performed on a reverse-phase analytical column (Zorbax SB-C18 100 × 3.0 mm i.d., 3.5 µm particle).

UV and MS modes were used for the detection of the compounds. A standard solution of polyphenols was used for collecting all spectra and integrating them into a library. The minimal concentration which produced a reproductive peak characterized by a signal-to-noise ratio greater than three was considered for calculation of the detection limits.

The retention times for the compounds were determined using reference standards and were based on the mass spectrum for each compound. Spiking samples with a solution containing each polyphenol (10 µg mL<sup>-1</sup>) was used for accuracy check.

For identification of compounds, their retention times and the recorded ESI-MS spectra were compared with those of standards, which were obtained under identical working conditions. The method of the external standard was employed for the quantification of polyphenols in each extract and the calibration curves for a five-point plot were linear in the range 0.5 – 50.0 µg.mL<sup>-1</sup> ( $R^2 > 0.999$ ).

### Antioxidant activity

Radical scavenging activity of samples was measured using 2,2-diphenyl-1-picrylhydrazyl (DPPH) according to Sánchez-Moreno, Larrauri, and Saura-Calixto (1998) with slight modification. The ethanol extract (1 mL) was mixed with 4 mL of DPPH solution (0.025 g of radical in 100 mL of ethanol). The absorbance of the sample extract was determined using the spectrophotometer Jenway (6405 UV/Vis, England) at 515 nm. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) 10 – 100 mg.L<sup>-1</sup> ( $R^2 = 0.983$ ) was used as a standard and the results were expressed in mg.g<sup>-1</sup> Trolox equivalents (TE).

### Reducing power of extracts

Reducing the power of extracts was determined by the phosphomolybdenum method of Prieto, Pineda, and Aguilar (1999) with slight modifications. The mixture of 1 mL of sample, 2.8 mL of monopotassium phosphate (0.1 M), 6 mL of sulfuric acid (1 M), 0.4 mL of ammonium heptamolybdate (0.1 M) and 0.8 mL of distilled water was incubated at 90 °C for 120 min, then rapidly cooled and detected by monitoring absorbance at 700 nm using the spectrophotometer Jenway (6405 UV/Vis, England). Trolox 10 – 1000 mg.L<sup>-1</sup> ( $R^2 = 0.998$ ) was used as the standard and the results were expressed in mg.g<sup>-1</sup> TE.

### Chemicals

Acetonitrile was of HPLC grade and supplied by Sigma-Aldrich (Steinheim, Germany). Methanol, ethanol, and acetone were of analytical grade and were purchased from CentralChem (Slovakia).

Water was filtered through the Millipore HPLC grade water preparation cartridge (Millipore, Bedford, USA). The reference substances, chlorogenic acid (purity ≥95.33%), rutin trihydrate (purity 97.11%), and isoquercetin (purity ≥94.16%), were purchased from HWI ANALYTIK GmbH (Germany); quercitrin (purity ≥98.0%) was obtained from Sigma-Aldrich (Steinheim, Germany).

### Statistical analysis

The statistically treated data are given as the arithmetical mean values and their standard errors. Data were submitted ANOVA and differences between means compared through the Tukey-Kramer test ( $p < 0.05$ ).

## RESULTS AND DISCUSSION

Several *in vitro* and *in vivo* studies revealed that the presence of polyphenolic compounds in plant extracts could be related to important biological properties, such as antioxidant, immunomodulatory, antimicrobial, anticancer, prebiotic-like, vasodilating activities (Brglez Mojzer et al., 2016).

Since flavonoids and phenolic acids are among the most important phytochemical constituents of some *Solidago* species, we evaluated their content in *S. canadensis* extracts. The results of the quantitative determination of total phenolics and flavonoids from different extracts (mg extract per g plant material) are presented in Figure 2.

Total phenolic contents (TPC) and total flavonoid contents (TFC) of the extracts were determined; the TPC

and TFC of the aerial part extracts varied from 204.19 to 293.43 mg GAE.g<sup>-1</sup> DW, and 64.99 – 175.25 g QE.g<sup>-1</sup> DW, respectively. The highest values were observed in the aerial parts of *S. canadensis* ethanol extract, with total phenolics (293.42 mg GAE.g<sup>-1</sup> extract) and flavonoids (175.25 mg QE.g<sup>-1</sup> extract). In the aerial parts, the amount of TPC under investigation can be arranged in descending order: EE > ME ≈ AE ≈ WE ( $p < 0.05$ ). The EE (175.25 QE.g<sup>-1</sup>) extracts showed the highest TFC, for ME (141.05 QE.g<sup>-1</sup>) and AE (144.48 QE.g<sup>-1</sup>) were found to be similar, the lowest level was in the aqueous extracts (WE) (64.99 QE.g<sup>-1</sup>).

Obtained results were in good agreement with the ones presented by **Deng et al. (2015)**, who determined the total polyphenols and flavonoid contents in ethanol extracts from leaves of *S. canadensis*. Similarly, the highest contents of bioactive compounds were found in ethanol extracts from *S. graminifolia* (TPC – 192.69 mg.g<sup>-1</sup>, TFC – 151.25 mg.g<sup>-1</sup>) (**Toiu et al., 2019**), *S. microglossa* (TPC – 226.0 mg.g<sup>-1</sup>, TFC – 115.2 mg.g<sup>-1</sup>) (**Sabir et al., 2012**) and *S. virgaurea*, *S. canadensis*, *S. gigantea* (TFC – 118.0; 156.0 and 156.0 mg.g<sup>-1</sup>, respectively) (**Kołodziej Kowalski and Kędzia, 2011**). Recent research carried out by **Woźniak et al. (2018)** on *Solidago* sp. showed that the methanol extracts from aerial parts from *S. canadensis* contain 82.1 mg flavonoids per g extract and 130.5 mg polyphenols per g extract, which is lower than the content determined in *S. canadensis* in our study. Studies pointed out that certain factors, such as the extraction method, the type of solvents and solubility of active compounds, the temperature, the extraction time, and the ratio of solvent-to-sample are essential parameters that greatly influence the yield and quality of obtained extracts from plant materials.

Also, it should be noted that the flavonoid content meets the quality criteria of European Pharmacopoeia mentioned at *Solidaginis herba* (minimum 2.5% flavonoids).

Taking into account that the highest amounts of total flavonoids and total phenolics were observed in *S. canadensis* extracts, the HPLC analysis for identification and quantification of polyphenolic compounds was carried out and the obtained results are presented in Table 1.

Three groups of phenolic compounds have been identified in the aerial parts of *S. canadensis* – phenol carboxylic acids, such as chlorogenic acid, caftaric acid and t-ferulic acid (and other acids according to the mass spectrum), and flavonoids, such as flavonol glycosides (rutin, hesperidin, quercitrin), flavonol aglycones (quercetin, kaempferol), and catechin (Table 1). These compounds had chromatographic and spectral characteristics similar to those previously identified in *S. canadensis* L. (**Apáti et al., 2003; Apáti et al., 2006; Woźniak et al., 2018**).

Rutin (200.45 – 211.20 mg.g<sup>-1</sup>), quercetin (121.74 – 122.41 mg.g<sup>-1</sup>), quercitrin (102.50 – 125.70 mg.g<sup>-1</sup>) and chlorogenic acid (134.95 – 147.00 mg.g<sup>-1</sup>) were the major active compounds in *S. canadensis* aerial parts ME, EE and AE extracts. The WE extract was rich in polar compounds, especially chlorogenic acid (834.5 mg.g<sup>-1</sup>) and vanillic acid (154.08 mg.g<sup>-1</sup>), which was the major phenolic acid present, and represented 1186.87 mg.g<sup>-1</sup> of the extract.

The majority of flavonoids in the WE extract were identified as monoglycosides (127.67 mg.g<sup>-1</sup>) of kaempferol and quercetin (Table 1). Also, other compounds were detected that corresponded to rutin (44.77 mg.g<sup>-1</sup>), quercitrin (35.84 mg.g<sup>-1</sup>) and hesperidin (11.55 mg.g<sup>-1</sup>).

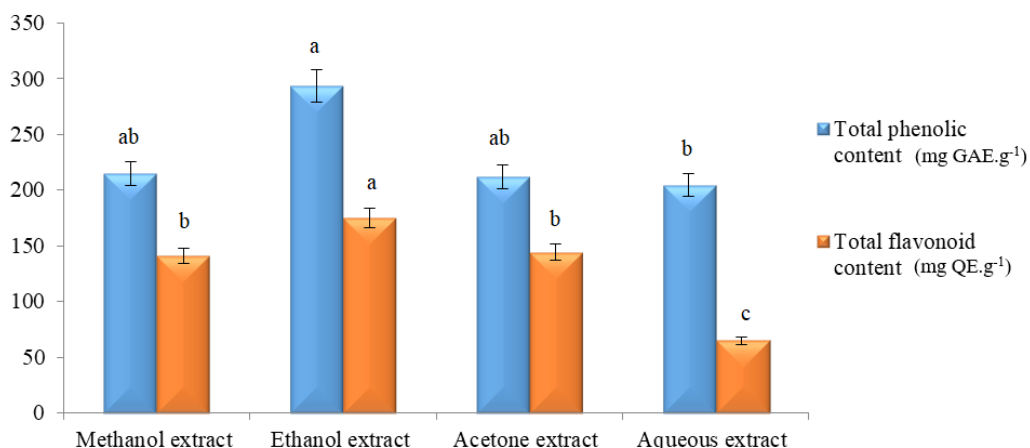
Rutin (quercetin-3-rhamnosyl glucoside) and quercetin were the main flavonoids identified in *S. canadensis* aerial parts extracts. These compounds are the important contributors to the antioxidant, anti-inflammatory, vasodilator, antiatherosclerotic, antihypercholesterolemic, anti-obesity, and angioprotective potential of plant extracts (**Yang, Guo and Yuan, 2008; D'Andrea, 2015**). Chlorogenic acid (5-O-caffeoylquinic acid) is a plant secondary metabolite widely distributed in coffee, tea, many fruits, vegetables, and herbs. Recent studies on this phenolic compound have demonstrated multiple biological properties, such as antioxidant, anti-inflammatory, antibacterial, antiviral, cardioprotective, hepatoprotective, neuroprotective, antihypertensive, anti-obesity, antidiabetic, antiapoptotic. Additionally, many *in vivo* studies and clinical trials have been done concerning the health benefits of chlorogenic acid as a nutraceutical agent for the prevention and treatment of metabolic syndrome and associated diseases (**Naveed et al., 2018**).

Due to their multiple biological activities, the phenolic compounds from some *Solidago* species have been formerly examined. *S. gigantea* methanol extracts contain the chlorogenic acid (0.1 mg.g<sup>-1</sup> DW plant material) and the quercitrin (4.5 mg.g<sup>-1</sup> DW plant material) (**Woźniak et al., 2018**), ethanol extracts of *S. graminifolia* contain the chlorogenic acid (997.88 mg.100g<sup>-1</sup> extract), quercitrin (431.59 mg.100g<sup>-1</sup>) and hyperoside (253.19 mg.100g<sup>-1</sup>) (**Toiu et al., 2019**). Ethanol extract of leaves of *S. microglossa* contains the quercetrin (51.9 mg.g<sup>-1</sup>), gallic acid (24.1 mg.g<sup>-1</sup>), rutin (3.82 mg.g<sup>-1</sup>), and quercetin (2.57 mg.g<sup>-1</sup>) (**Sabir et al., 2012**). The hydroalcoholic extract of *S. canadensis* found rutin (8.93% w/w) as the main compound, as well as caffeic acid derivatives (**Apáti et al., 2006**).

Because the most significant differences of *S. canadensis* in different extracts were determined by rutin, quercetin, quercitrin, and chlorogenic acids establishing the metabolic profile of polyphenols that may contribute to ensuring plants material of high quality and safety for more efficient phytopharmaceuticals.

Considering that plant extracts are complex mixtures of numerous natural compounds with synergic or additive effects, the investigation on new sources of chlorogenic acid could reveal possible applications in medicine and pharmacy.

Plants are a potential source of natural antioxidants, which act as reducing agents, hydrogen donors, oxidants, and free radical scavengers. The antioxidant activity evaluation was carried out by DPPH and RP radical scavenging activity assays. These frequently used methods are rapid and valuable for the evaluation and quantification of the free radical scavenging activity of natural compounds from plant extracts. As shown in Table 2, there were wide variations in the DPPH and RP of the leaves and inflorescences *S. canadensis*, ranging from 5.34 to 19.87 mg TE.g<sup>-1</sup>, and from 66.78 to 258.22 mg TE.g<sup>-1</sup>, respectively.



**Figure 2** Total phenolic and flavonoid contents (mg.g<sup>-1</sup> extract) in *Solidago canadensis* extracts (means in columns followed by different letters are different at  $p < 0.05$ ; each value represents the mean of three independent experiments ( $\pm$ SD)).

**Table 1** Content of phenolics and flavonoids (mg.g<sup>-1</sup> extract) in different extracts of aerial parts of *Solidago canadensis*; LOQ variation for antioxidant compounds.

Compound	LOQ, $\mu\text{g.mL}^{-1}$	Methanol extract	Ethanol extract	Acetone extract	Water extract
Galic acid	<0.1	3.02 $\pm$ 0.41	<0.1	<0.1	28.05 $\pm$ 1.04
Protocatechuic acid	<0.1	19.50 $\pm$ 0.74	26.33 $\pm$ 0.59	43.50 $\pm$ 1.86	71.84 $\pm$ 2.05
Chlorogenic acid	<0.1	146.05 $\pm$ 5.05	147.00 $\pm$ 4.85	134.95 $\pm$ 4.50	834.50 $\pm$ 9.75
Epicatechin	<0.1	45.50 $\pm$ 2.05	32.00 $\pm$ 1.95	20.15 $\pm$ 1.78	11.99 $\pm$ 0.95
Catechin	<0.1	12.01 $\pm$ 0.78	18.04 $\pm$ 0.82	<0.1	<0.1
Caffeic acid	<0.2	<0.2	<0.2	65.95 $\pm$ 2.05	<0.2
Vanillic acid	<0.5	<0.5	<0.5	54.49 $\pm$ 2.09	154.08 $\pm$ 5.11
Syringic acid	<0.1	26.45 $\pm$ 1.01	<0.1	78.09 $\pm$ 2.85	<0.1
Coumaric acid	<0.1	17.99 $\pm$ 0.74	19.00 $\pm$ 1.05	23.50 $\pm$ 1.25	72.30 $\pm$ 2.18
t-Ferulic acid	<0.2	55.02 $\pm$ 1.98	48.25 $\pm$ 1.08	32.85 $\pm$ 1.84	25.38 $\pm$ 0.75
Hydroxy flavanon	<0.2	25.41 $\pm$ 0.55	37.60 $\pm$ 0.99	27.84 $\pm$ 0.65	<0.2
Rutin	<0.1	200.45 $\pm$ 5.95	211.20 $\pm$ 6.50	211.14 $\pm$ 5.80	44.77 $\pm$ 0.67
Quercitrin	<0.2	112.85 $\pm$ 4.05	102.50 $\pm$ 3.95	125.70 $\pm$ 4.20	35.84 $\pm$ 0.55
Quercetin	<0.2	121.74 $\pm$ 4.10	122.08 $\pm$ 5.05	122.41 $\pm$ 4.80	68.95 $\pm$ 0.93
Hesperidin	<0.1	97.65 $\pm$ 2.07	51.87 $\pm$ 1.85	58.45 $\pm$ 1.37	11.55 $\pm$ 0.28
Kaemferol	<0.2	<0.2	45.00 $\pm$ 1.24	28.05 $\pm$ 0.95	58.72 $\pm$ 1.05

Note: LOQ: limit of quantification. Values are expressed as the mean  $\pm$ SD (n = 3).

**Table 2** Free radical scavenging activity by DPPH and RP assays of *Solidago canadensis* L. extracts.

Extracts	DPPH (mg TE.g <sup>-1</sup> )		RP (mg TE.g <sup>-1</sup> )	
	leaves	inflorescences	leaves	inflorescences
Methanol extract	15.12 $\pm$ 0.47 <sup>ab</sup>	16.27 $\pm$ 0.51 <sup>b</sup>	190.05 $\pm$ 2.18 <sup>b</sup>	225.80 $\pm$ 3.07 <sup>a</sup>
Ethanol extract	10.30 $\pm$ 0.35 <sup>b</sup>	12.14 $\pm$ 0.40 <sup>c</sup>	128.95 $\pm$ 2.75 <sup>c</sup>	124.74 $\pm$ 2.81 <sup>b</sup>
Acetone extract	17.16 $\pm$ 0.53 <sup>a</sup>	19.87 $\pm$ 0.42 <sup>a</sup>	214.70 $\pm$ 3.01 <sup>a</sup>	228.22 $\pm$ 2.54 <sup>a</sup>
Aqueous extract	5.34 $\pm$ 0.28 <sup>c</sup>	6.09 $\pm$ 0.21 <sup>d</sup>	66.78 $\pm$ 1.51 <sup>d</sup>	97.15 $\pm$ 1.75 <sup>c</sup>

Note: Values are expressed as the mean  $\pm$ SD (n = 3). Means in columns followed by different letters are different at  $p < 0.05$ .

The DPPH radical is a stable lipophilic free radical and is a measure of non-enzymatic antioxidant activity of plant extracts (Deng et al., 2015). The higher the DPPH values, the higher the antioxidant activity. The DPPH values in the inflorescences were higher than in the leaves under all kinds of extraction. We found that the antioxidant activity of investigated extracts of leaves *S. canadensis* was in the range from 5.34 to 17.16 mg TE.g<sup>-1</sup> (Table 2). For

inflorescence extracts of *S. canadensis*, this parameter ranged from 6.09 to 19.87 mg TE.g<sup>-1</sup>. The AE extracts of inflorescences and leaves had the highest DPPH radical scavenging activity, followed by the ME extracts; the poorest antioxidant activity was found in the WE extracts. The scavenging effect on the DPPH radical in the leaves and inflorescence extracts decreased in the order: AE > ME > EE > WE.

The RP assay is based on the redox reaction of the reduction of Mo (VI) to Mo (V) ion in the presence of a reducer and is expressed as absorbance value at 700 nm, in which a greater absorbance corresponded to a higher reducing activity. All kind's extracts of inflorescences of *S. canadensis* exhibited more significant antioxidant activity compared with the leaves extracts ( $p < 0.05$ ). The AE inflorescence extracts had the highest reducing power, followed by the ME extracts; the WE extracts exhibited the smallest RP. The RP ascended in the order: EE < WE < ME  $\approx$  AE for the inflorescences extracts and WE < EE < ME < AE for the leaf extracts.

The results of our research indicate that the antioxidant potential may be due to the presence of phenolic acids and flavonoids, which were found in significant amounts in *S. canadensis* all kinds of extracts. Each phenolic compound reacts differently and its antioxidant effect is closely related to the structure, for example, rutin and quercetin contain vicinyl dihydroxyl groups. The presence of vicinyl dihydroxyl groups was shown to affect the ability of phenols to inhibit iron and copper-catalyzed production of initiating radical species (Yang, Guo and Yuan, 2008). Thus, it is likely that metal chelation and/or free radical scavenging properties contribute to the inhibition of glucose autoxidation by rutin and quercetin metabolites containing vicinyl dihydroxyl groups. While chlorogenic acid inhibits lipid oxidation in oil-in-water emulsion through a complex effect, metal-chelating in the hydrophilic phase and free radical scavenging in the hydrophobic phase (Santana-Gálvez, Cisneros-Zevallos and Jacobo-Velázquez, 2017).

## CONCLUSION

*S. canadensis* in Slovakia was a poorly studied species of the genus *Solidago*, which includes medicinal plants known for their diuretic, anti-inflammatory, antimicrobial, antioxidant, antispasmodic properties. Saponins, flavonoids, salicylic acid derivatives, tannins, etc. contained in the plant material are active substances of medicinal products. We have studied the content of phenolic compounds in various extracts and the best results were obtained for ethanol extract. Some phenolic compounds were identified by HPLC in methanol, ethanol, acetone, and aqueous extracts of the aerial parts of *S. canadensis* with significant amounts of rutin, quercetin, quercitrin, and chlorogenic acid. The high total phenolic compounds and flavonoids content can be used as a valuable source of phytochemicals in herbal remedies. Our study of *Solidago canadensis*, growing in Slovakia, shows the promising potential that can be evaluated as an effective antioxidant and antimicrobial agent in effective herbal medicines.

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