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Heavy metal contents in *Veronica* species and soil from mountainous areas in Serbia

JELENA ŽIVKOVIĆ[1]*, SLAVICA RAŽIĆ[2#], JELENA ARSENIJEVIĆ[3]
and ZORAN MAKSIMOVIĆ[3]

[1]Institute for Medicinal Plant Research “Dr. Josif Pančić”, Belgrade, [2]Department of Analytical Chemistry, School of Pharmacy, University of Belgrade, Belgrade and [3]Department of Pharmacognosy, School of Pharmacy, University of Belgrade, Belgrade, Serbia

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Abstract: This paper describes the relationships between the concentrations of selected trace elements in soil and their bioaccumulation in the aerial parts of three *Veronica* species (Plantaginaceae). Plant and soil samples were collected from three mountainous areas in Serbia, prepared by microwave-assisted acid digestion and analyzed by flame and flameless atomic absorption spectrometry. The total concentrations of Cu, Zn, Mn, Fe and Cr in the soil varied from 12.38 to 47.77, 62.78 to 138.00, 517.58 to 1675.78, 13574.22 to 35920.00 and 36.18 to 115.15 mg kg^{-1}, respectively, while those in the plants ranged from 6.04 to 12.8, 27.66 to 58.01, 25.38 to 89.25, 35.53 to 563.26 and 0.44 to 18.96 mg kg^{-1}, respectively. There were no significant differences in heavy metal concentrations between the tested *Veronica* species from the same location, indicating that their heavy metal uptake pattern was not species specific. In the case of Mn, despite its wide variation in the soil, the concentrations in the plant samples were uniform, which suggests the potential ability of the tested species to control Mn uptake and/or its translocation to the upper plant parts. Additionally, the lowest concentrations of Cu were obtained in plant samples collected from soil with the highest Fe concentrations, indicating that Cu availability to plants might be reduced due to high Fe contents in soil solution.

Keywords: atomic absorption spectroscopy; correlation analysis; trace elements; soil; plants.

INTRODUCTION

Environmental pollution and constant exposure to heavy metals are considered to be among the most important threats to human health today. The in-

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* Corresponding author. E-mail: jelenazivkovic1@yahoo.com
\# Serbian Chemical Society member.
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creased and still growing levels of heavy metals in the environment are a consequence of their utilization in various industrial activities.[1] As "miners" of the Earth's crust, plants absorb numerous elements from the soil. Some of them are referred to as essentials because they are required by plants to complete their life cycle. Certain heavy metals, such as iron, manganese, copper and zinc, are known as micronutritients because they are required by plants in minute quantities, while other have proven to have a stimulatory effect on plants growth, but are not considered essential. Moreover, plants also absorb elements, such as chromium, which have no known biological function and are even known to be toxic at low concentrations.[2] Due to their non-biodegradable nature, heavy metals tend to accumulate in biological compartments and move through the food chains. Although some of them are micronutrients, in high concentrations they are toxic to various life forms.[1]

Inorganic trace pollutants exhibit their influence in many different ways. Being active in diverse metabolic processes, they enter the plant tissues and could be stored as inactive compounds in cells and on the surface of cell membranes. Apart from the specific mechanism of the target plant tissue, it was reported that trace elements, even in higher concentrations, may affect the chemical composition of plants without causing readily visible injury.[3] Accordingly, they are particularly responsible for the medicinal and nutritional properties of foods and medicinal plant products, as well as their toxicity.

The main objective of this study was, therefore, to determine the levels of several heavy metals (Cu, Zn, Mn, Fe and Cr) in three *Veronica* species (Plantaginaceae) growing wild in Serbia (*Veronica jacquinii* Baumg., *Veronica teucrium* L. and *Veronica urticifolia* Jacq.). Additionally, in order to explore the uptake patterns of specific metals in the plants, corresponding soil samples were analyzed.

The major external source of heavy metals in soils is usually pollution caused by anthropogenic activities, such as metal mining, smelting and processing or the use of fossil fuels. Additionally, diffuse pollution by wet and dry deposition has resulted in the long-term accumulation of heavy metals in many parts of the world. On the other hand, some high metal concentrations in soils are of natural origin, resulting from weathering of the underlying bedrock.[4] Since soils on different types of parent rock contain different levels of elements, especially heavy metals,[5] three mountainous areas with different geological settings were selected as the target sites. The first investigation site is located in the northern part of Serbia where acidic soils derived on albite-muscovite schist and granite gneiss are prevalent. The reverse process (alkalization) occurs in the second investigated site located on Mt. Stol, where the bedrock consists primarily of limestone and the third investigation site is located on Mt. Goč, one of the serpentine sites in central Serbia.

Veronica species were selected for the present investigation having in mind their widespread use in a traditional medicine worldwide, mostly as diuretics, for their wound-healing properties, in medical treatment of influenza and other respiratory diseases, as well as expectorants and antiscorbutic agents.[6] Extracts obtained from the above-ground parts of various *Veronica* species are used as folk remedies for the treatment of various inflammatory ailments, including rheumatism.[7] In addition, the stems and leaves of some *Veronica* species are edible, either raw or cooked.[8]

Numerous studies on the identification of secondary metabolites in *Veronica* species have already been published, with iridoid glucosides, phenylethanoid and flavonoid glycosides being mainly reported,[9–12] but only a few refer to the determination of inorganic components,[13,14] or relationship between the inorganic content of a herb and corresponding soil.[15,16] Zurayk *et al*. evaluated the role of some *Veronica* hydrophytes (*V. beccabunga*, *V. lysimachioides*, *V. anagalloides*) in the aquatic phytoremediation of Cr.[17] In addition, Abu Ziada *et al*. determined that *V. anagalis–aquatica* had the highest value of ferric ion content, among five common macrohydrophytes.[14] Wang *et al*. showed that *V. didyma* exhibited a high accumulation ability for Zn.[15] While previous investigations were primarily realized with *Veronica* species that were grown on polluted areas, plant samples from relatively clean environments were selected for this study.

This work, to the best of our knowledge, is the first report of the metal accumulation ability of *V. jacquinii* Baumg., *V. teucrium* L. and *V. urticifolia* Jacq. This paper gives new information about the content of certain elements, their correlations in these species and also in conjunction with their concentrations in the soil.

EXPERIMENTAL

All chemicals were of analytical reagent grade. For the preparation of all solutions, double distilled water was used. Stock solutions of Cu, Mn, Zn, Fe and Cr salts (1 g L^{-1}) were purchased from Merck (Germany). Working solutions were obtained by suitable dilution of the corresponding stock solution with 2.5 % HNO_3. Nitric acid (65 %, v/v) was provided by Merck (Germany), a solution of H_2O_2 (30 %, v/v) and KCl from Zorka Pharma Šabac (Serbia).

Acidity of soil samples was measured using a pHM 240 Radiometer analytical pH-meter. For the microwave-assisted acid digestion of the plants and soil samples, a closed-vessel, high-pressure microwave digester-CEM MDS-2000 was used.

The determination of Cu, Zn, Mn, and Fe was performed with a Perkin–Elmer model 5000 atomic absorption spectrophotometer under optimized measurement conditions using suitable hollow cathode lamps. The signals were measured with background correction (deuterium lamp) at the optimal flame (A–A_c) height.[18] The determination of Cr was performed using a Perkin–Elmer model 5000 atomic absorption spectrophotometer with a graphite furnace HGA 400 Automatic Burner Control, with pyrolytic graphite tubes. The optimal temperatures were set as follows: drying, pyrolysis, atomisation and cleaning – 110, 1650, 2500 and 2650 °C, respectively.[19]

The plant materials (aerial flowering parts of three *Veronica* species; eleven samples) were collected in June 2008 and 2009 from mountainous areas in Serbia: Goč in central Serbia, Vršačke planine in southern Banat and Stol in eastern Serbia (Table I). Bulk soil samples were collected at the same locations from areas with the greatest vegetation cover. In the case of plant samples 2, 3, 4, 10 and 11, soil was collected from the location approximately 20–30 cm from the plant root, and for the remaining plant samples, from within 10 m (depth of 0–15 cm) of where a particular plant was growing.

TABLE I. A list of the plant species and sampling locations

Location	Species	Description of sampling site	Coordinates	Bedrock (Marković)[40]
Mt. Goč	*V. urticifolia*	Meadow	N 43° 33’ 39.2’’ E 20° 44’ 24.8’’ H 870 m	Serpentinite
Mt. Goč	*V. urticifolia*	Sawmill	N 43° 33’ 29.5’’ E 20° 44’ 53.3’’ H 840 m	Serpentinite
Mt. Goč	*V. urticifolia*	Ball park	N 43° 33’ 28.6’’ E 20° 44’ 53.3’’ H 858 m	Serpentinite
Mt. Goč	*V. urticifolia*	Meadow	N 43° 33’ 32.8’’ E 20° 45’ 04.4’’ H 844 m	Serpentinite
Mt. Goč	*V. jacquinii*	Meadow	N 43° 33’ 39.2’’ E 20° 44’ 24.8’’ H 870 m	Serpentinite
Mt. Vršačke planine	*V. teucrium*	Hillside road (light traffic)	N 45° 07’ 11.7’’ E 21° 19’ 47.1’’ H 293 m	Amygdaloidal and Augen gneiss
Mt. Vršačke planine	*V. teucrium*	Forest path	N 45° 07’ 10.5’’ E 21° 19’ 57.6’’ H 291 m	Amygdaloidal and Augen gneiss
Mt. Vršačke planine	*V. teucrium*	Forest path	N 45° 07’ 18.5’’ E 21° 21’ 10.0’’ H 418 m	Amygdaloidal and Augen gneiss
Mt. Vršačke planine	*V. jacquinii*	Mountain lodge	N 45° 07’ 37.7’’ E 21° 20’ 31.9’’ H 357 m	Amygdaloidal and Augen gneiss
Mt. Stol	*V. jacquinii*	Forest	N 44° 10’ 08.3’’ E 22° 07’ 41.8’’ H 831 m	Limestone
Mt. Stol	*V. teucrium*	Mountain lodge	N 44° 10’ 19.6’’ E 22° 07’ 30.0’’ H 855 m	Limestone

Both plant and soil samples were air-dried at room temperature and ground. Prior to the microwave-assisted digestion procedure, acidity measurements were performed on the soil samples. The pH values of the soil samples were measured in the supernatant of suspensions.

For the determination of real acidity, soil samples and distilled water were mixed in the ratio of 1:2.5. For the determination of the potential acidity, the same ratio was applied, but with addition of 1 M KCl solution, in order to make available the H^+ that were adsorbed on the colloidal soil particles.

The plant and soil samples were then subjected to microwave-assisted acid digestion according to the procedure presented elsewhere.[19] Each sample (about 0.5 g dry weight) was digested with 2 mL hydrogen peroxide (30 % v/v) and 7 ml nitric acid in a microwave oven. After filtration, the obtained solutions were transferred into 25 ml volumetric flasks and diluted to the volume with redistilled water. One sample blank containing the same amounts of acid and oxidant was processed along with each set of samples. Wavelengths and method detection limits used for measuring (both in flame and graphite furnace atomic absorption spectroscopy) were as follows: 324.7 nm/0.05 mg L^{-1} (Cu), 213.9 nm/0.05 mg L^{-1} (Zn), 279.5 nm/ 0.05 mg L^{-1} (Mn), 248.3 nm/0.05 ml L^{-1} (Fe) and 357.6 nm/0.005 mg L^{-1} (Cr).

Accuracy of the methods applied for determination of Cr, Mn, Fe, Zn and Cu after microwave-assisted acid digestion of plants and soil samples was checked by analysis of standard reference materials (NIST SRM 1547–Peach Leaves and NIST SRM 2711–Montana II Soil) and good recoveries (89.0–115.3 %) were obtained. Concentrations of different elements in these samples were determined by external calibration by using corresponding calibration curves. The calculations of the standard deviations as well as correlation and regression analysis were performed using the statistical functions of Microsoft Excel, MS Office 2007.

RESULTS AND DISCUSSION

The concentrations of Zn, Cu, Mn, Fe and Cr were measured in samples of the aerial parts of three *Veronica* species growing on mountainous regions in Serbia. As heavy metal concentrations in plants depend mainly on their concentrations in the soil in which they grew or were cultivated,[20] the measurements were also performed for the corresponding soil samples. The results of the determinations of heavy metals in the analyzed plant and soil samples are summarized in Table II. Bearing in mind the diverse chemical properties of the various elements, each of them will be discussed in relation to its significance in terms of their essentiality and toxicity.

Analysis of heavy metal contents in Veronica *species*

Chromium is a toxic, non-essential element for plants; hence, there is no specific mechanism for its uptake. A possible pathway could involve the carriers used for the uptake of the metals essential for plant metabolism.[21] According to Pawlisz,[22] the regular Cr content in plants usually ranges from 0.006 to 18 mg kg^{-1}. According to the present findings, the Cr content in the investigated plant samples varied between 0.44 and 18.96 mg kg^{-1}. Samples from Mt. Vršačke planine contained the lowest chromium levels (0.44–0.59 mg kg^{-1}) in the investigated set, while the highest value was obtained for plant sample 3 (Mt. Goč). Zurayk *et al*. showed that *V. beccabunga* L., *V. lysimachioides* L. and *V. anagalloides* L. may be used as bio-indicators of Cr pollution and found that Cr was predominantly accumulated in the roots.[17] The translocation of chromium from roots to shoots is extremely limited and its accumulation by roots is 100-fold higher than by shoots, regardless of the investigated species. According to Chaney *et al*. any plant species that accumulates Cr in shoots to levels higher than 5 mg kg^{-1} is of interest as a possible hyperaccumulator.[23] From the results of the present investigation, the same could be concluded for species *V. urticifolia* and *V. jacquinii* when grown on serpentinite soil.

TABLE II. Metal content measured in the plant and soil samples after microwave-assisted acid digestion (expressed in mg kg^{-1} of dry weight)

Sample	Cr		Zn		Cu		Fe		Mn	
	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil
1	3.55	111.33	46.69	88.87	8.40	24.41	102.73	13574.20	49.5	517.58
2	5.18	115.15	34.53	105.15	11.17	21.91	182.82	18226.40	30.47	665.97
3	18.96	97.13	31.41	91.06	10.83	31.36	563.26	14164.30	43.33	536.22
4	2.48	95.74	33.04	94.98	10.10	30.40	100.95	17667.20	38.55	750.38
5	7.43	111.33	55.76	88.87	10.33	24.41	175.55	13574.20	27.88	517.58
6	0.59	54.19	31.66	112.43	6.64	29.53	158.29	33580.00	34.21	803.53
7	0.53	48.86	27.66	63.29	7.17	12.38	143.44	26560.00	32.27	927.37
8	0.44	48.93	58.01	62.78	6.69	14.63	98.18	22100.00	89.25	1675.78
9	0.48	65.86	31.61	125.87	6.04	22.97	97.62	35920.00	33.00	980.20
10	1.62	53.08	39.59	138.00	12.18	47.77	35.53	20169.90	25.38	923.57
11	3.84	36.18	35.45	78.84	12.80	29.05	118.16	15435.70	36.43	639.00
Min	0.44	36.18	27.66	62.78	6.04	12.38	35.53	13574.22	25.38	517.58
Max	18.96	115.15	58.01	138.00	12.80	47.77	563.26	35920.00	89.25	1675.78
x_{sr}	4.10	76.16	38.67	95.47	9.30	26.26	161.50	20997.44	40.02	812.47
SD	5.420	30.040	10.312	23.668	2.407	9.427	139.770	7876.856	17.707	332.371
Max/Min	43.09	3.18	2.10	2.20	2.12	3.86	15.85	2.65	3.52	3.24

Manganese ions activate numerous enzymes in plant cells. The most important role of this element in green plants is its involvement in the process of decomposition of water molecules with the release of oxygen.[24] To fulfil its metabolic functions, Mn is only necessary at low concentration (20 mg kg^{-1} dry mass).[25] In the studied plant samples, the amount of Mn was relatively uniform (from 25.38 to 49.5 mg kg^{-1}), with the exception of sample 8 (89.25 mg kg^{-1}), where soil was also loaded with this element. The obtained values are close to those found by Mezyk and Wieckowski, when the Mn content in *V. officinalis* was 52.3 mg kg^{-1}.[13] The uniformity of Mn concentrations in plant samples despite the wide range of Mn concentrations in soil could be explained by an inner mechanisms of the tested *Veronica* species to control/prevent Mn uptake into the roots and/or avoid Mn translocation and accumulation into the upper plant parts. These mechanisms are controlled by their request for micronutrients and their capacity to absorb and eliminate toxic elements.

Zinc is important as a component of enzymes for protein synthesis and energy production, as well for maintaining the structural integrity of biological membranes.[26] It is not highly phytotoxic and the toxicity limits (300 to 400 mg kg^{-1}) depend on the plant species and growth stage.[3] For medicinal plants, WHO limits have not yet been established for Zn. According to Allaway,[20] the range of this element in agricultural products should be between 15 and 200 ppm. According to the present findings, the values of the Zn concentration in all plant species at the studied locations ranged from 27.66 to 58.01 mg kg^{-1}.

Copper is essential for photosynthesis and mitochondrial respiration, carbon and nitrogen metabolism, oxidative stress protection and is required for cell wall synthesis.[26] The content of Cu in plant samples varied between 6.04 and 12.8 mg kg^{-1}, depending on the location where the samples were collected. Medium values of 10.17, 6.64 and 12.49 mg kg^{-1} were obtained in the samples from Mt. Goč, Mt. Vršačke planine and Mt. Stol, respectively. The lowest concentrations of copper were obtained from Mt. Vršačke planine where the highest iron concentrations were recorded. These results are in accordance with literature data that copper availability to plants might be reduced due to high iron contents in the soil solution.[27] In well-aerated soil, Fe occurs mostly in the form of Fe^{3+} oxides or hydroxides,[28] which are known as efficient sorbents for inorganic cations, such as Cu.[29] According to Allaway,[20] the range of Cu in agricultural products should be between 4 to 15 ppm.

Iron is one of the key elements for normal enzyme functions, especially those involved in redox processes, such as synthesis of the porphyrin (chlorophyll and haeme biosynthesis), reduction of nitrite and sulphate, and N_2-fixation (as part of leghemoglobin).[30] The iron content in the investigated *Veronica* species ranged from 35.53 to 563.26 mg kg^{-1}, with the highest concentrations being recorded in the samples from Mt. Goč.

The ratio of Fe/Mn in vegetal tissue should be between 1.5 and 2.5 since both elements are involved in metabolic processes; hence, they must be present in suitable proportions for adequate plant growth.[3] In the present study for most of the tested plant samples (with the exception of samples 1 and 10), this ratio was not within the expected range.

Analysis of heavy metal contents in soil

The heavy metal content of soil is dependent on both natural and anthropogenic sources in the local ecosystems. While natural forms are usually found in relatively low concentrations, the number and intensity of anthropogenic sources have increased the local environmental heavy metal concentrations in recent decades.[31]

The acidity of the soil indirectly affects the availability and toxicity of heavy metals, causing a minimal or a maximal effect depending on the pH range.[32] Their mobility in soil is generally low, especially when the soil is more alkaline.[33] The obtained pH values for the real and potential acidity of the analyzed soils ranged from 5.24 to 7.43 and from 4.09 to 7.09, respectively (Table III). With the exception of sample 4, the soil samples from Mt. Vršačke planine had slightly lower real acidity values compared to the other samples. The average pH values were 6.62, 5.91 and 6.97 for Mt. Goč, Mt. Vršačke planine and Mt. Stol, respectively. The latter is situated in the Carpathian part of eastern Serbia, in the vicinity of the town of Bor. The processing of ore in the Copper Mining and Smelting Complex Bor causes massive air contamination by sulphur dioxide. The high concentrations of this air pollutant lead to the formation of acid rain. The effect of acid rain on the environment depends greatly on the ability of soils to neutralize the acid. Alkaline or basic soils, such as those rich in limestone, calcium carbonate, can neutralize the acid directly. This may be the explanation for the slightly higher pH values of the soil samples from Mt. Stol having underlying limestone.

TABLE III. Acidity of the soil samples

Soil sample	Location	pH	
		Real acidity	Potential acidity
S1	Mt. Goč	6.77	5.44
S2	Mt. Goč	6.39	5.28
S3	Mt. Goč	7.43	7.09
S4	Mt. Goč	5.87	4.74
S5	Mt. Vršačke planine	6.09	4.87
S6	Mt. Vršačke planine	6.14	5.43
S7	Mt. Vršačke planine	6.18	5.41
S8	Mt. Vršačke planine	5.24	4.09
S9	Mt. Stol	7.18	6.45
S10	Mt. Stol	6.76	5.80

In the investigated soil samples, the Cr concentrations ranged from 36.18 to 115.15 mg kg^{-1} and the highest were recorded in the samples collected on Mt. Goč (from 95.74 to 115.15 mg kg^{-1}), which is in a good accordance with previous research.[34] This location is one of the serpentinite sites in central Serbia,[35] and high levels of potentially phytotoxic elements (Ni, Cr and Co) is one of the characteristics of this soil type.[36]

In the soil samples, the levels of Cu varied from 12.38 to 47.77 mg kg^{-1}. The elevated copper concentrations in the samples from Mt. Stol in comparison to the others could be explained by potential pollution as a result of industrial emissions from mines (Bor).

The zinc content in the analyzed soils was higher in samples 6 and 9 than in samples 7 and 8 (Mt. Vršačke planine), showing the possible influence of anthropological activities. Location 9 is close to the mountain lodge, while location 6 is near by the main road. Location 7 and 8 are in the forest region and free of any anthropological activities.

According to Adriano,[37] the regular Mn content for most soil types ranges from 500–1000 mg kg^{-1}. The present results for the total Mn content in the soils varied widely, from 517.58 to 1675.78 mg kg^{-1} and were higher at locations from Mt. Vršačke planine.

Iron was the most abundant trace element in the analyzed soil samples, with values over a wide range, from 13574.2 to 35920.0 mg kg^{-1}. The highest concentrations were recorded in soil samples collected from Mt. Vršačke planine (22100 to 35920 mg kg^{-1}). These results are in agreement with earlier findings that gneiss soils contain high amounts of iron.[38]

For the potentially hazardous elements (Cu, Zn and Cr), the bioconcentration factor (*BCF*), also known as the plant uptake factor, was calculated as the ratio of a particular element in plant to its concentration in the soil (Table IV).[19] With the exception of the *BCF* value for Cr in sample 3, which was close to the allowed limit, all the calculated *BCF* values were lower than the maximum value recommended by the Idaho National Engineering and Environmental Laboratory (Cu = = 0.80, Zn = 1.50 and Cr = 0.19), suggesting the absence of significant pollution.[39]

TABLE IV. Calculated *BCF* values for toxic elements Cu, Cr and Zn

Sample	Cu	Cr	Zn
1	0.34	0.03	0.52
2	0.51	0.04	0.33
3	0.34	0.19	0.35
4	0.33	0.03	0.35
5	0.42	0.07	0.63
6	0.22	0.01	0.23
7	0.58	0.01	0.44
8	0.46	0.01	0.92
9	0.26	0.01	0.25
10	0.25	0.03	0.29
11	0.44	0.16	0.45

Correlation analysis

Correlation analysis has been used to establish relationships between heavy metal concentrations in tested plant and soil samples and several conclusions could be extracted from the obtained results (Table V). No direct correlation was identified between the content of the analyzed trace metals in the soil and *Veronica* species, except in the case of the Mn concentrations (r = 0.694, $p <$ < 0.05). The chromium content was in a strong positive correlation to the Fe content in plant samples (r = 0.928, $p < 0.001$). This is in agreement with the synergistic interactions between Cr and Fe already reported in the literature.[3]

Furthermore, a high correlation (r = 0.721, $p < 0.05$) was found between the Cu and Zn contents in the soil samples, indicating that the general contamination sources for these metals were primarily traffic and industrial activities.

TABLE V. Correlation analysis of the concentrations of elements measured in *Veronica* species and soil samples

Sample	Element	Plant					Soil			
		Cu	Fe	Mn	Zn	Cr	Cu	Fe	Mn	Zn
Plant	Fe	0.172	–	–	–	–	–	–	–	–
	Mn	–0.383	–0.001	–	–	–	–	–	–	–
	Zn	–0.028	–0.238	0.558	–	–	–	–	–	–
	Cr	0.442	0.928^{a}	–0.077	–0.060	–	–	–	–	–
Soil	Cu	0.601	0.011	–0.436	–0.154	–0.442	–	–	–	–
	Fe	-0.728^{b}	–0.281	–0.076	–0.397	–0.558	–0.189	–	–	–
	Mn	–0.512	–0.368	0.694^{b}	0.307	–0.519	–0.327	0.448	–	–
	Zn	0.147	–0.158	–0.554	–0.283	–0.085	0.721^{b}	0.328	–0.199	–
	Cr	0.194	0.355	–0.164	0.183	–0.491	–0.022	–0.511	–0.574	0.081

^{a}Significant at $p < 0.001$; ^{b}significant at $p < 0.05$

CONCLUSIONS

This study of heavy metal contents did not show any significant variation between the tested *Veronica* species from the same location, indicating that their heavy metal uptake pattern was not species specific. The results of the study confirmed that *V. urticifolia* and *V. jacquinii* are promising Cr hyperaccumulator plants. Further research needs to be performed to determine the Cr content in different organs of *Veronica* species from serpentine soil, in order to determine the translocation of Cr from the roots to the tops of the plants. The contents of the measured elements in the soil samples were in the expected ranges for the particular biogeochemical backgrounds.

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ИЗВОД

СПОСОБНОСТ АКУМУЛАЦИЈЕ ТЕШКИХ МЕТАЛА *Veronica* ВРСТА СА ПЛАНИНСКИХ ЛОКАЛИТЕТА У СРБИЈИ

ЈЕЛЕНА ЖИВКОВИЋ[1], СЛАВИЦА РАЖИЋ[2], ЈЕЛЕНА АРСЕНИЈЕВИЋ[3] и ЗОРАН МАКСИМОВИЋ[3]

[1]Институт за проучавање лековитог биља ''Др Јосиф Панчић'', Београд, [2]Катедра за аналитичку хемију, Фармацеутски факултет, Универзитет у Београду, Београд и [3]Катедра за фармакогнозију, Фармацеутски факултет, Универзитет у Београду, Београд

У овом раду приказан је однос садржаја одабраних елемената у траговима у земљишту и њихове биоакумулације у надземним деловима три *Veronica* врсте (Plantaginaceae). Биљни и узорци земљишта сакупљени су са три планинска локалитета у Србији, подвргнути су микроталасној дигестији у киселој средини и анализирани применом пламене и електротермалне атомске апсорпционе спектроскопије. Укупна концентрација Cu, Zn, Mn, Fe и Cr у узорцима земљишта варира од 12,38 до 47,77, 62,78 до 138,00, 517,58 до 1675,78, 13574,22 до 35920,00 и 36,18 до 115,15 mg kg^{-1}, док се у биљним узорцима креће у опсегу од 6,04 до 12,8, 27,66 до 58,01, 25,38 до 89,25, 35,53 до 563,26 и 0,44 до 18,96 mg kg^{-1}, редом. Нису показане значајне разлике у концентрацији тешких метала између тестираних *Veronica* врста са истих локалитета, што показује да модел усвајања тешких метала није карактеристика врсте. Упркос великих варирања концентрације Mn у земљишту, концентрација у биљним узорцима је униформна, што указује на потенцијалну могућност тестираних врста да контролишу преузимање Mn или његов транспорт до надземних делова биљке. Најнижа концентрација Cu добијена је у биљним узорцима сакупљеним на земљишту са највећом Fe концентрацијом, сугеришући да је доступност Cu биљкама редукована услед високог садржаја Fe у земљишном раствору.

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