RESEARCH PAPER

FEATURES OF THE FIRST HAZARD CLASS ELEMENTS ACCUMULATION BY PLANTS OF THE *PAEONIA* L. GENUS

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Received: April 13th, 2022 / Accepted: November 11th, 2022 / Published: December 31st, 2022
https://DOI-10.24057/2071-9388-2022-049

ABSTRACT. Heavy metals are generally recognized as primary soil pollutants. The most active pollutants are their mobile forms, which can migrate from a solid state into soil solutions and become absorbed by plants. The aim of this work was to study the features of heavy metal accumulation in the aboveground and underground parts of the *Paeonia* L. genus representatives in the urbanized environment of Ufa. The research considered four species and three varieties of hybrid paeony. The elemental composition of the aboveground and underground parts was analyzed using the method «Determination of As, Pb, Cd, Sn, Cr, Cu, Fe, Mn and Ni in samples of food products and food raw materials by the atomic absorption method with electrothermal atomization». Eight elements were studied for each raw material group and their concentrations were determined in mmol/kg of air-dry raw material. The minimum concentrations of arsenic, chromium, manganese, and iron were observed in the roots; lead, cadmium, and copper – in the leaves; nickel – in the flowers of the studied paeonies. The maximum content of arsenic and chromium was found in leaves; lead, nickel, manganese, and iron – in stems; cadmium and copper – in flowers. The results of the correlation analysis showed that there is a moderate or strong relationship between the concentrations of the studied elements in the considered taxa of paeonies.

KEYWORDS: *Paeonia*, heavy metals, aboveground organs, underground mass, Republic of Bashkortostan.

CITATION: Reut A. A., Denisova S. G. (2023). Features Of The First Hazard Class Elements Accumulation By Plants Of The *Paeonia* L. Genus. Geography, Environment, Sustainability, 1(16), 172-180
https://DOI-10.24057/2071-9388-2022-049

ACKNOWLEDGEMENTS: The work was carried out under the Program of Basic Research of the Praesidium of the Russian Academy of Sciences «Biodiversity of Natural Systems and Plant Resources of Russia: Assessment of the State and Monitoring of Dynamics, Problems of Conservation, Reproduction, Increase and Rational Use» and within the framework of the state assignment of the SUBGI UFRC RAS on the topic No. FMRS-2022-0072.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Currently, a lot of attention all over the world is paid to the protection of the external and internal human environment from the increasing influence of chemicals (in particular, heavy metals and soluble forms of their toxic compounds) of anthropogenic and natural origin (Bashmakov and Lukatkin 2009; Kaloev and Kumsiev 2014). Ufa is the capital of the Republic of Bashkortostan, a city of republican significance, and the administrative center of Ufa district. The environmental conditions in the city are determined not only by natural, but also by man-made factors, the role of which increases every year. Ufa ranks 8th in terms of pollution among major Russian cities and has more than 700 enterprises that operate in the city, polluting the natural environment in various ways. The leading industrial sectors of the city are oil refining, engineering, and chemical industries. The main contribution to emissions from stationary sources is made by the oil refining industry – 48% (Bashneftekhim) and the electric power industry – 21% (Ufa heating networks). Vehicle emissions into the atmosphere, such as sulfur dioxide, nitrogen oxide, and ash elements, also have a great influence on the environment, contributing around 53% to the total emissions in the city. On the other hand, it is known that plants have a positive effect not only on the ecological conditions due to the accumulation of toxic substances, but also serve as a health factor for residents of urbanized environments. Many of them play a phytomeliorative role in the landscaping of many cities in the Altai Territory, Bashkiria, Crimea, the Urals, and the European part of Russia (Sedelnikova and Tsandekova 2021).

With the growth in urbanization, a significant transformation of the natural environment takes place. A common feature of urbanized areas is the contamination of soil with heavy metals, which also have a toxic and mutagenic effect on plants (Davydova and Tagasov 2002; Bityutsky 2005). Heavy metals are particularly important compared to other toxic technogenic elements because they do not undergo biogenic and physicochemical decay processes and thus can concentrate in the fertile soil layer, changing its properties (Titov et al. 2011). As a result, pollutants remain available for absorption by plant roots for a long time, and can subsequently move along the food chain of a biogeocenosis (Sedelnikova and Chankina 2016; Mikhalchuk 2017).

With an increase in the content of metals in the soil, its general biological activity decreases. This has a considerable effect on the growth and development of plants, which can have a different reaction to the excess of metals (Chirkova 2002; Titov et al. 2014). Metals are distributed throughout the plant organs unevenly, as they are primarily accumulated in leaves (Uzakov 2018).

Also, it was found that vegetable crops can accumulate significantly more heavy metals than tubers and root crops, which is particularly important for their cultivation (Ilyinsky 2020; Dinu et al. 2020). Ornamental flower cultures, meanwhile, firmly occupy their ecological niche and are almost never considered from this point of view (Mazhaisky et al. 2016; Elagina et al. 2016). However, representatives of the *Paeonia* L. genus are widely used in the landscaping of cities and towns of the Republic of Bashkortostan and can potentially be used as indicators for assessing the ecological state of the environment.

Therefore, the purpose of this research was to study the features of heavy metal accumulation in the aboveground and underground organs of *Paeonia* L. genus representatives in the urban environment of the city of Ufa.

MATERIALS AND METHODS

The study was conducted at the South-Ural Botanical Garden Institute of Ufa Federal Research Center of the Russian Academy of Sciences (hereinafter referred to as SUBGI UFRC RAS) during the growing seasons of 2018-2021 based on the collection of the laboratory of introduction and breeding of flowering plants (Abramova et al. 2019).

A combined soil sample was taken from the experimental plot during the same period. It consisted of 25 point samples, the sampling depth was 1–25 cm and the mass of the combined sample was 1 kg. These soil samples were later used to determine the content of mobile forms of heavy metals.

The research focused on four species: *Paeonia peregrina* Mill., *P. lactiflora* Pall., *P. lactiflora f. rosea* Pall., and *P. delavayi* Franch. (*Paeoniaceae* family). From P. *lactiflora* Pall., three varieties of paeony, particularly 'Appassionata', 'Mustai Karim', and 'Jeanne d'Arc' (Fig. 1), were introduced and grown at the SUBGI UFRC RAS facilities (Mironova and Reut 2017; Reut and Mironova 2018).

The study of the microelement composition of raw plant material (flowers, stems, leaves, and roots) was carried out at the analytical laboratory of the Research Institute of Agriculture. The phases of the raw material collection are defined by pharmacopoeia based on the dynamics of the accumulation of biologically active compounds. For example, grass should be collected from the regrowth phase to fruiting, flowers – in the phase of mass flowering, and roots – in the phase of death of aboveground organs (Demidenko 2020). For analysis, 10 middle-aged cultivars of

Paeonia delavayi Franch. *Paeonia peregrina* Mill. *P. lactiflora* Pall.

P. lactiflora f. rosea Pall. *P. lactiflora* 'Mustai Karim'

P. lactiflora 'Jeanne d'Arc'

P. lactiflora 'Appassionata'

Fig. 1. Studied *Paeonia* L. Species

each taxon of the generative stage of development in the flowering phase (May–June) were used. The collection of aboveground parts (flowers, leaves, stems) of the studied plants was carried out in the morning. The roots were dug in late September – early October (before the first frosts) and were washed first with regular water, and then with distilled water. For quantitative analysis, the raw material was dried to an air-dry state and then crushed to a particle size passing through a 1 mm sieve (Wang et al. 2016; Fotev et al. 2021).

The elemental composition of the samples was analyzed using the method «Determination of As, Pb, Cd, Sn, Cr, Cu, Fe, Mn and Ni in samples of food products and raw food materials by the atomic absorption method with electrothermal atomization» (Simonova et al. 2020; Reut et al. 2021).

Mathematical data processing was carried out using the general statistical methods implemented in the AgCStat Excel add-in and the AGROS 2.09 statistical and biometrical genetic analysis software package (Gonchar-Zaikin and Chertov 2012; Chekin and Nikiforov 2016; Nesterov et al. 2016; Budko et al. 2018; Zakharov and Mishenkina 2020).

RESULTS

The analysis showed that the content of heavy metals in the studied soil samples does not exceed the established maximum permissible concentrations.

The study of the trace element content in flowers, leaves, stems, and roots was carried out for seven different taxa of paeonies ('Appassionata', 'Mustai Karim', 'Jeanne d'Arc', *P. delavayi, P. lactiflora, P. lactiflora f. rosea, P. peregrina*.) and eight elements. The obtained quantitative estimates of their concentration are given below in mmol/kg of air-dry raw material (Fig. 2–5).

The analysis revealed a relatively high content of copper in all types of raw material and all studied plants with concentrations 4.15–2520.00 times higher compared to other elements. The maximum content of copper was noted in the roots, and the minimum – in the leaves of the plants.

It was also found that the minimum concentrations of arsenic, chromium, manganese, and iron correspond to the roots; lead, cadmium, and copper – to the leaves; nickel – to the flowers of the studied paeonies. The maximum content of arsenic and chromium was found in leaves; lead, nickel,

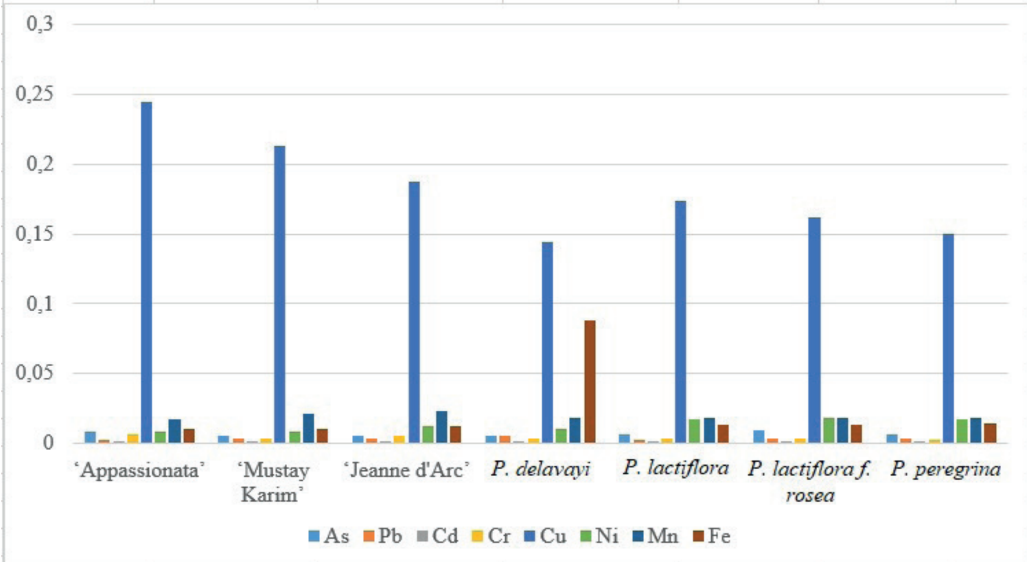

Fig. 2. The content of heavy metals in flowers of the Paeonia genus representatives (mmol/kg)

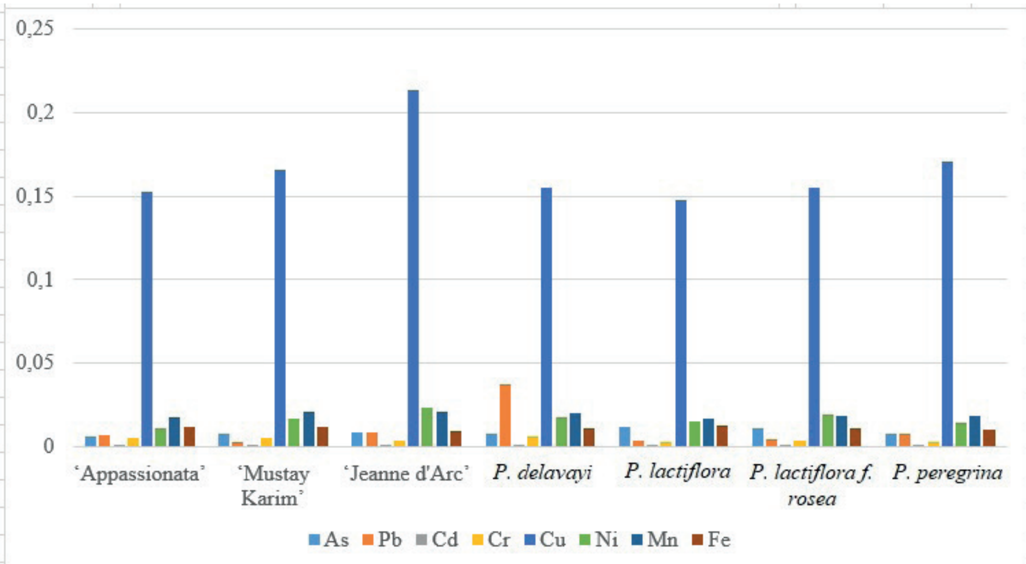

Fig. 3. The content of heavy metals in leaves of the Paeonia genus representatives (mmol/kg)

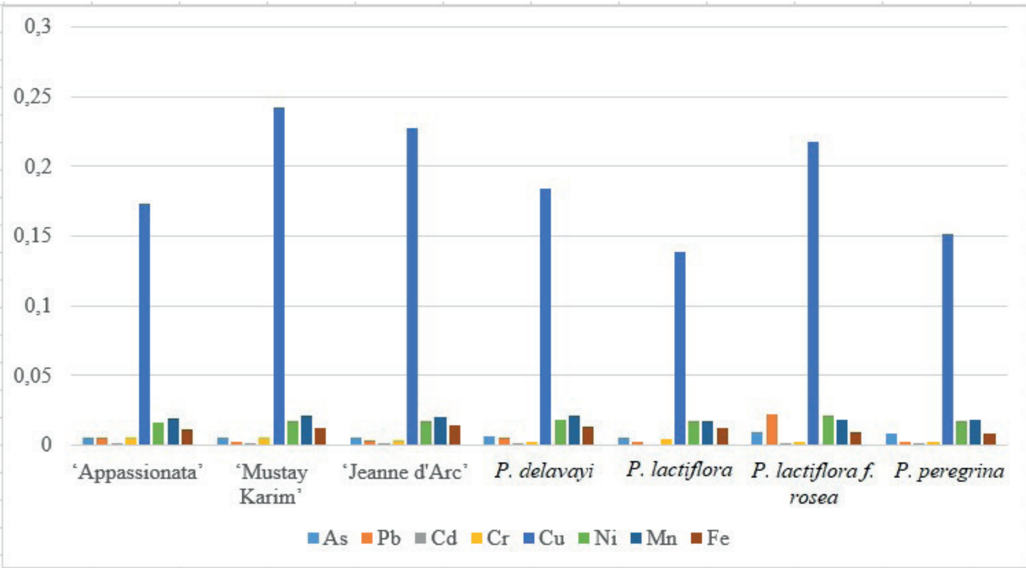

Fig. 4. The content of heavy metals in stems of the Paeonia genus representatives (mmol/kg)

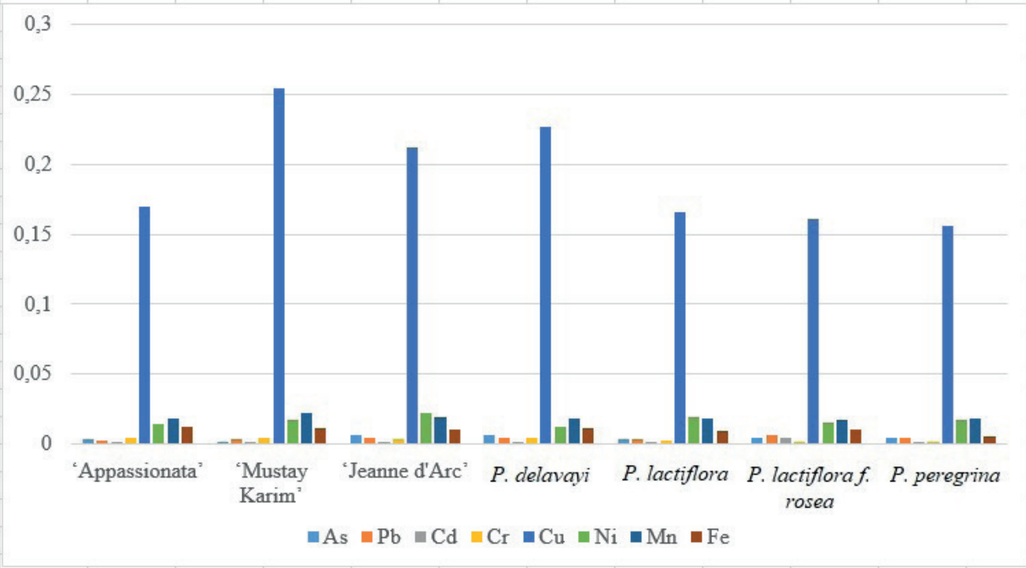

Fig. 5. The content of heavy metals in roots of the Paeonia genus representatives (mmol/kg)

manganese, and iron – in stems; cadmium and copper – in flowers.

For the convenience of the two-way analysis of variance, the concentration values were converted into logarithms. The results of this analysis showed significant differences in the content of heavy metals in different taxa and plant parts. It was revealed that the taxon has the most influence on the content of cadmium, chromium, and manganese, with an influence share of 56.45–70.83%; the second most important factor is the part of the plant, which accounts for 2.37–14.87%; the contribution of the taxon – plant part interaction is 17.11–29.23% (Table 1). The main contribution to the content of arsenic, lead, copper, nickel, and iron is made by the taxon – part of the plant interaction (41.16–68.87%); the share of the first factor accounts for 14.43–44.19%, while the share of the second one is 9.19–33.22% (Table 1).

As a result of the correlation analysis, relationships between the content of the studied elements in different plant parts were revealed (Tables 2–5). It was found that the amount of lead and cadmium in stems, as well as cadmium in flowers is directly dependent on the content of arsenic with a correlation in the range of 0.62–0.74. An inverse relationship between the amount of arsenic and the content of chromium in leaves, lead and manganese in flowers, manganese in roots, and chromium in stems was also revealed with a correlation in the range of 0.49–0.83.

Table 1. Results of the two-way analysis of variance of the elemental composition of paeonies

Element	Sources of variation	SS	Df	ms	Ffact	Share, %
Arsenic (As)	General	34.57	83.00	-	-	-
	Taxon (A)	7.74	6.00	1.29	1605.87	22.39
	Part of the plant (B)	11.48	3.00	3.83	4764.83	33.22
	Interaction (AB)	15.30	18.00	0.85	1057.89	44.26
	Random	0.04	54.00	0.0008	-	-

Lead (Pb)	General	30.67	83.00	-	-	-
	Taxon (A)	9.21	6.00	1.53	5353.04	30.01
	Part of the plant (B)	5.74	3.00	1.91	6678.85	18.72
	Interaction (AB)	15.71	18.00	0.87	3044.60	51.21
	Random	0.02	54.00	0.0003	-	-
Cadmium (Cd)	General	36.95	83.00	-	-	-
	Taxon (A)	21.32	6.00	3.55	51.83	57.71
	Part of the plant (B)	5.49	3.00	1.83	26.71	14.87
	Interaction (AB)	6.32	18.00	0.35	5.12	17.11
	Random	3.70	54.00	0.0686	-	-
Chromium (Cr)	General	10.06	83.00	-	-	-
	Taxon (A)	5.68	6.00	0.95	709.62	56.45
	Part of the plant (B)	1.36	3.00	0.45	339.60	13.51
	Interaction (AB)	2.94	18.00	0.16	122.48	29.23
	Random	0.072	54.00	0.00133	-	-
Copper (Cu)	General	2.68	83.00	-	-	-
	Taxon (A)	1.18	6.00	0.20	668.02	44.19
	Part of the plant (B)	0.25	3.00	0.08	277.82	9.19
	Interaction (AB)	1.23	18.00	0.07	231.78	46.00
	Random	0.016	54.00	0.00030	-	-
Nickel (Ni)	General	5.48	83.00	-	-	-
	Taxon (A)	1.66	6.00	0.28	421.16	30.25
	Part of the plant (B)	1.53	3.00	0.51	777.33	27.92
	Interaction (AB)	2.25	18.00	0.13	191.00	41.16
	Random	0.035	54.00	0.00066	-	-
Manganese (Mn)	General	0.50	83.00	-	-	-
	Taxon (A)	0.35	6.00	0.06	836.37	70.83
	Part of the plant (B)	0.01	3.00	0.00	55.97	2.37
	Interaction (AB)	0.13	18.00	0.01	102.48	26.04
	Random	0.004	54.00	0.00007	-	-
Iron (Fe)	General	2.95	83.00	-	-	-
	Taxon (A)	0.43	6.00	0.07	21.20	14.43
	Part of the plant (B)	0.30	3.00	0.10	30.25	10.30
	Interaction (AB)	2.03	18.00	0.11	33.73	68.87
	Random	0.181	54.00	0.00335	-	-

Table 2. Correlation matrix of the content of elements in flowers of paeony

Indicators	As	Pb	Cd	Cr	Cu	Ni	Mn	Fe
As	1.00							
Pb	-0.49*	1.00						
Cd	0.63**	-0.03	1.00					
Cr	-0.05	-0.26	-0.61**	1.00				
Cu	0.09	-0.48*	-0.41	0.78**	1.00			
Ni	0.32	-0.32	0.50*	-0.63**	-0.66**	1.00		
Mn	-0.65**	0.15	-0.36	0.33	0.16	-0.29	1.00	
Fe	0.21	-0.60**	0.25	-0.34	-0.31	0.84**	0.04	1.00

Note: * – significant at the 5% level; ** – significant at the 1% level; the absence of * indicates that the correlation is not significant

Table 3. Correlation matrix of the content of elements in leaves of paeony

Indicators	As	Pb	Cd	Cr	Cu	Ni	Mn	Fe
As	1.00							
Pb	-0.34	1.00						
Cd	0.38	-0.18	1.00					
Cr	-0.66**	0.65**	-0.02	1.00				
Cu	-0.14	-0.09	-0.14	-0.27	1.00			
Ni	-0.02	-0.03	-0.10	-0.27	0.17	1.00		
Mn	-0.39	0.29	0.08	0.40	0.53*	-0.01	1.00	
Fe	0.30	-0.13	-0.20	0.02	-0.78**	-0.14	-0.47*	1.00

Note: * – significant at the 5% level; ** – significant at the 1% level; the absence of * indicates that the correlation is not significant

Table 4. Correlation matrix of the content of elements in stems of paeony

Indicators	As	Pb	Cd	Cr	Cu	Ni	Mn	Fe
As	1.00							
Pb	0.74**	1.00						
Cd	0.62**	0.77**	1.00					
Cr	-0.83**	-0.60**	-0.32	1.00				
Cu	-0.03	0.27	0.64**	0.12	1.00			
Ni	-0.13	-0.05	-0.04	-0.00	0.26	1.00		
Mn	-0.38	-0.22	0.01	0.23	0.66**	0.13	1.00	
Fe	-0.20	-0.08	-0.20	0.38	-0.08	-0.06	0.10	1.00

Note: * – significant at the 5% level; ** – significant at the 1% level; the absence of * indicates that the correlation is not significant

Table 5. Correlation matrix of the content of elements in roots of paeony

Indicators	As	Pb	Cd	Cr	Cu	Ni	Mn	Fe
As	1.00							
Pb	0.39	1.00						
Cd	0.02	0.48*	1.00					
Cr	-0.26	-0.64**	-0.33	1.00				
Cu	-0.25	-0.17	-0.28	0.61**	1.00			
Ni	0.08	-0.08	-0.13	-0.43*	-0.04	1.00		
Mn	-0.64**	-0.19	-0.07	0.35	0.62**	-0.04	1.00	
Fe	-0.19	-0.27	-0.06	0.80**	0.52*	-0.35	0.26	1.00

Note: * – significant at the 5% level; ** – significant at the 1% level; the absence of * indicates that the correlation is not significant

DISCUSSION

It is known that heavy metals can migrate between different tissues and that their content can also change during the growing period of plants (Nan et al. 2019).

In previous studies, it was found that the highest amounts of arsenic are recorded in the leaves and roots of plants (Meshkinova et al. 2006). In this study, however, the highest concentration of this element was observed in the flowers and stems of P. lactiflora f. rosea.

Lead in natural populations is present in all plants, while its role in metabolism has not been established (Kabata-Pendias and Pendias 1989). The present research showed that the maximum content of lead in most samples corresponds to the leaves, while minimum concentrations are found in different types of raw materials.

According to literature data, the highest concentrations of cadmium in contaminated plants are always found in roots and leaves (Seregin and Ivanov 2001). In this study, the stems, leaves, flowers, and roots of *P. lactiflora* f. rosea were characterized by the high content of this element.

Some plants, mainly from areas near serpentinite or chromite deposits, can accumulate chromium up to 0.3% of their dry weight (Seregin and Kozhevnikova 2006). The highest levels of chromium in this study were found in different parts of plants – flowers, leaves, and stems. The lowest values were observed in the roots of most of the samples.

As a result of this study, a hypothesis can be made that cutting peonies in the autumn before retiring can help to avoid the accumulation of heavy metals in the soil. In addition, according to other researchers, harvesting plants that accumulate heavy metals is a potential method to prevent toxic pollutants from entering the food chain and conserve biodiversity (Parveen et al. 2022).

CONCLUSIONS

During this study, it was found that the content of mobile forms of heavy metals in the soil of the experimental site does not exceed the maximum permissible concentrations. Analysis of the content of eight elements in different samples of the Paeonia genus representatives revealed that the minimum concentrations of arsenic, cadmium, chromium, manganese, and iron are observed in the roots; lead and nickel – in flowers; copper – in the leaves of the studied paeonies. The maximum content of arsenic, lead, and chromium was found in the leaves; cadmium, nickel, and manganese – in stems; iron – in flowers. It was shown that all studied plants are characterized by relatively high concentrations of copper (4.15–2520.00 times higher compared to other elements) in all types of raw materials. The maximum content of copper was observed in the roots, while the minimum values corresponded to the leaves of plants. Certain patterns in the content of elements in the aboveground and underground plant parts were also identified.

Based on the accumulation in the phytomass of the studied cultivars, the metals were ranked in an ascending series as follows: Cd < Cr < Pb < As < Fe < Ni < Mn < Cu. The highest accumulation of heavy metals among the studied cultivars was observed in the species of *P. lactiflora f. rosea*, while the lowest was found in P. lactiflora.

The obtained data can be used as an indicator for monitoring and assessing the state of plants in an urbanized environment.

The results of the correlation analysis showed that there is a moderate to strong correlation between the concentrations of the studied elements in the considered taxa of Paeonia. A strong positive relationship was found for the following combinations: chromium and copper (0.78), and nickel and iron (0.84) in flowers; arsenic and lead (0,74), and lead and cadmium (0.77) in stems; chromium and iron in roots (0.80). A strong negative relationship was identified between iron and copper (–0.78) in leaves, and arsenic and chromium (–0.83) in stems.

Correlation study makes it possible to reveal the presence or absence of synergy in the accumulation of elements, which corresponds to the results of other studies.

In most of the studied samples, the highest concentration of heavy metals was found in the aboveground phytomass rather than in the roots. This is especially pronounced in *P. lactiflora f. rosea, P. delavayi*, and *P. peregrina*, which makes it possible not only to consider them as bioindicators of the pollution of aboveground ecosystems but also to use them in the phytoremediation method of removing heavy metals from soils.

REFERENCES

Abramova L.M., Anishchenko I.E., Vafin R.V., Golovanov Ya.M., Zhigunov O.Yu., Zaripova A.A., Kashaeva G.G., Lebedeva M.V., Polyakova N.V., Reut A.A., Shigapov Z.Kh. (2019). Plants of the South Ural Botanical Garden-Institute of the Ufa Federal Research Center of the Russian Academy of Sciences. Ufa: World of Printing (in Russian).

Bashmakov D.I., Lukatkin A.S. (2009). Ecological and physiological aspects of accumulation and distribution of heavy metals in higher plants. Saransk: Publishing House of the Mordovian University (in Russian).

Bityutsky N.P. (2005). Essential micronutrients for plants. St. Petersburg: DEAN Publishing House (in Russian).

Budko E.V., Yampolsky L.M., Zhukov I.M., Chernikova D.A. (2018). Concentration correlations of the elemental organization of hemostatic plants. International Journal of Applied and Fundamental Research, 7, 95-100 (in Russian with English summary).

Chekin G.V., Nikiforov V.M. (2016). Development of the root system of spring wheat at the early stages of ontogenesis during pre-sowing treatment of seeds with chelate preparations. Actual problems of agricultural technologies of the XXI century and the concept of their sustainable development: materials of the national correspondence scientific and practical conference / Ministry of Agriculture of the Russian Federation; Department of Science and Technology Policy and Education; Voronezh State Agrarian University named after Emperor Peter I; under total ed. N.I. Bukhtoyarova, N.M. Derkanosova, V.A. Gulevsky. Voronezh, 34-38 (in Russian with English summary).

Chirkova T.V. (2002). Physiological bases of plant resistance. St. Petersburg: Publishing House of St. Petersburg State University (in Russian).

Davydova S.L., Tagasov V.I. (2002). Heavy metals as supertoxicants of the XXI century: Proc. allowance. Moscow: RUDN University (in Russian).

Demidenko G.A. (2020). Phytomedicinal resources. Tutorial. Krasnoyarsk: Krasnoyarsk State Agrarian University (in Russian).

Dinu C., Vasile G.G., Buleandra M. (2020). Translocation and accumulation of heavy metals in Ocimum basilicum L. plants grown in a mining-contaminated soil. J. Soils Sediments, 20, 2141-2154, DOI: 10.1007/s11368-019-02550-w.

Elagina D.S., Arkhipova N.S., Sibgatullina M.Sh. (2016). Study of the features of the accumulation of heavy metals by plants of Amaranthus retroflexus L. Young scientists and pharmacy of the XXI century. Moscow: Nauka, 189-195 (in Russian with English summary).

Fotev Yu.V., Shevchuk O.M., Syso A.I. (2021). Study of the variability of the elemental composition of seeds of the cultivars Vigna unguiculata (L.) Walp. in the south of Western Siberia and Crimea. Chemistry of vegetable raw materials, 2, 217-226 (in Russian with English summary), DOI: 10.14258/JCPRM.2021027543.

Gonchar-Zaikin P.P., Chertov V.G. (2012). Excel add-in for statistical evaluation and analysis of the results of field and laboratory experiments [online] (in Russian with English summary). Available at: http://vniioh.ru/nadstrojka-k-excel-dlya-statisticheskoj-ocenki-i-analiza-rezultatov-polevyx-i-laboratornyx-opytov/ [Accessed 28 October 2021].

Guanjun Nan, Liying Guo, Yuqiong Gao, Xianxin Meng, Lina Zhang, Ning Song & Guangde Yang. (2019). Speciation analysis and dynamic absorption characteristics of heavy metals and deleterious element during growing period of Chinese peony. International Journal of Phytoremediation, 21(14), 1407-1414, DOI: 10.1080/15226514.2019.1633261.

Ilyinsky A.V. (2020). Analysis of biological absorption coefficients of heavy metals for fodder beet. Eurasian Union of Scientists, 2-6 (71), 9–12 (in Russian with English summary).

Kabata-Pendias A., Pendias H. (1989). Microelements in soils and plants. M.: Mir (in Russian).

Kaloev B.S., Kumsiev E.I. (2014). Accumulation and distribution of heavy metals in plants under natural geochemical conditions. Bulletin of the Gorsky State Agrarian University, 51(3), 97-102 (in Russian with English summary).

Mazhaisky Yu.A., Galchenko S.V., Guseva T.M., Cherdakova A.S. (2016). Accumulation of heavy metals by decorative flower crops. Successes of modern science and education, 9(3), 203-205 (in Russian with English summary).

Meshkinova S.S., Elchininova O.A., Shakhovtseva E.V. (2006). Trace elements in plants of Northern Altai. Polzunovskiy vestnik, 2, 291-295 (in Russian with English summary).

Mikhalchuk N.V. (2017). Heavy metals and microelements in background soils and agricultural landscapes in southwestern Belarus. Agroekological journal, 3, 27-31 (in Russian with English summary).

Mironova L.N., Reut A.A. (2017). Peonies. Collections of the Botanical Garden-Institute of the Ufa Scientific Centre of the Russian Academy of Sciences. Ufa: Bashk. Encycl. (in Russian).

Nesterov M.I., Krivokhizhina L.V., Ermolaeva E.N., Kantyukov S.A. (2016). Influence of the degree and duration of blood loss on the level of triglycerides, phospholipids, total cholesterol, cholesterol in lipoproteins. Modern Problems of Science and Education, 6, 101 (in Russian with English summary).

Parveen S., Bhat I.U.H., Khanam Z., (...), Yusoff H.M., Akhter M.S. (2022). Phytoremediation: In situ alternative for pollutant removal from contaminated natural media: A brief review. Biointerface Research in Applied Chemistry, 12(4), 4945-4960, DOI: 10.33263/BRIAC124.49454960.

Reut A.A., Biglova A.R., Allayarova I.N. (2021). Comparative analysis of the chemical composition of plant materials of some representatives of the genera Narcissus L. and Camassia Lindl. Agrarian Bulletin of the Urals, 2 (205), 79-90 (in Russian with English summary), DOI: 10.32417/1997-4868-2021-205-02-79-90.

Reut A.A., Mironova L.N. (2018). Rare species of the genus Paeonia L. cultivated in the Bashkir Urals. Agrarian Russia, 2, 30-34 (in Russian with English summary).

Sedelnikova L.L., Chankina O.V. (2016). The content of heavy metals in the vegetative organs of the hybrid Krasodnev (Hemerocallis hybrida) in an urbanized environment. The Bulletin of KrasGAU, 2(113), 34-43 (in Russian with English summary).

Sedelnikova L.L., Tsandekova O.L. (2021). On the specifics of the content of ash content and some biogenic elements (n, s, p) in the leaves of herbaceous plants in the conditions of the city of Iskitim, Novosibirsk Region. Chemistry of plant raw materials, 1, 213-218, DOI 10.14258/jcprm.2021018413 (in Russian with English summary).

Seregin I.V., Ivanov V.B. (2001). Physiological aspects of the toxic effect of cadmium and lead on higher plants. Plant Physiology, 48(4), 606-630 (in Russian with English summary).

Seregin I.V., Kozhevnikova A.D. (2006). Physiological role of nickel and its toxic effect on higher plants. Plant Physiology, 53(2), 285-308 (in Russian with English summary).

Simonova O.A., Simonov M.V., Tovstik E.V. (2020). Varietal features of bioaccumulation of iron in barley plants. Taurida herald of the agrarian sciences, 3 (23), 142-150 (in Russian with English summary), DOI: 10.33952/2542-0720-2020-3-23-142-151.

Titov A.F., Kaznina N.M., Talanova V.V. (2014). Heavy metals and plants. Petrozavodsk: Karelian Scientific Centre of the Russian Academy of Sciences (in Russian).

Titov A.F., Talanova V.V., Kaznina N.M. (2011). Physiological bases of plant resistance to heavy metals: textbook; Institute of Biology KarRC RAS. Petrozavodsk: Karelian Research Center RAS (in Russian).

Uzakov Z.Z. (2018). Heavy metals and their effect on plants. Symbol of Science, 1-2, 52-53 (in Russian).

Yanjie Wang, Chunlan Dong, Zeyun Xue, Qijiang Jin, Yingchun Xu. (2016). De novo transcriptome sequencing and discovery of genes related to copper tolerance in Paeonia osti. Gene, 576 (1), 126-135, DOI: 10.1016/j.gene.2015.09.077.

Zakharov V.G., Mishenkina O.G. (2020). Adaptive properties of new varieties of oats in the Middle Volga region. Vestnik of Ulyanovsk state agricultural academy, 4(52), 100-107 (in Russian with English summary).