Comparative analysis of the elemental composition of plant organs of the genus *Iris* L. (Iridaceae)

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Abstract. Plants of the genus *Iris* L. are promising medicinal raw materials with significant biological and pharmacological activity. The aim of this work was a comparative study of the accumulation and transfer of elements through the organs of plants of the genus *Iris* L. (Iridaceae). The content of As, Cd, Cr, Cu, Mn, Ni, and Pb in different parts of *I. orientalis*, *I. pseudacorus*, *I. sibirica* and *I. spuria* plants was analyzed by atomic absorption. It has been established that in the absence of soil pollution, irises accumulate arsenic in concentrations exceeding the maximum allowable. The accumulation of chromium in the raw material was also above the maximum allowable concentration for a number of study options. The efficiency of element transfers from the soil to the root system varied significantly. Iris rhizomes absorbed nickel most actively. The assimilation ability of the roots is also clearly expressed in relation to Pb, As, Cr, Cu, Mn. Depending on the element, accumulation in leaves is species-specific. The carrying capacity of the peduncle is most pronounced in *I. sibirica*, the barrier capacity is most pronounced in *I. orientalis*. Various types of translocations of elements in organs were revealed: acropetal, uniform, basipetal. All studied species are characterized by acropetal distribution of Pb and uniform distribution of Mn. The location of Cd may vary depending on the species. Cu is concentrated in the roots (*I. orientalis, I. sibirica*, *I. spuria*) or evenly distributed (*I. pseudacorus*). The revealed patterns of accumulation and distribution of elements in the organs of plants of the genus *Iris* make it possible to carry out a prognostic assessment of the quality of raw materials to obtain safe products.

1 Introduction

In the modern world, there are practically no territories left one way or another not affected by anthropogenic influence, so the problem of accumulation and distribution of chemical elements in plants becomes significant. This is especially true for species that are a potential source of medicinal and food raw materials.

The genus *Iris* L. (Iridaceae) includes more than 260 species, mostly distributed in the Northern Hemisphere. Species of the genus are rich in secondary metabolites; many of

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them are used in folk and official medicine [1]. The active components of representatives of the genus *Iris* exhibit antioxidant, cytotoxic, antimicrobial, antiviral, and immunomodulatory activities [2-6]. Secondary metabolites are concentrated in various parts of plants: iris leaves and rhizomes accumulate phenolic compounds, essential oils, seeds − glucomannans, rhizomes − iridal-type terpenoids, flowers − essential oils and flavones [7- 15].

The accumulation and distribution of chemical elements in organs varies among species and varieties [16-18]. Thus, some elements related to toxic accumulate in the cell wall, lead to a decrease in the total mass of the plant, affect the content of pigments and enzyme activity, and lead to an increase in oxidative stress [19]. The accumulation of potentially hazardous elements in plants is accompanied by their entry into the food chain of heterotrophs.

Based on the foregoing, the purpose of this work was to study and evaluate the specifics of the accumulation and distribution of chemical elements in plant materials of some species of the genus *Iris* L, which are promising for use in pharmacology [3].

2 Materials and Methods

For 2020-2022, the content of As, Cd, Cr, Cu, Mn, Ni, Pb was analyzed in plant and soil samples using the atomic absorption method. Four species of irises introduced into the South-Ural Botanical Garden-Institute of the Ufa Federal Research Center of the Russian Academy of Sciences (hereinafter referred to as SUBGI UFRC RAS), were selected for research: *I. orientalis*, *I. pseudacorus*, *I. sibirica*, *I. spuria* (Iridaceae). Separate healthy undamaged parts of plants were collected in a certain phase of vegetation: flowers and peduncles, seeds, leaves, rhizomes and roots in the stage of flowering, maturity, secondary growth and autumn period, respectively. The roots were thoroughly washed in running water to remove attached soil particles. Plant samples were dried at 60 ºC to constant weight and ground to a powder. From the total sample, 5 g of plant material was taken and acid mineralization of raw materials was carried out according to GOST 26929-94. The mineralizate was diluted to 50 ml with distilled water and filtered. Samples of 1 kg were taken from the surface layers (depth 0–20 cm) of the soil from 20 points of the experimental plot (iridarium). Samples were air dried and a homogenized 50 g aliquot was taken from each sample. The pooled soil sample was subjected to wet ashing (65% HNO3/39% H2O2; 9:1) at 180°C for 15 min. The content of elements was analyzed by atomic absorption (Shimadzu A-6800 with electrothermal atomizer GFA EX-7) at the Research Institute of Agriculture. The repetition of the measurement of elements in the samples is three times, with the calculation of average values. To assess the level of element content, generally accepted MPC indicators were used.

To assess the assimilation ability of the elements, the bioaccumulation factor (BAF) and the translocation factor (TF) were used. BAF was calculated as the ratio of the element concentration in the roots to its concentration in the soil [20]. BAF values >1 indicate a high potential for the accumulation activity of plant species. The TF values provide information on the mobility and transfer of elements in the plant itself [21]. TF was calculated as the ratio of the element concentration in flowers and seeds to its concentration in flower stalks.

3 Results

The properties of the soil of the experimental plot, the content of chemical elements and their MPC are presented in Table 1. As a result of the study, the presence of contamination by two elements − chromium and copper was revealed. The soil pollution coefficient (the ratio of the content of the element in the soil to the MPC) makes it possible to estimate the degree of excess of the level of the content of chemical elements over the MPC − 8.47 times for chromium and 1.44 times for copper. Consequently, the analysis of the content and distribution of chemical elements in plant organs was carried out against the background of elevated concentrations of two elements in the soil.

Table 1. Individual properties of the Iridarium soil, content of chemical elements and MPC, mg/kg.

Soil properties		Chemical element		Element hazard class [4]	MPC
Nitrate nitrogen	1.7	Pb	0.480±0.120	1	6[1]
Exchangeable calcium, mg/eq. per 100 g	12.8	Cd	0.033±0.009	1	0.1-0.5[2]
Exchangeable magnesium, mg/sq. per 100 g	0.65	As	0.5925±0.189	1	2[1]
Mobile phosphorus	140.9	Cr	0.424±0.144	2	0.05[1]
Mobile potassium	145.0	Cu	4.320±1.080	2	3[1]
Total humus, %	5.7	Mn	1.5475±0.495	3	100[3]
pH	6.33	Ni	0.3575±0.005	2	4[1]

Note: [1][22]; [2]High content on the Obukhov scale [23]; [3][24]; [4][25].

Currently, in accordance with the requirements of the State Pharmacopoeia of the Russian Federation, the content of lead, cadmium, mercury and arsenic is standardized in medicinal plant raw materials (MPR) and herbal medicinal products (HMP). The lack of sanitary standards regulating the permissible levels of nickel, chromium, manganese and copper in plants makes it difficult to evaluate the obtained data on their content in the studied raw materials. Therefore, we focused on the requirements for the content of elements in food products (SanPiN 2.3.2 1078-01 “Hygienic requirements for the safety and nutritional value of food products”).

The content of chemical elements in plant organs is presented in Table 2. Figure 1 shows bioaccumulation factors. Table 3 shows the translocation factors for all study options.

Table 2. The content of chemical elements in the organs of plants of the genus *Iris* L., mg/kg.

Organ	**Species**	**Pb**	**Cd**	**As**	**Cr**	**Cu**	**Mn**	**Ni**
Rhizomes and roots	*I. orientalis*	0.60±0.15	0.05±0.03	0.85±0.27	0.74±0.25	7.52±1.87	2.52±0.81	1.48±0.54
	I.pseudacorus	0.69±0.13	0.02±0.01	0.66±0.22	0.10±0.03	5.89±1.47	2.57±0.83	1.57±0.57
	I. sibirica	0.54±0.14	0.02±0.01	0.46±0.15	0.58±0.20	6.57±1.64	2.67±0.85	1.12±0.40
	I. spuria	0.67±0.17	0.03±0.01	0.83±0.26	0.78±0.26	7.20±1.80	2.76±0.88	0.72±0.26
Leaves	*I. orientalis*	0.84±0.21	0.02±0.01	0.46±0.15	0.06±0.19	5.19±1.29	2.42±0.77	1.01±0.36
	I.pseudacorus	0.78±0,19	0.02±0.01	0.48±0.15	0.56±0.19	6.32±1.58	2.74±0.87	1.19±0.43
	I. sibirica	0.74±0.18	0.05±0.02	0.54±0.17	0.88±0.29	4.77±1.19	2.55±0.82	1.23±0.44
	I. spuria	0.83±0.21	0.07±0.02	0.76±0.24	0.14±0.05	6.18±1.55	2.58±0.84	1.08±0.39
Peduncles	*I. orientalis*	0.74±0.18	0.06±0.02	0.42±0.14	0.48±0.16	6.22±1.56	2.59±0.83	1.09±0.39
	I.pseudacorus	0.91±0.23	0.03±0.01	0.46±0.15	0.33±0.11	6.48±1.62	2.57±0.83	1.16±0.42
	I. sibirica	0.89±0.22	0.03±0.01	0.78±0.25	0.24±0.08	3.02±0.75	2.09±0.67	0.84±0.31
	I. spuria	0.47±0.12	0.03±0.01	0.52±0.16	0.72±0.24	6.08±1.52	2.68±0.86	0.87±0.32
Flowers	*I. orientalis*	0.52±0.13	0.03±0.01	0.51±0.16	1.15±0.39	6.55±1.64	2.55±0.82	1.65±0.59
	I.pseudacorus	0.57±0.14	0.03±0.01	0.33±0.11	0.18±0.06	5.54±1.38	2.88±0.92	1.31±0.47

Organ	Species	Pb	Cd	As	Cr	Cu	Mn	Ni
	I. sibirica	0.51±0.13	0.05±0.01	0.75±0.24	1.05±0.36	4.76±1.19	2.03±0.65	0.93±0.34
	I. spuria	0.53±0.13	0.01±0.01	0.54±0.17	0.73±0.25	5.66±1.42	2.69±0.86	1.16±0.42
Seeds	*I. orientalis*	0.50±0.13	0.03±0.01	0.38±0.12	0.29±0.10	5.60±1.40	2.89±0.93	1.28±0.46
	I.pseudacorus	0.47±0.12	0.03±0.01	0.68±0.22	0.14±0.05	6.75±1.69	2.94±0.94	1.28±0.46
	I. sibirica	0.54±0.13	0.03±0,01	0.61±0.19	0.21±0.07	3.15±0.78	2.89±0.92	1.11±0.40
	I. spuria	0.84±0.21	0.03±0.01	0.52±0.16	0.33±0.01	5.43±1.36	2.89±0.92	1.29±0.46
General content	*I. orientalis*	3.2	0.18	2.63	2.73	31.06	12.98	6.51
	I.pseudacorus	3.43	0.12	2.63	1.3	30.98	13.71	6.52
	I. sibirica	3.24	0.18	3.14	2.96	22.27	12.24	5.24
	I. spuria	3.33	0.16	3.16	2.7	30.56	13.62	5.13
MPC		6[1]	1[1]	0.5[1]	0.5[2]	0.5–50[2]	500[3]	0.7–2[2]

Note: [1][26]; [2] [27]; [3][28].

Lead. The total lead content in the studied species practically does not differ and does not exceed the established MPC for medicinal plants. However, the intensity of absorption of the element from the soil for all species exceeds the threshold value (BAF >1). The content of the element in rhizomes and roots is 0.54−0.69 mg/kg, while in the aboveground organs − leaves and peduncles − the concentration of lead increases significantly, reaching a level of 0.902 mg/kg (*I. pseudacorus*). In the flowers and fruits of three species, the content of the element was lower than in the previous organ (TF is 0.57–0.82) − probably, the peduncle is a physiological barrier for lead and prevents it from entering the generative organs. The exception was *I. spuria* − seeds and flowers accumulate lead in an amount exceeding its content in the peduncle by 1.8 and 1.12 times, respectively.

Cadmium. Cadmium is not a necessary element for plant growth, however, it is easily absorbed by the roots and moves to the aerial part, inhibiting growth, photosynthesis, and nutrient uptake [29]. The intensity of absorption of cadmium by species from the soil can be judged from the BAF obtained (Fig. 1). For most root-soil studies, cadmium is a biological capture element (BAF <1). And only for *I. orientalis* does metal become a component of biological accumulation (BAF >1). The total content of cadmium in the studied species does not exceed the MPC for HMP. The lowest total content of the element was noted for *I. pseudacorus* (0.12 mg/kg). This species is characterized by an almost uniform distribution of Cd over all organs. The difference between the minimum (*I. orientalis*) and maximum (*I. spuria*) content of the element in iris leaves is 5.75 times. The peduncle of *I. orientalis* limits the accumulation of the element in flowers and seeds (TF=0.58 and 0.47, respectively). At the same time, the roots and peduncles of other species do not prevent the movement of the toxicant into the generative organs (TF=1−1.68).

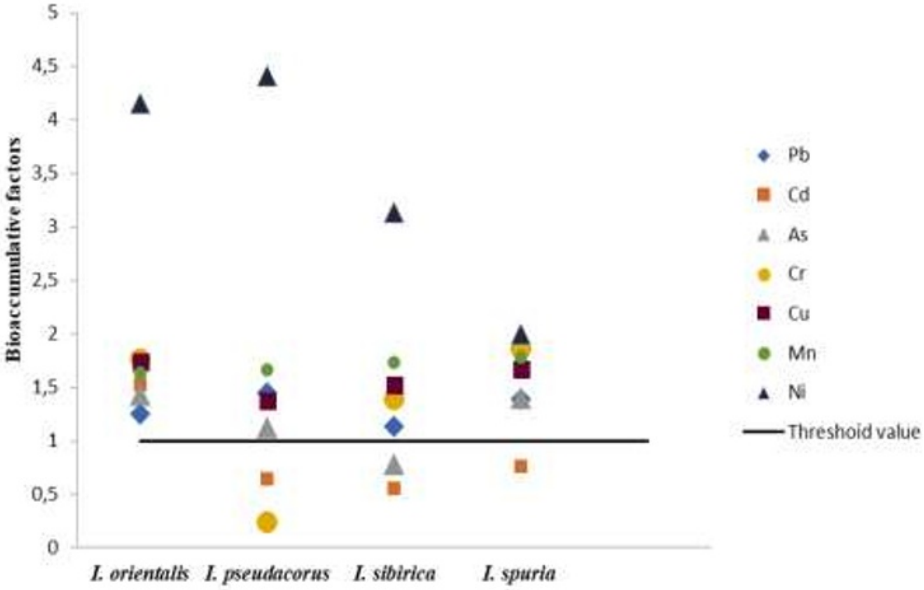

Fig. 1. Factors of bioaccumulation of chemical elements in species of the genus *Iris* L.

Arsenic. Plant materials containing arsenic in an amount of no more than 0.5 mg/kg are environmentally safe [26]. In our study, the content of arsenic in various plant organs ranges from 0.33 to 0.85 mg/kg. The most significant concentrations of the toxicant were established for the rhizomes and roots of three species of irises − *I. orientalis*, *I. pseudacorus* and *I. spuria*, their underground organs perform a barrier function in relation to the element. Calculation of bioaccumulation indices also showed that these species on uncontaminated soil are plants of arsenic basipetal accumulation (BAF>1). On the contrary, the protective function of the root system of *I. sibirica* with respect to arsenic is the least pronounced − the element does not accumulate in rhizomes and roots above the established MPC, however, leaves and generative organs are pollutant accumulators. The leaves of *I. spuria* also contain the toxicant in an amount exceeding the MPC, but to a lesser extent than the roots (0.76 mg/kg). Despite significant root accumulation, the generative organs of *I. spuria* also concentrate arsenic in amounts slightly exceeding the MPC (0.52–0.54 mg/kg). The study noted a trend towards the accumulation of arsenic in the seeds of *I. pseudacorus* (0.69 mg/kg). With this exception, peduncles play a protective role in relation to flowers and fruits (TF=0.78−1.1).

Chromium. Accumulation and distribution of chromium in plants were studied under conditions of soil pollution exceeding the MPC for soils by 8.5 times. In accordance with the data of our work, the total concentration of the element is minimal for *I. pseudacorus*. In all organs of this species, with the exception of leaves, the content of the toxicant is below the MPC established for foodstuffs (0.1–0.33 mg/kg). Underground organs of other species accumulate chromium in amounts exceeding the MPC (0.59–0.79 mg/kg). The high content of chromium in the roots was expected, since the concentration of this element in the soil was increased. As a consequence, bioaccumulation factors for three species were greater than 1. The metal is poorly transferred to the roots of *I. pseudacorus*, as indicated by a low BAF value (<1). The difference between the minimum (*I. orientalis*) and maximum (*I. sibirica*) content of the element in iris leaves is 16 times. In aboveground organs, chromium concentrations exceeding the MPC were found in leaves (*I. sibirica*, *I. pseudacorus*), peduncles (*I. spuria*), and flowers (*I. orientalis*, *I. sibirica*, *I. spuria*). The fruits of all studied species are protected from high concentrations of chromium (0.14–0.33 mg/kg). Translocation of chromium in generative organs has a different character − on the one hand, the peduncle performs a barrier function, limiting the flow of metal into fruits (TF=0.42–0.88), but on the other hand, it does not prevent its entry into flowers (TF=1.02−4.41) (with the exception of *I. pseudacorus*).

Copper. The distribution of copper in plant organs was studied under conditions of contamination with this soil element, exceeding the MPC by 1.44 times. The total metal content in plants, as well as in organs, does not exceed the MPC for plant products. Among the studied species, *I. sibirica* has the lowest total copper content – 22.3 mg/kg. The remaining species contain an approximately equal total amount of the element − from 30.6 to 31.1 mg/kg. The metal is well transferred from soil to plants − the bioaccumulation factor varied from 1.37 to 1.74. The content of copper in leaves varies from 4.8 to 6.3 mg/kg. The distribution of copper in the generative organs is almost equivalent to its content in the peduncles (TF=0.85−1.05), however, in the flowers of *I. sibirica* the metal content is 1.58 times higher than in the peduncle.

Manganese. It has been established that the soil of the experimental plot belongs to the group of soils with a low supply of mobile forms of manganese (< 10 mg/kg). Under these conditions, the accumulation of manganese in plants does not exceed the MPC, the content of the element in organs varies within 2–2.9 mg/kg. The difference in the total content of the element in different species is practically not expressed. The values of BAF differed insignificantly for the studied species (1.63−1.78), which indicates the same power of absorption of the element from the soil. The values of the translocation factor indicate a relatively uniform distribution of manganese in the generative organs of plants with a slight accumulation in flowers (TF=0.98−1.12) and seeds (TF=1.08−1.38).

Nickel. The content of nickel in the soil does not exceed the MPC for soils, and the content of the metal in plant organs does not exceed the MPC for food products. However, the studied species are able to accumulate Ni in concentrations higher than in the soil: BAF is the maximum value among all the studied elements (from 2 to 4.4), which indicates the biological accumulation of the metal in the rhizomes and roots of irises. No differences in the accumulation of nickel in the leaves of the studied iris species were found. Translocation factors determined for generative organs show a consistent outflow of the element from peduncles to flowers and seeds for all studied species (TF=1.1−1.5).

Table 3. Values of the translocation factor in the studied species of the genus *Iris* L.

Micro-element	*I. orientalis*		*I. pseudacorus*		*I. sibirica*		*I. spuria*	
	fl/p	s/p	fl/p	s/p	fl/p	s/p	fl/p	s/p
Pb	0.71	0.68	0.64	0.82	0.57	0.61	1.12	1.77
Cd	0.58	0.47	1.13	1	1.68	1.16	0.375	1.38
As	1.1	0.91	0.72	1.48	0.96	0.78	1.04	1
Cr	2.41	0.62	0.57	0.42	4.41	0.88	1.02	0.46
Cu	1.05	0.9	0.85	1.04	1.58	1.04	0.93	0.89
Mn	0.98	1.12	1.12	1.14	0.97	1.38	1	1.08
Ni	1.51	1.18	1.13	1.11	1.11	1.32	1.33	1.47

Note: fl/p − flower/peduncle, s/p − seeds/peduncle; values in the gray box are above the threshold used to assess the transfer of elements from peduncles to flowers and seeds.

4 Conclusions

A comparison of our data with the approved MPCs showed that contaminated soil does not always contribute to the accumulation of heavy metals in plant materials, and vice versa - an element that is within the normal range in the soil can accumulate in plants. The first statement illustrates the nature of the absorption and accumulation of copper in the studied species. At the same time, irises tend to accumulate another element (arsenic) even in the absence of soil pollution. The metalloid is concentrated in amounts exceeding the MPC for HMP in the roots of three species, in the leaves of two species, in the generative organs of four species. An increase in As bioaccumulation in the biomass of the studied plants can be dangerous for humans when used for medicinal purposes. The classical pattern of accumulation is observed for chromium – soil contamination with a pollutant has led to accumulation exceeding the MPC in underground organs (*I. orientalis*, *I. sibirica*), leaves (*I. sibirica*), peduncles (*I. spuria*) and flowers (*I. orientalis*, *I. sibirica*, *I. spuria*). Thus, since some taxa have been shown to exceed the limits for potentially harmful elements, precautions should be taken when using them as medicinal raw materials.

The efficiency of element transfers from soil to roots varied between plant species and elements, as evidenced by a significant range of bioaccumulation factors (0.24−4.4). Iris roots absorbed nickel most effectively. With the exception of *I. orientalis*, a low level of cadmium uptake by rhizomes and roots of the studied species was shown. In the studies of other authors [30], it was shown that *I. pseudacorus* is recognized as an effective chromium rhizofilter from aqueous solutions of the hydroponic system, but the pollutant is weakly absorbed by this species from the soil. Weak absorption of arsenic (BAF <1) by roots was also noted for *I. sibirica*. In addition to these isolated cases, the assimilation ability of iris roots in relation to Pb, As, Cr, Cu, Mn is clearly expressed (BAF=1.12–1.86), which is important when harvesting and using raw materials from underground organs.

In the distribution of elements over leaves, two variants of accumulation can be traced: the content of the element does not depend on the type of irises (Pb, Ni, Mn), or the accumulation of the element in leaves is species-specific (Cd, As, Cr).

Although in our study the results were obtained from harvesting plant raw materials during the period of the greatest maturity of each of the organs, we can talk about three main strategies in the course of accumulation and distribution of elements among plant organs: metals are either concentrated in the aboveground parts of plants, or their translocation to shoots is limited, or the element is evenly distributed throughout the plant organism. The acropetal concentration of lead and the uniform distribution of manganese are characteristic of all studied species. The remaining elements, depending on the type of plant, can be distributed in different ways. Thus, the location of the toxicant of the first hazard class of cadmium can be basipetal (*I. orientalis*), aboveground (*I. sibirica, I. spuria*), uniform (*I. pseudacorus*). Chromium accumulates in the roots (*I. orientalis, I. spuria*) or in the aerial part (*I. pseudacorus*, *I. sibirica*). Copper is mostly concentrated in the roots (*I. orientalis*, *I. sibirica*, *I. spuria*), or evenly distributed (*I. pseudacorus*).

The carrying capacity of the peduncle, which controls the entry of elements into flowers and seeds, is most pronounced in *I. spuria* − 10 out of 14 variants are at the level or higher than the accumulation of the element in the peduncle. The retarding function of the peduncle is most pronounced in *I. orientalis* – only 4 variants out of 14 exceed the threshold level of the element. If we consider the ascending current of individual elements, then we should note the active translocation of nickel into flowers and seeds for all the studied species; chromium, copper and cadmium in the flowers of *I. sibirica*; chromium in flowers of *I. orientalis*; arsenic in the fruits of *I. pseudacorus*; lead in flowers and seeds, cadmium in the seeds of *I. spuria*. The limited translocation of chromium into the seeds of the studied species under conditions of pollution indicates effective mechanisms that protect the reproductive organs of plants from the toxicant.

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