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HEAVY METAL CONTENTS IN PLANTS GROWING IN THE RUSSIAN BALTIC COASTAL AREA

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Introduction. Prior to use in the production of food additives, ingredients, and biologically active substances, wild plants should be assessed in terms of heavy metal (HM) accumulation. This task is also relevant because wild plants can be consumed by the survived after accidents, disasters, or military operations at sea.
Objective. To assess the HM-related danger of coastal flora in the areas of potential landing of shipwrecked crews in the seas of the Russian Federation.
Materials and methods. The study objects were coastal algae and higher plants growing in the coastal area of the Gulf of Finland. Plant samples were collected in the Bolshoy Beryozovy Island, Hogland Island, and the Kurgalsky Peninsula. Prior to elemental analysis, the samples were dried at 80°C to a constant weight; their dry weight was estimated with an accuracy of 1 mg. The raw mass was estimated based on the dry weight data and the assumption that the water content in native tree leaves comprises 75%, in grass leaves — 85%, and in *F. vesiculosus* thalli — 70%. The dried material was mineralized by an MS-6 microwave sample preparation system (Volta, Russia). Elemental analysis was performed using an MGA-915M atomic absorption spectrometer. The measurement results were processed using the Statistica software.
Results. The Cu and Pb content in the studied plants was found to range within permissible limits. The permissible level of cadmium was exceeded by 2–4 times in *A. ptarmica*, *C. angustifolium*, and *U. dioica* on the Kurgalsky Peninsula, indicating the risk of food consumption. The minimum values of Mn content (less than 20 mg/kg of dry matter) were typical of two plant species (*L. japonicus* and *Salix* sp.) from the Bolshoy Beryozovy Island and *A. podagraria* from the Kurgalsky Peninsula. The toxic effects of Mn begin to appear when the daily intake exceeds 2 mg/day, while the maximum Mn content in the studied objects was 11.9 mg/kg. The high Zn content was typical of all plants on the Hogland Island, as well as *T. repens* and *A. podagraria* from the Kurgalsky Peninsula and *Salix* sp. and *L. japonicas* from the Bolshoy Beryozovy Island. The maximum amount of plant material that can be safely consumed was calculated to be approximately 0.17 kg/day of raw leaf mass.
Conclusions. The absence of daily intake limits for essential elements in regulatory documents makes it difficult to assess the severity of consequences of using plant raw materials for food and medicinal purposes and to apply a risk-based approach to assessing food safety. The high degree of danger associated with the use of plants from the Kurgalsky Peninsula (*A. ptarmica*, *C. angustifolium*, and *U. dioica*) is due to a significant excess of Cd limits. The Cu and Pb levels in all the studied plants was below the limits, indicating the absence of danger associated with these elements. The Zn content can be considered safe, since more than 1 kg of raw leaf mass must be consumed daily to meet the daily requirement, which is practically impossible in actual conditions.

Keywords: wild plants; wild plant-based food; micronutrients; heavy metals

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СОДЕРЖАНИЕ ТЯЖЕЛЫХ МЕТАЛЛОВ В РАСТЕНИЯХ ПОБЕРЕЖЬЯ БАЛТИЙСКОГО МОРЯ В РОССИЙСКОЙ ФЕДЕРАЦИИ

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Введение. Использование дикорастущих растений в производстве пищевых продуктов, добавок, ингредиентов и биологически активных веществ требует оценки сырья на содержание тяжелых металлов (ТМ). Это важно учесть и в связи с использованием дикоросов в пищу при выживании после аварий, катастроф или боевых действий на море.
Цель. Оценить потенциальную опасность употребления в пищу прибрежной флоры, способной аккумулировать ТМ, в местах возможной высадки экипажей судов, терпящих бедствие в акватории морей Российской Федерации.
Материалы и методы. Объектами исследования служили прибрежные водоросли и высшие растения, произрастающие на побережье Финского залива. Образцы растений собраны на участках побережий Финского залива: о-ва Большой Березовый, о-ва Гогланд, а также Кургальского п-ова. До проведения элементного анализа образцы всех растений досушивали при 80 °С до постоянного веса и оценивали их сухую массу с точностью до 1 мг. Оценку сырой массы осуществляли, опираясь на данные по сухой массе и условно принимая, что содержание воды в нативных листьях деревьев составляет 75%, в листьях трав — 85%, а в слоевищах *F. vesiculosus* — 70%. Минерализацию высушенного материала осуществляли в СВЧ-минерализаторе МС-6 («Вольта», Россия). Элементный анализ выполняли на атомно-абсорбционном спектрометре МГА-915М. Результаты измерений обрабатывали с помощью пакета прикладных программ Statistica for Windows 7.
Результаты. Содержание меди и свинца у изученных растений были в границах ПДУ. Допустимый уровень кадмия был превышен в 2–4 раза у *A. ptarmica, C. angustifolium* и *U. dioica* на п-ове Кургальский, что определяет риск использования их в пищу. Минимальные величины содержания марганца (менее 20 мг/кг сухой массы) характерны для двух видов растений (*L. japonicus* и *Salix sp.*)

с о-ва Березовый и для *A. podagraria* с п-ова Кургальский. Токсическое действие марганца (Mn) начинается при превышении нормы суточного потребления 2 мг/сут, в то время как максимальное содержание Mn у изученных объектов составляло 11,9 мг/кг. Высокое содержание Zn характерно для всех растений о-ва Гогланд, а также *T. repens* и *A. podagraria* с п-ова Кургальский и *Salix sp.* и *L. japonicas* с о-ва Большой Березовый. Было рассчитано предельное количество растительного материала, которое можно безопасно употребить в пищу; оно составило приблизительно 0,17 кг/сут сырой массы листьев.

Выводы. Отсутствие в нормативных документах ВДУ суточного потребления эссенциальных элементов затрудняет оценку тяжести последствий использования растительного сырья для пищевых и лекарственных целей и применение риск-ориентированного подхода в оценке безопасности питания. Высокая степень опасности использования в пищу растений п-ова Кургальский (*A. ptarmica, C. angustifolium и U. dioica*) обусловлена существенным превышением ПДУ по Cd. Содержание Cu, Pb во всех изученных растениях ниже ПДУ, т.е. опасность по этим элементам отсутствует. Содержание Zn является безопасным, поскольку для обеспечения суточной потребности в нем необходимо употреблять более 1 кг сырой массы листьев ежедневно, что в реальных условиях практически невозможно.

Ключевые слова: дикорастущие растения; пищевое применение дикоросов; микронутриенты; тяжелые металлы

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INTRODUCTION

The study of wild edible and medicinal plants combines two seemingly unrelated research directions: the search for safe food resources for human survival in nature and the development of innovative technologies for specialized and functional foods, food ingredients (food organic acids, enzymes, food and feed additives, biologically active substances, etc.). The use of wild plants is impossible without a related safety assessment of new types of plant-based food raw materials obtained from plants growing in areas that are not protected from pollutants produced by modern industries, energy facilities, and transportation vehicles.

Heavy metals (HM) are among the most dangerous agents that pollute the natural environment. It is customary to divide microelements into non-essential (not necessary for vital activity) and essential (microelements or indispensable nutritional factors). Excess amounts of even essential elements, such as zinc (Zn), copper (Cu), and manganese (Mn), have a toxic effect on living organisms, including humans [1].

The above problem necessitated the development of standards for physiological requirements for micronutrients, as well as the identification of maximum permissible levels (MPL) for their intake[1,2]. The methodological guidelines that establish the regulatory levels of micronutrients are revised on a constant basis; however, the daily requirements for Zn, Cu, and Mn remain unchanged at 12, 1 and 2 mg/day, respectively[3,4,5]. On the contrary, the MPL values for Zn and Mn were revised downward in 2004–2008 and, in the latest version of 2021[6], were excluded from the list of regulated parameters. This situation makes it difficult to assess the risks of using wild plants for food and medicinal purposes. However, paragraph 21 of the Food Security Doctrine of the Russian Federation calls for the continued harmonization of the characteristics and parameters of food quality and safety based on fundamental research in the fields of hygiene and nutrition science[7].

In the above connection, research efforts aimed at developing approaches to expert assessment of the risks of using wild plants for nutritional and (or) medicinal purposes due to their possible contamination with HM seem highly relevant. In the present study, we set out to assess the potential danger of consuming coastal flora in terms of HM accumulation, with a particular focus on the areas of potential landing of marine crews in distress in the seas belonging to the responsibility zone of the Russian Federation.

MATERIALS AND METHODS

Plant samples were collected along the coast of the Gulf of Finland, including the Bolshoy Beryozovy Island, located in the northern part of the Gulf, Hogland Island,

1 MR 2.3.1.2432-08 Standards of physiological requirements for energy and nutrients for various population groups in the Russian Federation. Moscow: Federal Center for Hygiene and Epidemiology of Rospotrebnadzor; 2009.
2 MR 2.3.1.1915-04:2.3.1 Healthy eating. Recommended levels of food and biologically active substance consumption. Moscow: State Sanitary and Epidemiological Standards of the Russian Federation; 2004.
3 MR 2.3.1.2432-08 Standards of physiological requirements for energy and nutrients for various population groups in the Russian Federation. Moscow: Federal Center for Hygiene and Epidemiology of Rospotrebnadzor; 2009.
4 MR 2.3.1.1915-04:2.3.1 Healthy eating. Recommended levels of food and biologically active substance consumption. Moscow: State Sanitary and Epidemiological Standards of the Russian Federation; 2004.
5 MR 2.3.1.0253-21 Standards of physiological requirements for energy and nutrients for various population groups in the Russian Federation. Moscow: Federal Service for Supervision of Consumer Rights Protection and Human Welfare; 2021.
6 Ibid.
7 Food Security Doctrine of the Russian Federation. Moscow: Rosinformagrotech, 2020.

located in the center of the water area, and the Kurgalsky Peninsula, which protrudes into the Gulf of Finland from the south and separates its Narva and Luga bays. The study objects were coastal algae and higher plants that grow in the coastal area of the Gulf of Finland. These plants have a long history of being consumed as food and are known for their medicinal properties:

Atriplex prostrata Boucher — hastate-leaved (spear-leaved) orache. It is widespread in the European part of the Russian Federation, in the Altai region, and in Eastern and Western Siberia. The leaves of this species contain vitamins A, E, P, PP, rutin, proteins, essential oil, fiber, and minerals. The leaves are a nutritious component of salads, hot and cold vegetable soups, side dishes, and omelets. The leaves are consumed before flowering. This species contains a set of substances with antioxidant and radioprotective properties [2].

Achillea ptarmica L. — pearl yarrow. In Russia, it is widespread in the European part, and, as an adventive plant, can be found in Western Siberia. The leaves have a tart, spicy taste with a slight bitterness, as well as a pleasant herbal aroma. The infusion reduces appetite and lowers blood glucose levels. Fresh herbs are added to ready-made dishes. The study of the phytochemistry and biological activity of substances extracted from different species of the *Achillea* genus has shown the prospects of their use in the food and pharmaceutical industries [3].

Aegopodium podagraria L. — bishop's goutweed. It is widespread in the European part of the Russian Federation, except for the Far North. Young light green leaves are edible. By autumn, the vitamin C concentration increases, sometimes up to 60–100 mg. It contains fiber, malic and citric acids, choline, beta-carotene, flavonoids, coumarins, mineral salts and essential oils, in noticeable quantities of iron, magnesium, potassium [4]. In terms of antioxidant activity, extracts of *Aegopodium podagraria* L. are superior to those of other studied species [5].

Chamaenerion angustifolium L. — narrow-leaved fireweed. It is widespread in the cold and temperate zones of Russia, including the Caucasus, Siberia, and the Far East, where it grows primarily on sandy and loamy soils. Fireweed tea is rich in iron, copper, potassium, and calcium. The above-ground mass contains 18.8% protein, 5.95% fat, 50.44% nitrogen-free extractive substances, 16.62% fiber, 8.14% ash, 0.75% calcium, and 0.43% phosphorus [6].

Fucus vesiculosus L. — bladderwrack. In the marine waters of the Russian Federation, it grows abundantly in the tidal zone of the White Sea, the southern part of the Barents Sea, and the western regions of the Baltic Sea, including the coast of the Hogland Island. It is used for making salads and as a fiber-rich additive to sea fish. Currently, it is considered a promising source of biologically active substances [7].

Lathyrus japonicus Wild — beach vetchling or sea pea. It is widespread in the northern territories of the Russian Federation and in areas with a temperate climate. It is a conditionally edible plant. It is not recommended for regular consumption due to the presence of oxalyldiaminopropionic acid (ODAP), which has neurotoxic properties. The aerial parts of the plant (stems, leaves, and seeds) are used for food purposes, and decoctions are used to treat cardiovascular diseases [8]. Beach vetchling is rich in vitamins (A, B_1, B_2, B_3, B_4, B_6, B_7, B_9, and C) and minerals (sulfur, chlorine, phosphorus, potassium, calcium, sodium, magnesium, titanium, nickel, cobalt, silicon, boron, molybdenum, selenium, manganese, copper, zinc, iodine, and iron).

Polygonum aviculare L. — dooryard knotweed. It is widespread in the Russian Federation, with the exception of the Arctic. Young leaves can be used in salads, soups, and stews. The extracts of this plant have been studied for their antioxidant, anti-inflammatory, antimicrobial, antitumor, and antidiabetic properties [9]. The infusion of this herb is used in traditional medicine as an anti-inflammatory agent due to its ability to remove kidney and bladder stones. It is also used as a hemostatic, hypotensive, diuretic, and astringent agent. It is included in herbal preparations used for chronic gastritis, stomach ulcers, bronchitis, kidney stones, uterine bleeding, cystitis, pulmonary tuberculosis, and other diseases [10]. Moreover, in comparison with other *Polygonum* species, knotweed extracts have the greatest potential in terms of their pharmaceutical effects on the kidneys and urinary tract [11].

Plantago media L. — hoary plantain. It is widespread in the European part of the Russian Federation and in various regions of Siberia. Young leaves are rich in fiber, flavonoids, polysaccharides, vitamins, and minerals, making them a recommended food for vegan and vegetarian diets as addition to cereals, sauces, smoothies, juices, and other beverages. Young leaves can be eaten raw (added to salads or cold soups), boiled, or canned [12].

Salix L. — willow. It is a plant genus that includes about 350 species. They are widespread in the Russian Federation from the subtropics to the Arctic and from the western borders to the east, including Kamchatka and Primorsky Krai. Willow leaves, which are a source of fiber, plant protein, organic acids, and vitamin C, can be boiled or consumed without heat treatment, but after being mashed and then fermented for 8–12 h [13].

Trifolium repens L. — white clover. It is ubiquitous in the Russian Federation. Fresh leaves of young plants are added to vegetable salads, soups, and stewed side dishes for meals of vegetables, meat, and seafood. In a dried and crushed form, fresh leaves are used in the manufacture of sauces, cheeses, and bakery flour. The results of research into the anticholinesterase and antiradical activities of *T. repens* extracts indicate their applicability in the treatment of neurodegenerative diseases [14]. It was found that clover flavonoids reduce intracranial and arterial pressure, relieve dizziness, improve hearing, and reduce tinnitus [15].

Urtica dioica L. — stinging nettle. In Russia, it grows in the European part and Western Siberia, and has been introduced to Eastern Siberia and the Far East. Young shoots and fresh leaves are used after boiling to make vitamin-rich green salads. The shoots and leaves are also used to make soups. Leaf puree is used to make omelets and casseroles. Stinging nettle leaves can be salted, pickled, or marinated. *U. dioica* is a medicinal plant that is widely used in various countries to treat hypertension [16]. It is capable of reducing glucose levels and regulating blood lipid levels, as well as exhibiting anti-inflammatory and antioxidant effects [17].

Sample plants were collected in an open sea area, simulating a survival situation on the coast, where help can only be expected from the sea. The species of terrestrial plants were identified in the areas where they were collected using the Plant Identification Guide for the Leningrad Oblast [18].

Young leaves from the apical part of the shoot were used for analysis. The collected leaves of higher plants were placed between sheets of ashless filter paper and dried in a plant press. Before placing the fragments of the brown alga *F. vesiculosus* in the plant press, moisture was removed from the fragments using ashless filter paper. Prior to elemental analysis, all plant samples were dried at 80°C to a constant weight; their dry weight was estimated with an accuracy of 1 mg. The raw mass estimation was carried out indirectly, based on the dry weight data and assuming that the water content in native tree leaves is 75%, in grass leaves — 85%, and in *F. vesiculosus* thalli — 70%. The dried material was mineralized by an MS-6 microwave sample preparation system (Volta, Russia) using the standard procedure [19]: in three stages, with a temperature and pressure increase from 120°C and 15 atm to 180°C and 25 atm. The total process time lasted 12 min.

Elemental analysis was performed using an MGA-915M atomic absorption spectrometer (Lumex, Russia) at a wavelength of the studied element spectral line, using certified reference materials (CRMs) for elemental analysis[8]. The content of all elements was identified by parallel measurements of the same mineralized samples.

The measurement results were processed using the Statistica softwire package. Sample collections were formed by combining plant samples based on their species and collection points. The sample size (4–6 specimens) was determined by the availability and material quantity at the point of debarkation. The distribution type of the sample collections was assessed using the Shapiro–Wilk test, which ultimately determined the use of parametric methods. The results include the mean values with confidence intervals for a significance level of $p = 0.05$. Based on the latter, the values obtained by direct measurements were rounded to three significant digits. The data on the element content in the raw mass, which is the result of converting the initial values on dry weight basis, contains the same number of digits after the decimal point as the initial values.

RESULTS AND DISCUSSION

The study of heavy metal accumulation, plant groups without significant differences between the members of relevant samples were determined. For example, a high content of manganese (more than 40 mg/kg of dry weight) was typical of three plants (*L. japonicus*, *A. prostratum*, *P. aviculare*) growing on the Hogland Island, and three (*P. minuta*, *A. ptarmica* and *U. dioica*) collected on the Kurgalsky Peninsula. Minimum values of manganese content (less than 20 mg/kg of dry weight) were typical of two plant species (*L. japonicus* and *Salix* sp.) from the Bolshoy Beryozovy Island and for *A. podagraria* from the Kurgalsky Peninsula. The mean manganese content (less than 40 mg/kg, but more than 20 mg/kg) was identified in the *F. vesiculosus* thallus and plants (*Salix* sp., *C. angustifolium*, *T. repens*) from the Kurgalsky Peninsula, as well as *C. angustifolium* from the Bolshoy Beryozovy Island (Table 1).

Plants were divided into two groups based on their zinc content. Its high content (more than 30 mg/kg of dry weight) was typical of all plants of the Hogland Island. This category also includes *T. repens* and *A. podagraria* from the Kurgalsky Peninsula, as well as *Salix* sp. and *L. japonica* from the Bolshoy Beryozovy Island. In the remaining plants, the Zn content was about 20 mg/kg of dry weight, showing no significant differences.

The highest lead content (over 0.4 mg/kg) was found in *L. japonicus* from the Hogland Island and in *P. aviculare* from the Bolshoy Beryozovy Island, as well as in *A. ptarmica* and *U. dioica* collected on the Kurgalsky Peninsula. In six plants, lead was either not detected (*A. prostratum*, *T. repens*, *A. podagraria*), or its content was estimated as low, no more than 0.1 mg/kg (*F. vesiculosus*, *P. minuta*, and *Salix* sp. from the Bolshoy Beryozovy Island). In the remaining three plants, the element level ranged within 0.2–0.4 mg/kg (*Salix sp.* from the Kurgalsky Peninsula and *C. angustifolium* from both habitats), i.e., they contained a mean concentration of the element.

It was difficult to compare plants in terms of their copper and cadmium contents due to the significant variation in the data in the studied sample collections. However, the mean values used to compose a descending order of element contents in plants (Table 2) showed that copper consistently ranks third, surpassed only by the lead content in *P. aviculare* and *L. japonicas* from the Bolshoy Beryozovy Island. The cadmium content was almost always lower than the lead content. The predominant sequences in the descending order of elements are as follows: Mn ≥ Zn > Cu > Pb ≥ Cd.

[8] M 04-64-2017. Food products and food raw materials. Feeds, compound feeds, and raw materials for their production. Method for measuring the mass fraction of cadmium, arsenic, tin, mercury, lead, and chromium using atomic absorption spectroscopy with an MGA-915, MGA-915M, MGA-915MD, or MGA-1000 atomic absorption spectrometer with electrothermal atomization. S. Petersburg; 2017.

Table 1. **Elemental content in plants from different locations**

Location	Plant	Elemental content, mg/kg of dry weight (upper values), mg/kg of wet weight (lower values)				
		Mn*	Zn*	Cu▪	Pb▪	Cd▪
Hogland Island	*A. prostratum*	46.7 ± 20.4	42.3 ± 9.3	0.327 ± 0.485	not detected	0.019 ± 0.013
		7.0 ± 3.1	6.3 ± 1.4	0.049±0.072	not detected	0.003 ± 0.002
	F. vesiculosus	37.3 ± 8.8	37.0 ± 11.2	1.66 ± 2.30	0.070 ± 0.046	0.306 ± 0.413
		11.2 ± 2.6	11.1 ± 3.4	0.49 ± 0.69	0.021 ± 0.013	0.091 ± 0.124
	L. japonicus	55.5 ± 9.4	69.3 ± 36.1	0.881 ± 0.931	0.506 ± 0.192	0.030 ± 0.025
		8.3 ± 1.5	10.4 ± 5.4	0.132 ± 0.139	0.076 ± 0.029	0.004 ± 0.004
	P. aviculare	79.2 ± 42.8	53.3 ± 30.4	0.073 ± 1.34	0.479 ± 0.158	0.007 ± 0.004
		11.9 ± 6.4	8.0 ± 4.6	0.011 ± 0.201	0.072 ± 0.024	0.001 ± 0.001
Bolshoy Beryozovy Island	*C. angustifolium*	30.6 ± 9.8	30.6 ± 9.8	1.99 ± 0.35	0.299 ± 0.042	0.106 ± 0.045
		4.6 ± 1.5	4.6 ± 0.3	0.30 ± 0.05	0.045 ± 0.006	0.016 ± 0.007
	L. japonicus	17.6 ± 3.5	47.2 ± 4.6	0.548 ± 0.025	0.585 ± 0.143	0.007 ± 0.002
		2.6 ± 0.5	7.1 ± 0.7	0.082 ± 0.003	0.088 ± 0.021	0.010 ± 0.000
	Salix sp.	17.2 ± 10.0	39.1 ± 7.1	0.544 ± 0.068	0.102 ± 0.021	0.025 ± 0.018
		4.3 ± 2.5	9.8 ± 1.8	0.136 ± 0.017	0.026 ± 0.005	0.006 ± 0.004
Kurgalsky Peninsula	*A. ptarmica*	57.4 ± 13.4	25.6 ± 2.6	2.26 ± 0.43	0.870 ± 0.324	0.870 ± 0.340
		8.6 ± 2.0	3.8 ± 0.4	0.339 ± 0.064	0.130 ± 0.049	0.130 ± 0.051
	A. podagraria	3.7 ± 3.5	34.1 ± 3.7	0.562 ± 0.410	not detected	0.010 ± 0.006
		0.6 ± 0.5	5.1 ± 0.6	0.084 ± 0.061	not detected	0.002 ± 0.001
	C. angustifolium	34.0 ± 4.6	21.1 ± 2.1	1.01 ± 0.43	0.213 ± 0.072	0.551 ± 0.231
		5.1 ± 0.7	3.2 ± 0.3	0.152 ± 0.064	0.032 ± 0.011	0.083 ± 0.035
	P. minuta	74.9 ± 12.5	21.2 ± 3.9	2.91 ± 2.06	0.040 ± 0.028	0.041 ± 0.029
		11.2 ± 1.9	3.2 ± 0.6	0.44 ± 0.31	0.006 ± 0.004	0.006 ± 0.004
	Salix sp.	31.2 ± 4.0	19.9 ± 7.1	2.09 ± 0.35	0.311 ± 0.049	0.054 ± 0.059
		7.8 ± 1.0	5.0 ± 1.8	0.52 ± 0.09	0.078 ± 0.012	0.013 ± 0.015
	T. repens	36.0 ± 7.8	42.7 ± 18.4	2.40 ± 1.78	not detected	0.007 ± 0.003
		5.4 ± 1.2	6.4 ± 2.8	0.36 ± 0.27	not detected	0.001 ± 0.000
	U. dioica	65.7 ± 28.2	22.9 ± 1.4	4.16 ± 0.82	0.440 ± 0.060	0.395 ± 0.107
		9.9 ± 4.2	3.4 ± 0.2	0.62 ± 0.12	0.066 ± 0.009	0.059 ± 0.016

Table prepared by the authors using their own data

Note: * — human daily element requirement[9] (mg): Mn = 2; Zn = 12; ▪ — element maximum permissible level[10] (mg/kg of wet weight): Cu = 5; Pb = 0,5; Cd = 0,03.

[9] MR 2.3.1.0253-21 Standards of physiological requirements for energy and nutrients for various population groups in the Russian Federation. Moscow: Federal Service for Supervision of Consumer Rights Protection and Human Welfare; 2021.

[10] Technical Regulations of the Customs Union. TP TC 021/2011 «About food safety» dated 9.12.2011. No. 880.

Table 2. Descending orders of elements in plants

Location	Plant	Descending orders of elements in plants
Hogland Island	*A. prostratum*	Mn ≥ Zn > Cu > Cd
	F. vesiculosus	Mn = Zn > Cu > Cd ≥ Pb
	L. japonicus	Zn ≥ Mn > Cu > Pb > Cd
	P. aviculare	Mn ≥ Zn > Pb > Cu > Cd
Bolshoy Beryozovy Island	*C. angustifolium*	Mn ≥ Zn > Cu > Pb > Cd
	L. japonicus	Zn > Mn > Pb ≥ Cu > Cd
	Salix sp.	Zn > Mn > Cu > Pb > Cd
Kurgalsky Peninsula	*A. ptarmica*	Mn > Zn > Cu > Pb = Cd
	A. podagraria	Zn > Mn > Cu > Cd
	C. angustifolium	Mn > Zn > Cu > Cd > Pb
	P. minuta	Mn > Zn > Cu > Pb = Cd
	Salix sp.	Mn > Zn > Cu > Pb > Cd
	T. repens	Zn ≥ Mn > Cu > Cd
	U. dioica	Mn > Zn > Cu > Pb ≥ Cd

Table prepared by the authors using their own data

Note: the decreasing orders of elements in plants are composed using the mean value and the standard error of mean ($M \pm m$).

In the group of plants from the Hogland Island, the closest Mn and Zn concentrations were observed, compared to other habitats. For example, two plants (*L. japonicus* and *Salix* sp.) from the Bolshoy Beryozovy Island and *A. podagraria* from the Kurgalsky Peninsula accumulated significantly more Zn than Mn.

The copper and lead content in all studied plants did not exceed the permissible limit[11]. The zinc and cadmium concentrations require our comment. Cadmium is highly toxic not only to animals and humans, but also to plants, including those used as food and pharmaceutical raw materials [20].

When the actual cadmium content was compared with the maximum permissible level (MPL), the cadmium level was 2–4 times higher in the plants of the Kurgalsky Peninsula (*A. ptarmica*, *C. angustifolium*, and *U. dioica*). In the leaves of the remaining 11 plants, the cadmium concentration was within the MPL, or the excess was not statistically significant. This also applies to the leaves of willow, the most well-known accumulator of cadmium [21, 22].

The zinc content in 1 kg of raw plant mass of all the studied plants was found to be below the daily requirement; thus, the dietary use of these plants is safe in terms of this element.

The regulatory documents of the Russian Federation do not regulate manganese concentration (MPL) in plants; therefore, the safety assessment of this element was carried out in accordance with the norms of physiological daily requirements[12], comprising 2 mg/day for manganese. Since the maximum content of manganese, noted in the studied plant objects, was 11.9 mg/kg, the reference to this value allowed us to determine the amount of plant material that can be consumed safely, namely up to 0.17 kg/day of raw leaf mass. However, the daily requirement for manganese does not coincide with the maximum permissible level, which requires knowledge of the excretion rate of this element from the body to assess its maximum safe daily intake. The MPL[13] value is 5 mg/day, which suggests that the safe consumption will be 0.42 kg/day. Unfortunately, the obtained value has to be recognized as unreliable, since it relies on data from a repealed regulation. In this regard, the issue of returning MPL to the number of regulated parameters becomes relevant.

[11] M 04-64-2017. Food products and food raw materials. Feeds, compound feeds, and raw materials for their production. Method for measuring the mass fraction of cadmium, arsenic, tin, mercury, lead, and chromium using atomic absorption spectroscopy with an MGA-915, MGA-915M, MGA-915MD, or MGA-1000 atomic absorption spectrometer with electrothermal atomization. S. Petersburg; 2017.

[12] MR 2.3.1.0253-21 Standards of physiological requirements for energy and nutrients for various population groups in the Russian Federation. Moscow: Federal Service for Supervision of Consumer Rights Protection and Human Welfare; 2021.

[13] MR 2.3.1.1915-04:2.3.1 Healthy eating. Recommended levels of food and biologically active substance consumption. Moscow: State Sanitary and Epidemiological Standards of the Russian Federation; 2004.

CONCLUSION

It can be stated that the absence of daily intake norms of essential elements in Russian regulatory documents makes it difficult to assess the consequences of wild plant consumption for food and medicinal purposes and to apply a risk-based approach in assessing food safety.

Manganese becomes a hazard factor at moderate daily intake doses of plant material provided that the level of daily requirement is exceeded.

A high-degree danger of consuming plants from the Kurgalsky Peninsula (*A. ptarmica*, *C. angustifolium*, and *U. dioica*) has been revealed due to a significant excess of the MPL for Cd. The Cu, Pb, and As content in all the studied plants is below the MPL, i.e., presenting no danger. The Zn content can be considered safe, since it is necessary to consume more than 1 kg of raw leaf mass daily to meet the daily requirement for this element, which is practically impossible in real survival conditions.

Since no universal heavy metal accumulators have been found among the studied plants, the exclusion of monophagous patterns in the diet of wild plants can be a reliable means of preventing metal toxicity in self-rescue situations on the seashore.

When assessing the suitability of natural plants from different habitats to serve as raw materials for the production of specialized food products, dietary supplements, and beverages enriched with essential elements, it is important to pay attention not only to the content of elements with micronutrient properties, but also to determining the full range of sorbed heavy metals.

The results obtained can be used when creating survival guides that recommend the consumption of wild plants.

References

1. Skugoreva SG, Ashikhmina TIa, Fokina AI, Lialina EI. Chemical bases of toxic effects of heavy metals (review). *Theoretical and Applied Biology.* 2016;1:4–13 (In Russ.). https://doi.org/10.25750/1995-4301-2016-1-014-019
2. Kumorkiewicz-Jamro A, Gorska R, Krok-Borkowicz M, Mielczarek P, Popenda Ł, Lystvan K, et al. Unveiling alternative oxidation pathways and antioxidant and cardioprotective potential of amaranthin-type betacyanins from spinach-like *Atriplex hortensis* var. "*Rubra*". *Journal of Agricultural and Food Chemistry*. 2023;71(41):15017–34. https://doi.org/10.1021/acs.jafc.3c03044
3. Salehi B, Selamoglu Z, Sevindik M, Fahmy NM, Al-Sayed E, El-Shazly M, et al. *Achillea* spp.: A comprehensive review on its ethnobotany, phytochemistry, phytopharmacology and industrial applications. *Cellular and Molecular Biology*. 2020;66(4):78–103. https://doi.org/10.14715/cmb/2020.66.4.13
4. Fedotov SV. *Aegopodium podagraria* L. — a new essential oil plant, its economic and medical significance (review). *Aromacorrection of a person's psychophysical state*. Collection of materials of the V International scientific and practical conference. Yalta; 2015 (In Russ.). EDN: YNCTKL
5. Yılmaz Sarıaltın S, Cicek Polat D, Yalcın CÖ. Cytotoxic and antioxidant activities and phytochemical analysis of *Smilax excelsa* L. and *Aegopodium podagraria* L. *Food Bioscience*. 2023;52:102359. https://doi.org/10.1016/j.fbio.2023.102359
6. Saparklycheva SE, Poiarkova NM. The chamerion angustifolia [*Chamerion angustifolium* (L.) *Holub]*. *Agricultural Education and Science*. 2019;4:15 (In Russ.). EDN: YSMMJS
7. Podkorytova AV, Roshchina AN. Marine brown algae is a promising source of BAS for medical, pharmaceutical and food applications. *Trudy VNIRO.* 2021;186(4):156–72 (In Russ.). https://doi.org/10.36038/2307-3497-2021-186-156-172
8. Kalinkina VA. The development of *Lathurys Japonicas willd.* (*Fabaceae*) in the first year of life in the cultivated condition. *TvGU Bulletin. Series: Biology and Ecology.* 2016;4:184–94 (In Russ.). EDN: XHLPHV
9. Uçar Esra. *Polygonum aviculare* L.'s biological activities: investigating its anti-proliferative, antioxidant, chemical properties supported by molecular docking study. *Inorganic Chemistry Communications.* 2024;162:11–2. https://doi.org/10.1016/j.inoche.2024.112228
10. Petruk AA, Vysochina GI. *Polygonum aviculare* L. (*Polygonaceae*) phenol compounds in geographically distant populations*. Proceedings of Universities. Applied Chemistry and Biotechnology*. 2019;9(1):95–101 (In Russ.). https://doi.org/10.21285/2227-2925-2019-9-1-95-101
11. Shaiymov BK, Sarkisova EIu, Sakhetdurdyeva G. Species of the genus Highlander (*Polygonum* L.) flora of Turkmenistan with nephroprotective and diuretic properties. *Young Scientist.* 2022;45(440):65–9 (In Russ.).
12. Torikov VE. *Medicinal value of vegetable, fruit and berry, field plants and wild plants.* Bryansk: Publishing house of the Bryansk State Agricultural Academy; 2013 (In Russ.). EDN: TUJVPZ
13. Andreev VP, Andriianov AI. *Food resources of the coastal zone of the Northern Seas*. St. Petersburg: Publishing House of RGPU named after A.I. Herzen; 2014 (In Russ.).
14. Ahmad S, Zeb A, Ayaz M, Murkovic M. Characterization of phenolic compounds using UPLC-HRMS and HPLC-DAD and anti-cholinesterase and anti-oxidant activities of *Trifolium repens* L. leaves. *European Food Research and* Technology. 2020;246:485–96. https://doi.org/10.1007/s00217-019-03416-8
15. Abramchuk AV, Karpukhin MIu. The effectiveness of the clover (*Trifolium* L.) in the treatment of various diseases. *Bulletin of Biotechnology.* 2019;3(20):16 (In Russ.).
16. Ekici M, Tuncay OH, Akalın E, Yaman Bucak A, Üresin AYa. Evaluation of the efficacy, safety, and mechanism of action of plants traditionally used in the treatment of hypertension in Turkey. *Journal of Herbal Medicine.* 2024;43:100835. https://doi.org/10.1016/j.hermed.2023.100835
17. Chehri A, Yarani R, Yousefi Z, Novin Bahador T, Shakouri SK, Ostadrahimi A. Anti-diabetic potential of *Urtica Dioica*: current knowledge and future direction. *Journal of Diabetes and Metabolic Disorders.* 2022;21(1):931–40. https://doi.org/10.1007/s40200-021-00942-9
18. Averianov LV, Budantsev AL, Geltma DV, Konechnaia GIu, Krupkina LI, Sennikov AN. *Illustrated determinant of plants of the Leningrad region.* Moscow: Association of Scientific Publications of the KMK; 2006 (In Russ.).
19. Andreev VP, Plakhotskaia ZhV. Comparative analysis of accumulation of copper and cadmium by macrophytes of the

Chupa Bay of the Kandalaksha Bay of the White Sea. Biology of Inland Waters. 2019;1:96–9 (In Russ.). https://doi.org/10.1134/S0320965219010029

20. Zulfiqar U, Hussain S, Ahmad M, Ishfaq M, Jiang W, Xiukang W, et al. Cadmium phytotoxicity, tolerance, and advanced remediation approaches in agricultural soils; a comprehensive review. *Frontiers in Plant Science*. 2022;13:773815.22. https://doi.org/10.3389/fpls.2022.773815
21. Rodkin OI. Assessment of the effectiveness of using fast-growing tree crops for phytoremediation of polluted ecosystems. *Bulletin of the IrGSHA*. 2018;84:40–50 (In Russ.). EDN: MANZON
22. Andreev VP, Zakrevsky YuN, Martynova ES, Plahotskaya ZhV. Food safety on heavy metals of vegetation samples from a route of the Northern Fleet's complexed expedition «Novaya Zemlya-2018». *Marine Medicine*. 2020;6(1):56–63 (In Russ.). https://doi.org/10.22328/2413-5747-2020-6-1-56-63

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