
Journal of Agriculture and Crops
ISSN(e): 2412-6381, ISSN(p): 2413-886X
Vol. 9, Issue. 4, pp: 503-513, 2023
URL: https://arpgweb.com/journal/journal/14
DOI: https://doi.org/10.32861/jac.94.503.513

Academic Research Publishing Group

Original Research Open Access


# Search for Toxic Trace Elements in *Rosa rugosa* Thunb. By Instrumental Neutron Activation Analysis: Accumulation and Responses to Exposure


**Kirill Tkachenko**
Peter the Great Botanical Gardens of the Komarov Botanical Institute of Russian Academy of Sciences, str. Prof. Popov, 2, 197376 St. Petersburg, Russian Federation

**Alla Kapelian**
Peter the Great Botanical Gardens of the Komarov Botanical Institute of Russian Academy of Sciences, str. Prof. Popov, 2, 197376 St. Petersburg, Russian Federation

**Elizaveta Varfolomeeva**
Peter the Great Botanical Gardens of the Komarov Botanical Institute of Russian Academy of Sciences, str. Prof. Popov, 2, 197376 St. Petersburg, Russian Federation

**Marina Frontasyeva** (Corresponding author)
Sector of NAA and Applied Research, Division of Nuclear Physics, Frank Laboratory of Neutron Physics, Joint Institute of Nuclear Research, str. Joliot-Curie, 6, 141980 Dubna, Moscow Region, Russian Federation
Email: marina@nf.jinr.ru

**Inga Zinicovscaia**
Sector of NAA and Applied Research, Division of Nuclear Physics, Frank Laboratory of Neutron Physics, Joint Institute of Nuclear Research, str. Joliot-Curie, 6, 141980 Dubna, Moscow Region, Russian Federation

**Dmitry Grozdov**
Sector of NAA and Applied Research, Division of Nuclear Physics, Frank Laboratory of Neutron Physics, Joint Institute of Nuclear Research, str. Joliot-Curie, 6, 141980 Dubna, Moscow Region, Russian Federation



**Article History**
**Received:** 6 April, 2023
**Revised:** 9 September, 2023
**Accepted:** 25 September, 2023
**Published:** 29 September, 2023





## Abstract

Species of the genus *Rosa* L. are widely used in urban gardening, and they are of considerable interest as plants accumulating heavy metals in an urban environment. Literature data are ambiguous about whether these species accumulate trace and toxic elements. Its fruits are used as medicinal raw materials in folk and official medicine. The purpose of the study is to determine whether this type of wild rose accumulates toxic metals (as well as various macro- and microelements), if so, which ones and in which organs, and to what extent raw materials of the plant can be used. For the first time, multi-element instrumental neutron activation analysis at the reactor IBR-2 of FLNP JINR in Dubna, Russia, was applied to examine accumulation of major and trace elements in various organs of *Rosa rugosa* Thunb. (Rosaceae family), namely, roots, leaves, fruits and seeds. A total of 33 elements (Al, Ca, Cl, I, Mg, Mn, V, As, Br, K, La, Na, Mo, Sm, U, W, Ba, Ce, Co, Cr, Cs, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, Yb, and Zn) were determined. Samples were taken in the summer-autumn period of 2020, both in the city of St. Petersburg and on the coast of the Baltic Sea, Russia. This research found no critical accumulation of trace and toxic elements in different organs of *R. rugose*, but revealed quite high accumulation of Fe and Co in urban transport highway area.



**Keywords:** Wrinkled rosehip, Heavy metals and metalloids; Pollutants; Multi-element instrumental neutron activation analysis.

**How to Cite:** Kirill Tkachenko, Alla Kapelian, Elizaveta Varfolomeeva. et. al. 2023. " Search for Toxic Trace Elements in Rosa rugosa Thunb. By Instrumental Neutron Activation Analysis: Accumulation and Responses to Exposure." *Journal of Agriculture and Crops*, vol. 9, pp. 503-513.


## 1. Introduction

In the spectrum of pollutants in the urban environment, trace toxic elements, among them heavy metals (HMs), occupy a significant place, since (without undergoing significant physical, chemical and biological degradation) they are accumulated in the surface layer of soils and remain available for root absorption by plants for a long time. Furthermore, they are actively involved in the migration processes along trophic routes.

Different plant species accumulate trace toxic elements and remove them differently from the cycle of substances; therefore, it is necessary to create multi-species plantations with high biological resistance, allowing the effective improvement of the quality of the surrounding urban environment. Dynamics of the metal content is individual for each plant species growing in different urban environments [1-11].

Trace elements, heavy metals and metalloids, such as Fe, Mo, Cu, Mn, Zn, Co, S and B, are necessary for the normal course of physiological processes in the life of plants, animals and humans. They are involved in the processes of photosynthesis and respiration, the synthesis of proteins and fats, are part of enzymes, and affect plant metabolism, but only if they are present in amounts measured in thousandths of a percent of the dry mass [12]. In this case, they are called trace elements. However, at high concentrations, they also have a toxic effect on biochemical and physiological processes, causing inhibition of plant growth and development, and a decrease in the productivity of pollen and seeds [13].

Heavy metals such as Cd, Hg, and Pb have a negative effect on plants even at low concentrations [14]. According to the classification of N. Reimers, metals with a density of more than 8 $g/cm^3$ should be considered heavy. Thus, heavy metals include Pb, Cu, Zn, Ni, Cd, Co, Sb, Sn, Bi, Hg. In works devoted to the problems of environmental pollution and environmental monitoring, today more than 40 metals of the periodic system of D. I. Mendeleev with an atomic mass of more than 50 atomic units are classified as heavy metals: V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Cd, Sn, Hg, Pb, Bi, *etc*., since we are talking about element concentrations that are dangerous for living organisms.

This takes into account their biological activity, toxicity to living organisms, and their participation in natural and technogenic processes [15]. Heavy metals are able to enter the human and animal organisms through the food chain, which poses a threat to life [16].

Sources of heavy metal pollution can be natural and anthropogenic in origin. Natural sources include rocks, volcanic eruptions, cosmic dust, soil erosion, evaporation from the surface of the seas and oceans, dust storms and forest fires [17-19]. No more than 20% of the total content of elements that are accumulated in the surface horizons [20] are due to natural technogenic processes.

The main sources of heavy metals are anthropogenic ones. These are coal mining, metallurgical enterprises, chemical industry and the energy complex. Emissions from various vehicles, especially play an ever-increasing role in environmental pollution with heavy metals. Pesticides, herbicides, and fertilizers used in agro-technical activities, which contain these elements, are also important sources of pollution [7, 21]. Heavy metals are predominantly dispersed chemical elements, so the entire earth's surface is exposed to them, namely: the soil cover, hydrosphere and atmosphere [22, 23].

The strongest anthropogenic impact on the environment and population is in large industrial cities, such as St. Petersburg. The report on the environmental situation in St. Petersburg in 2018 (2019) states: “Total emissions of pollutants into the atmospheric air of the city of St. Petersburg from stationary and mobile sources increased by 40% over the period from 2008 to 2017. An increase in emissions is observed for all pollutants except $SO_2$. The contribution of emissions from road transport to the total emissions of pollutants in St. Petersburg varied from 73% in 2008 to almost 85% in 2017, which is associated with an increase in the number of motor vehicles (ATS), especially cars” [24].

Despite the high anthropogenic load and the accumulation of heavy metals in urban ecosystems, there are plant species that can grow and develop for a long time without serious violations of physiological processes [7].

This ability to grow under conditions of soil and air pollution with heavy metals is provided by a complex system of mechanisms that limit the flow of excess amounts of heavy metals into plants, and a system of mechanisms that reduce their toxic effect. The restriction of the entry of HMs ions into cells occurs in the rhizosphere due to the release of various chelators by the root cells, as well as the sorption of HMs by the cell wall.

The system of mechanisms for reducing the toxic effect of HMs includes cellular resistance mechanisms and the antioxidant system of the cell. The cell resistance mechanism is provided by the work of the cell wall and plasmolemma, which delay the entry of HMs into the cell, and also contribute to the removal of their excess from the cell [25].

An important role in plant resistance to HMs is played by the antioxidant system of the cell. Its antioxidants are carotenoids, ascorbic acid, and phenols [26, 27]. In relation to toxic and HMs, different types of plants have both selective accumulation and different resistance. Species sensitive to HMs are of practical importance for the bioindication of contamination. Species resistant to toxic and HMs are important for landscaping and phytoremediation [7, 28].

In the landscaping of St. Petersburg, wrinkled rosehip (wrinkled rose) *Rosa rugosa* Thunb is used everywhere in different parts of the city. *Rosa rugosa* is found in yards, parks, along highways and railways in the form of single plantings, clumps and hedges [29-31].

In different areas of the city, the concentrations of toxic and HMs in the soil and atmosphere differ depending on the degree of remoteness from the industrial facility and the intensity of the traffic flow.

Rose hips are found in all districts of the city and, according to phenological surveys, bloom and bear fruit well everywhere [29]. This condition characterizes the wrinkled rose as a species resistant to pollution by HMs under conditions of high technogenic load. It can be assumed that one of the significant mechanisms that ensure resistance is the antioxidant system of the cell. All organs of wild rose wrinkled – roots, branches, leaves, fruits – contain flavonoids, carotenoids and ascorbic acid [32]. In Russian folk medicine, and in China, they are used as medicinal raw materials: roots, leaves, buds, flowers, fruits (gepanthium) and seeds (nuts) [33-36].

In St. Petersburg, plants are affected by salt used to clean sidewalks and roadways from snow and ice. This dirty snow-salt mixture is dumped on plantings along the roads. Rose wrinkled withstands such salinity. Obviously, it is resistant to soil salinity, since it is found along the sea coast in places of natural growth (southern Kamchatka, Sakhalin, the Kuril Islands, Primorsky Krai, North China, Korea, Japan).

In the work of Maslennikov, *et al.* [7], it is noted that wrinkled rosehip accumulates heavy metals (Mn, Fe, Zn, Sr) in leaves more actively than all other shrubs, the total content of which reaches 867 mg/kg with predominant accumulation of iron – 81.0-83, eight%.

Thus, *Rosa rugosa* is an important species for urban landscaping, not only as a highly ornamental shrub, but also as a species with significant biological stability, capable of accumulating HMs and removing them from the cycle of substances, which can effectively improve the quality of the urban environment.

The native range *of Rosa rugosa* includes northern Japan (Hokkaido and Honshu south to 35 N; Ohwi, 1965), the Korean Peninsula [37], north-east China (on the coast and islands of southern Liaoning province and eastern Shandong province, where it is classified as an endangered species; [38], and the Russian Far East (Kamchatka north to 55 N, Sakhalin, Kuriles, Khabarovsk region, and Primorye region) [39].

The observed increase in element concentrations and alterations in microbial com-munity structure suggests that invasion of *R. rugosa* may threaten nutrient-poor habitats of coastal dunes. Changes in the soil environment may hinder remediation of these valuable habitats after invader removal [40]. The distribution of *R. rugosa* is determined by both natural and anthropogenic factors, higher anthropogenic disturbance and slightly higher nutrient loads adjacent to houses, roads and the beach explain increased establishment and clonal growth of the species [41, 42].

It has proven easier to identify types of habitats that are relatively invasible, such as islands and riverbanks. Factors thought to render habitats invasible include low intensities of competition, altered disturbance regimes and low levels of environmental stress, especially high resource availability. These factors probably often interact; the combination of altered disturbance with high resource availability may particularly promote invasibility. When biotic factors control invasibility, non-natives that are unlike native species may prove more invasive; the converse may also be true [43-45].

Flowers of plants, including roses, are popular in the restaurant business for deco-rating (not only the table, but also dishes,) including as edible plants [46-48]. And in this regard, among other things, it is very important to know what elements are in those parts of plants that are eaten by humans.

The phytochemistry of *Rosa rugosa* of the secondary metabolites identified are listed and aspects of their chemistry are discussed.

The metabolites are grouped according to structural classes and include hydrolysable tannins (contained in the leaves and petals), catechin derivatives (roots), flavonoids (leaves), 2-phenoxychromones (leaves), monoterpenes (floral parts, leaves), sesquiterpenes (leaves, especially from glandular trichomes) and triterpenes (leaves and roots).

*R. rugosa* can provide biological responses strictly related to relevant environmental pollutants, such as heavy metals. The quality of pollen from plants growing in rural and urban areas significantly changed, depending on the different levels of major contaminants such as Pb or Cr. The bioassay based on *R. rugosa* pollen quality seems to be a potentially early and effective monitoring test for heavy metal pollution, which today is still a primary cause of concern to relevant environmental pollutants, such as heavy metals [3, 49-51].

On the other hand, the species of genus *Rosa*, as a source of a large number of biologically active compounds, has long been used in traditional and folk medicine world-wide for the treatment of various types of arthritis including rheumatoid arthritis and osteoarthritis. The active constituents of *Rosa* spp., such as flavonoids, triterpenoids, flavonoids, and phytosterols. Leaves, bark of stems and roots, flowers, fruits, seeds and essential oils of R. rugosa are used to develop new drugs against various human diseases.

The *Rosa* genus is a treasure waiting for further exploration by researchers interested in the development of safe and effective anti-arthritic and anti-cancer agents [52-60].

Non-destructive multi-element reactor instrumental neutron activation analysis happened to be most efficient analytical technique for the purpose of both remediation and medicinal-plant studies [61, 62].

# 2. Material and Methods

## 2.1. Study Area

Geographically, the Leningrad region located in the north of the Eurasian continent is part of the Baltic basin. Is the location with humid climate and multiple lowlands the main factor that determines the characteristics of the soils of this area.

These factors, including geomorphology, and the presence of various lower horizons, directly affect features formation vegetation. On the territory of the city of St. Petersburg and the Leningrad region, predominantly podzolic soils are distributed, located in lowlands and spruce conifers. It is a loamy, highly acidic soil with sand, clay, and loam as its parent rock. A significant problem of the Leningrad region is the pollution of important territorial areas with industrial waste.

According to the latest results of agrophysical and ag-rochemical analyzes, soil degradation is steadily occurring [63-66].

## 2.2. Sampling and Sample Preparation

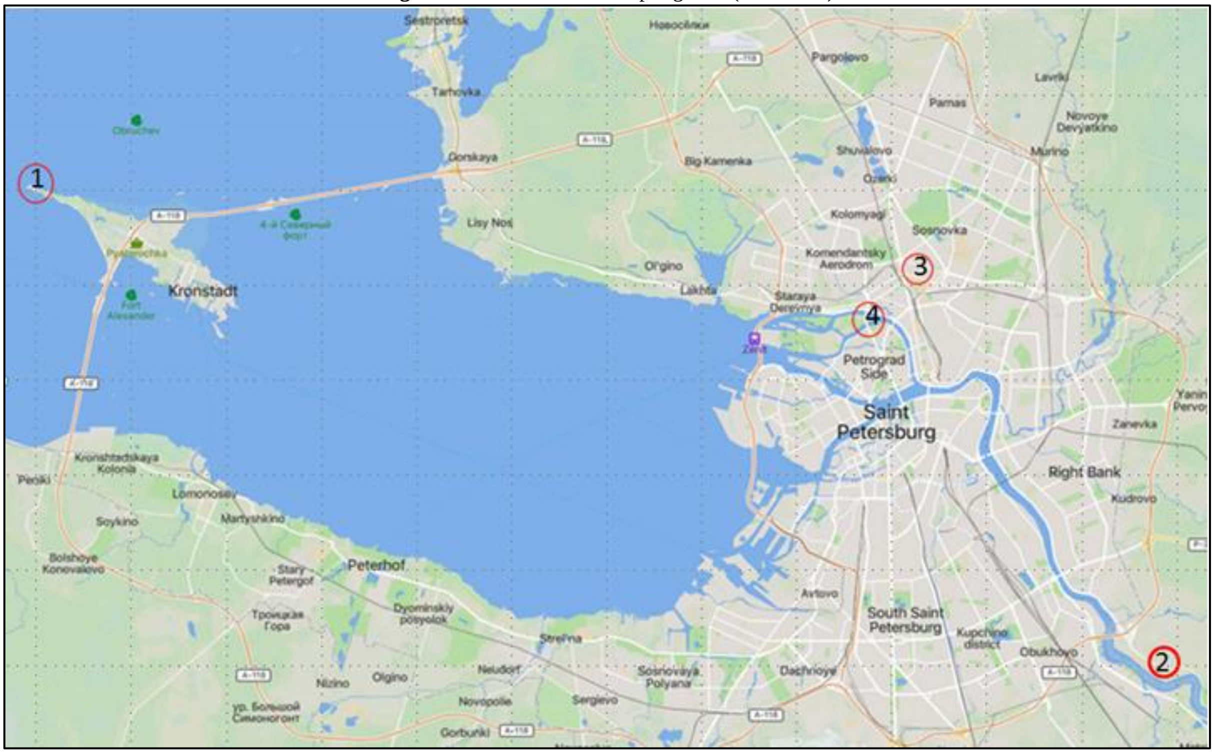
All material was collected during summer-autumn 2020 in St. Petersburg and some places around the city (Table 1 and Figure 1). The location of the *Rosa* sampling in this work – 59°57′ N 30°19′ E).

**Table-1.** Allocation of sampling sites and collection time

| Place on a map | N° | Plant segment | Sampling site location | Month |
|---|---|---|---|---|
| 1 | 1 | Hypanthium | SPb, Kotlin Island, Kronstadt neighborhood, Western Kotlin | September |
| 1 | 2 | Seeds (nuts) | SPb. Kotlin Island, Kronstadt neighborhood, Western Kotlin | September |
| 1 | 3 | Seeds (white-flowered nuts) | SPb, Kotlin Island, Kronstadt neighborhood, Western Kotlin | July |

| | | | | |
|---|---|---|---|---|
| 1 | 8 | Roots | SPb, Kotlin Island, Kronstadt neighborhood, Western Kotlin | September |
| 1 | 9 | Leaves | SPb, Kotlin Island, Kronstadt neighborhood, Western Kotlin | September |
| 2 | 4 | Seeds (nuts) | Neighborhood of the city of SPb, Nevsky forest park. Right bank of the Neva river | September |
| 2 | 5 | Hypanthium. | Neighborhood of the city of SPb, Nevsky forest park. Right bank of the Neva river | September |
| 3 | 6 | Seeds | SPb, transport highway, Muzhestva Square | September |
| 3 | 7 | Hypanthium | SPb, transport highway, Muzhestva Square | September |
| 3 | 10 | Leaves | SPb, transport highway, Muzhestva Square | September |
| 4 | 11 | Roots | SPb, Embankment of the Bolshaya Nevka river. Territory of the BIN Botanical Garden | September |

**Figure-1.** Location of the sampling sites (red circles)




In the laboratory, root samples were washed with distilled water. Then all samples were dried until constant weight and homogenized using homogenizer (Pulverisette 6, Fritsch Laboratory Instruments GmbH, Germany) at 400 rpm provided with agate jar and agate balls. They were thoroughly cleaned after each processing to avoid any samples contamination.

Separation into tissues of plant organs was not performed; whole parts of plants were used for analysis: leaves were separated (without division into leaf blade and petioles), roots (without separation of the bark, central cylinder), gepantia, and seeds (nuts). only in fruits. From 50 to 100 g of fresh raw material were taken for analysis.

Further, about 0.3 g from each sample were packed in polyethylene bags for determination of elements with short-lived isotopes and aluminum cups for determination of elements with long-lived isotopes.

## 2.3. Instrumental Neutron Activation Analysis (INAA)

The analytical procedures and the basic characteristics of the pneumatic system employed at the IBR-2M (pulsed fast reactor) reactor are described in detail elsewhere. Two types of irradiation were carried out. One is a short irradiation for 3 min to determine short-lived isotopes (Al, Ca, Cl, I, Mg, Mn, and V).

Samples were measured immediately after irradiation for 15 min. A long-irradiation of 4 days was used to analyze for long-lived radionuclides. After irradiation the samples were re-packed and measured twice: first after 4 days for 30 min to determine As, Br, K, La, Na, Mo, Sm, U, and W and after 20 days for 1.5 h to determine Ba, Ce, Co, Cr, Cs, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, Yb, and Zn.

The gamma spectra of induced activity were measured with an HPGe detector with a resolution of 1.9 keV for the 60Co 1332 keV line. The processing of spectra data and calculation of elemental concentrations were performed using Genie-2000 (Camberra) and software developed in FLNP JINR.

### 2.4. Quality Control of the Results Obtained

To ensure the quality of the results a set of reference materials: OBTL-5 (Tobacco leaves), SDC1 (Misa Schist), 1549 (Non-fat milk powder), 1632c (Trace elements in coal), 528 (phosphorous-rare earth elements uranium ore), 1566b (Oyster Tissue), 667 (ESTU-ARINE SEDIMENT), FFA1 (Fine Fly Ash), and 2711a (Montana Soil) were irradiated in the same conditions with samples. Certified and measured values of elements content in reference materials are presented in Table 2.

**Table-2.** Certified and measured values of elements in reference materials

| Element | Reference material | Certified value | Uncertainty | Measured value | Uncertainty |
|---|---|---|---|---|---|
| Al | 528 | 29805 | 2.1 | 30674 | 7.1 |
| As | FFA1 | 53.6 | 5 | 54.7 | 7.3 |
| Ba | 1632c | 41.1 | 3.9 | 41.7 | 5.9 |
| Br | 1632c | 18.7 | 2.1 | 21 | 4.5 |
| Ca | SDC1 | 10000 | 5 | 10137 | 8.8 |
| Ce | FFA1 | 120 | 5.8 | 119 | 6.2 |
| Cl | 1566b | 5140 | 1.9 | 4715 | 1.2 |
| Co | 667 | 23 | 5.7 | 22.2 | 5.4 |
| Cr | 667 | 178 | 9 | 177 | 6.8 |
| Cs | 1632c | 0.59 | 1.7 | 0.58 | 4.6 |
| Fe | 667 | 48900 | 2.2 | 47616 | 5 |
| Hf | FFA1 | 6.09 | 7.4 | 5.98 | 4.6 |
| I | 1549 | 3.38 | 0.6 | 3.4 | 1.9 |
| K | FFA1 | 22000 | 10 | 22564 | 9.8 |
| La | FFA1 | 60.7 | 6.6 | 60.5 | 4.7 |
| Mg | SDC1 | 11739 | 5.9 | 10140 | 9.1 |
| Mn | 1566b | 18.5 | 1.1 | 18.01 | 9.4 |
| Mo | FFA1 | 17 | 15 | 17.2 | 14 |
| Na | 2711a | 12000 | 8.3 | 12052 | 7.7 |
| Ni | 1632c | 9.32 | 5.5 | 9.17 | 11 |
| Rb | 2711a | 120 | 2.5 | 122 | 6.5 |
| Sb | FFA1 | 17.6 | 14.2 | 17.7 | 7.5 |
| Sc | 2711a | 8.5 | 1.2 | 8.4 | 5.2 |
| Sm | 667 | 4.66 | 4.3 | 5 | 8.8 |
| Sr | 2711a | 242 | 4.1 | 245 | 9.1 |
| Ta | FFA1 | 2.11 | 7.6 | 1.98 | 3.6 |
| Tb | FFA1 | 1.36 | 10.1 | 1.38 | 4 |
| Th | 1632c | 1.4 | 2.1 | 1.39 | 4.7 |
| U | 1632c | 0.51 | 2.3 | 0.53 | 7.2 |
| V | OBTL-5 | 4.1 | 9.9 | 4.07 | 13.3 |
| W | FFA1 | 10.5 | 10.5 | 10.5 | 11.1 |
| Yb | FFA1 | 4.24 | 4.5 | 4.24 | 8.3 |
| Zn | 667 | 175 | 7.4 | 177 | 4.2 |

## 3. Results and Discussion

The results of our study are presented in Table 3. The obtained values are in lines with the similar indexes and do not differ statistically according to Duncan test at $p<0.05$.

**Table-3.** The content of major and trace elements in different parts of *Rosa rugosa* obtained in the present study by instrumental neutron activation analysis and literature data

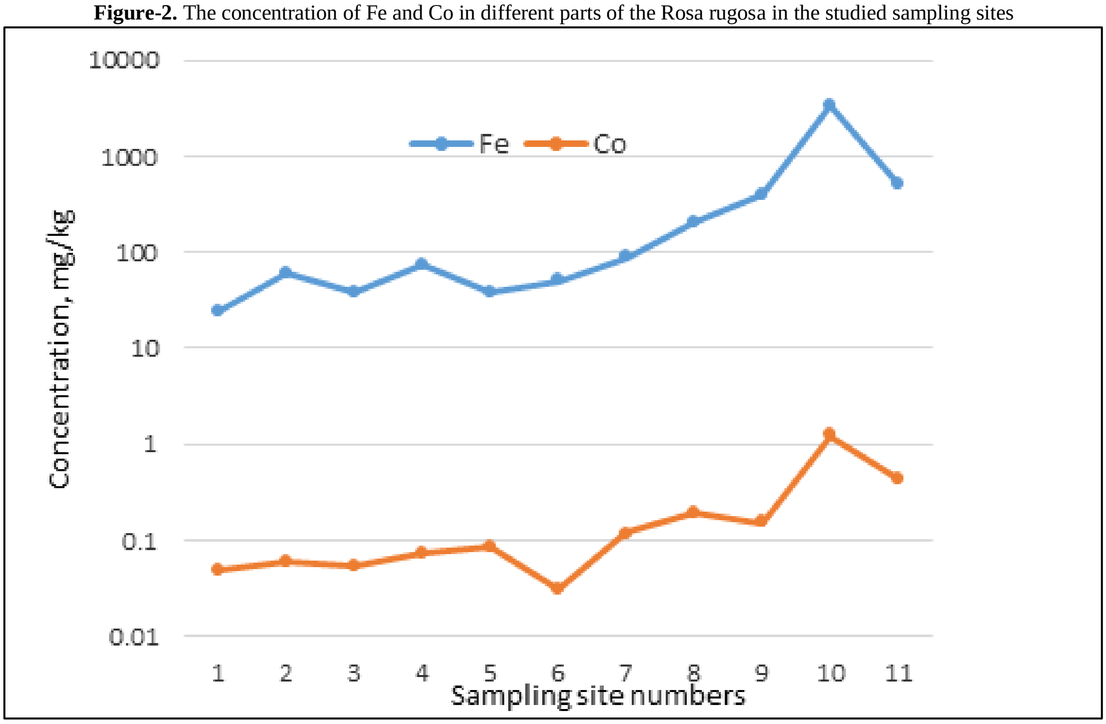
| Sampling site Elements | 1 Western Kotlin | 2 Western Kotlin | 3 Western Kotlin | 4 Nevsky forest park | 5 Nevsky forest park | 6 Muzhestva Square | 7 Muzhestva Square | 8 Western Kotlin | 9 Western Kotlin | 10 Muzhestva Square | 11 Botanical gargen | Reference Plant (Markert, 1992) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Na | 214 / 8.1 | 53 / 9 | 36 / 10.3 | 31 / 10.3 | 104 / 8.6 | 88 / 8.7 | 266 / 8.1 | 92 / 8.7 | 227 / 8.2 | 950 / 7.8 | 1390 / 7.7 | 150 |
| Mg | 770 / 9 | 560 / 9.2 | 570 / 9.3 | 360 / 9.9 | 700 / 9.2 | 480 / 9.6 | 780 / 9.1 | 390 / 10 | 760 / 9.3 | 1130 / 9.2 | 510 / 9.8 | 200 |
| Al | 35 / 7.8 | 26.4 / 8 | 26.3 / 8 | 29.2 / 7.9 | 48 / 7.6 | 151 / 7.3 | 96 / 7.4 | 265 / 7.2 | 580 / 7.2 | 2470 / 7.1 | 440 / 7.2 | 80 |
| Cl | 240 / 12.9 | 83 / 13.6 | 65 / 14.1 | 46 / 14.8 | 230 / 12.9 | 44 / 14.7 | 260 / 12.8 | 68 / 14 | 1100 / 12.5 | 1470 / 12.4 | 270 / 12.8 | 200 |
| K | 39000 / 9.3 | 7700 / 9.7 | 6100 / 9.8 | 4700 / 10.2 | 29200 / 9.4 | 5100 / 10.2 | 30900 / 9.4 | 4900 / 10.2 | 13000 / 9.7 | 16500 / 9.5 | 2600 / 11.7 | 19 000 |
| Ca | 7700 / 18.1 | 2900 / 18.4 | 2700 / 18.4 | 3900 / 18.3 | 8700 / 18.1 | 3600 / 18.3 | 8600 / 18.1 | 4100 / 18.3 | 22000 / 18 | 32000 / 18 | 5700 / 18.2 | 1 000 |
| Sc | <0.00732 | <0.00472 | <0.00429 | 0.0086 / 23.2 | <0.00943 | 0.0075 / 23.3 | 0.021 / 14.9 | 0.039 / 9.1 | 0.097 / 6.7 | 0.78 / 5.3 | 0.132 / 6 | – |
| Ti | <17.4 | <15.1 | <15.3 | <16.1 | <21.6 | <15 | <16.3 | <16.8 | <32 | 275 / 8.4 | 49 / 19.5 | 50.1 |
| V | <0.0493 | <0.0396 | <0.037 | <0.0393 | <0.056 | <0.0464 | 0.096 / 20.7 | 0.21 / 14.9 | 0.46 / 13.2 | 4.6 / 9.8 | 0.97 / 10.6 | 0.5 |
| Mn | 24.2 / 9 | 32.5 / 8.8 | 35 / 8.8 | 39 / 8.8 | 68 / 8.7 | 23.5 / 9 | 9.7 / 9.5 | 16.9 / 9.1 | 97 / 8.7 | 59 / 8.7 | 32.8 / 8.9 | 200 |
| Fe | 24 / 22.4 | 60 / 11.6 | 39 / 15.1 | 74 / 10.4 | 38 / 17.7 | 50 / 13.8 | 88 / 10.8 | 206 / 7.2 | 398 / 6.5 | **3370 / 5.2** | 510 / 5.9 | **150** |
| Co | 0.048 / 15.5 | 0.061 / 12.4 | 0.054 / 13.3 | 0.074 / 11.9 | 0.084 / 11 | 0.031 / 21 | 0.12 / 9.2 | 0.194 / 7.7 | 0.152 / 8.8 | **1.23 / 5.7** | 0.436 / 6.4 | **0.2** |
| Ni | <1.01 | <0.622 | <0.599 | 1.56 / 17.6 | 4 / 14.1 | <0.602 | <0.979 | <0.746 | 0.96 / 29.4 | **3.6 / 14** | 0.97 / 25.1 | **1.5** |
| Zn | 17.6 / 4.7 | 24.2 / 4.5 | 24.7 / 4.5 | 21.9 / 4.6 | 33 / 4.4 | 20.3 / 4.6 | 14.9 / 4.9 | 114 / 4.1 | 30.3 / 4.5 | 51.4 / 4.2 | 32 / 4.4 | 50 |
| As | <0.01 | 0.03 / 16.5 | 0.023 / 18.6 | <0.01 | 0.024 / 25.4 | 0.014 / 27.8 | <0.01 | 0.046 / 11.9 | 0.046 / 17.7 | 0.212 / 8.4 | 0.111 / 9.4 | 0.1 |
| Se | 0.074 / 20.5 | 0.115 / 14.3 | 0.119 / 13.4 | 0.117 / 14.3 | 0.078 / 24.3 | 0.082 / 17.8 | 0.128 / 15.6 | 0.035 / 34.4 | 0.131 / 18 | 0.076 / 31.8 | 0.095 / 16.5 | 0.02 |
| Br | 1.33 / 4.6 | 1.24 / 4.6 | 1.27 / 4.6 | 0.99 / 4 | 1.43 / 4.6 | 0.72 / 4.8 | 0.479 / 4.3 | 0.584 / 4.9 | 2.23 / 4.6 | 1.7 / 4.6 | 1.09 / 4.7 | 4 |
| Rb | 58 / 16.6 | 12.4 / 16.6 | 8.8 / 16.6 | 18 / 16.6 | 94 / 16.5 | 11.1 / 16.6 | 51 / 16.6 | 8.3 / 16.6 | 17.2 / 16.6 | 20 / 16.6 | 3.6 / 16.7 | 50 |
| Sr | 54 / 9.2 | 14.7 / 10 | 7 / 11.7 | 11.2 / 10.7 | 32 / 9.5 | 18.3 / 9.7 | 57 / 9.1 | 14.6 / 10.2 | 176 / 9 | 228 / 8.9 | 29.8 / 9.3 | 50 |
| Mo | 1.2 / 30.4 | 1.2 / 30.4 | 0.92 / 30.4 | 0.76 / 30.5 | 1.1 / 30.4 | 0.6 / 30.5 | 0.78 / 30.5 | 0.55 / 30.5 | 1 / 30.5 | 1.4/ 30.4 | 0.26 / 31.2 | 0.5 |
| Sb | 0.0049 / 27.2 | 0.0049 / 16.3 | 0.0102 / 17 | 0.039 / 10.2 | 0.0177 / 14.2 | 0.0068 / 20.6 | 0.025 / 12 | 0.0205 / 12.6 | 0.043 / 10.4 | 0.65 / 7.7 | 0.071 / 9.1 | 0.1 |
| Cs | 0.049 / 8 | 0.0088 / 19.9 | 0.0102 / 16.9 | 0.047 / 7.1 | 0.267 / 4.8 | 0.0109 / 15.6 | 0.04 / 8.9 | 0.0299 / 8.9 | 0.05 / 7.7 | 0.117 / 5.5 | 0.0197 / 10.5 | 0.2 |
| Ba | 52 / 15.7 | 16.5 / 16 | 4.2 / 18 | 14.7 / 16.1 | 40 / 15.8 | 12 / 16.2 | 24 / 15.9 | 137 / 15.6 | 160 / 15.6 | 115 / 15.6 | 41 / 15.7 | 40 |
| La | 0.07 / 15.7 | <0.0144 | <0.0155 | <0.0206 | 0.097 / 13.5 | 0.067 / 12.6 | <0.0304 | 1.22 / 5.3 | 6.5 / 4.8 | 2.53 / 5 | 0.387 / 7.1 | 0.2 |
| Ce | <0.334 | <0.287 | <0.271 | <0.29 | <0.367 | <0.29 | <0.331 | 1.86 / 8.4 | 3.41 / 7.6 | 4.9 / 7 | 0.53 / 16.8 | 0.5 |
| Sm | 0.0064 / 20.1 | <0.0016 | <0.00146 | 0.0035 / 21 | 0.0072 / 19.8 | 0.0076 / 19.4 | 0.0093 / 19.4 | 0.099 / 22.2 | 0.68 / 18.8 | 0.42 / 18.8 | 0.06 / 19.5 | 0.04 |
| Tb | <0.00271 | <0.00165 | <0.00159 | <0.00185 | <0.00334 | <0.00158 | <0.00273 | 0.0152 / 8.2 | 0.102 / 4.4 | 0.0503 / 5.2 | 0.0086 / 10.3 | 0.008 |
| Hf | <0.0119 | <0.00856 | <0.0078 | <0.00967 | <0.015 | <0.00833 | <0.0123 | 0.083 / 7.8 | 0.045 / 12.7 | 0.432 / 5.2 | 0.066 / 8.5 | 0.05 |
| Ta | <0.0012 | 0.0038 / 16 | <0.00122 | <0.00112 | <0.00143 | <0.00122 | <0.00141 | 0.0052 / 12.5 | 0.0116 / 9.8 | 0.0473 / 5.2 | 0.006 / 13 | 0.001 |
| W | <0.0365 | <0.0302 | <0.0286 | <0.0293 | <0.0403 | 0.04 / 28 | 0.22 / 13.4 | 0.037 / 30.7 | 0.048 / 42 | 1.19 / 11.4 | 0.195 / 14.2 | 0.2 |
| Th | <0.00405 | <0.00316 | <0.00277 | 0.0079 / 16.1 | <0.00452 | 0.0194 / 8.3 | 0.0093 / 16 | 0.075 / 5.4 | 0.124 / 5.2 | 0.69 / 4.7 | 0.067 / 5.4 | – |
| U | <0.00608 | <0.0057 | <0.00544 | <0.00578 | <0.00778 | <0.00553 | <0.00549 | 0.031 / 11 | 0.049 / 11.1 | 0.142 / 7.6 | 0.024 / 13.3 | 0.01 |

**Note:** first value – Conc, µg/g, second value – Err, %; "–" elements not found.

Sorption of dust and aerosols containing metal particles by leaf blades depends on the size of the trapping surface - this is the first way for the elements to enter plants, the second way is absorption from the soil. However, the penetration of toxic substances from the soil through the root system depends on the protective abilities of plants. The high content of Fe and Co in comparison with the Reference Plant [67] is also due to the fact that these elements are included in the "skeleton" of plants and are associated with enzymes, proteins, participates in photosynthesis, nitrogen fixation, in redox reactions, and also associated with organelles (mitochondria, chloroplasts, enzyme systems).

Figure 2. represents dependence of concentrations on the sampling sites with different anthropogenic loadings (see Table 1, 3)

**Figure-2.** The concentration of Fe and Co in different parts of the Rosa rugosa in the studied sampling sites



Interactions between trace elements observed in the plants themselves show that they can be either antagonistic or synergistic. The largest number of antagonistic reactions is noted for Fe, Mn, Co, and Zn, which are key elements in plant physiology [68-70]. The functions of these elements are associated with absorption processes and with enzymatic reactions. From the literature data, a number of rosehip species accumulate a lot of Fe in fruits (hypanthium) [71].

Phytoremediation is also an important problem. This problem is given more importance in the world. And different types of the genus Rosa are the basis for cleaning urban areas from pollution. An analysis of a large number of publications shows the promise of using precisely the species of the genus Rosa to change the ecological situation of urban landscapes for the better in order to improve the human environment [72-83] etc.).

Fe in plants, including dog roses, increases resistance to dehydration [84]. It was found that R. rugosa (growing in Baikal region) plants are characterized by a higher Cu content and a low level of Mn; the hips of these plants also accumulate Fe, Zn, and Co in the sepals, leaves, stems and roots. It has been shown that rose hips, as well as the leaves and stems of Rosa rugosa, can serve as a potential source of Mn, Cr, and Co for the human body [85]

## 4. Conclusion

Various species of the genus Rosa need further study by researchers interested in the development of safe and effective anti-arthritic anti-cancer agents as a source of human nutrition and providing the body with important elements for a fulfilling life.

For the first time various organs of *Rosa rugosa* collected in St. Petersburg and its environs with different anthropogenic impact were analyzed by the method multi-element instrumental neutron activation analysis. There were no sharp differences in the accumulation of heavy metals in plants collected both within the city (ecologically polluted) and parks and suburbs (ecologically clean). The provision was approved that these plants accumulate Fe, Ca, K and Mg. For the collection of raw materials (primarily fruits), urban ornamental plantings of wild Roses can also be used.

The content of toxic elements in different parts of Rosa rugosa showed that even in urban conditions this species does not accumulate toxic elements (including HMs) in different organs, and therefore Rosa rugosa can be used both as a food raw material and medicinal ones.

## 5. Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

## Acknowledgments

Authors express their gratitude to S.F. Gundorina for processing spectra of induced activity and to Prof. R.B. Hoover (NASA, USA) for editing the English language.

## References

[1] Ahsan, M., Younis, A., Jaskani, M. J., Tufail, A., Riaz, A., Schwinghamer, T., and Nawaz, F., 2018. "Heavy metal accumulation imparts structural differences in fragrant Rosa species irrigated with marginal quality water." *Ecotoxicology and Environmental Safety*, vol. 159, pp. 240–248. Available: https://www.sciencedirect.com/science/article/abs/pii/S0147651318303750

[2] Akay, A., 2022. "Lead tolerance and accumulation characteristics of Cubana Kordes rose in lead-contaminated soil." *Environ Monit Assess*, vol. 194, p. 307. Available: https://doi.org/10.1007/s10661-022-09944-3

[3] Calzoni, G. L., Antognoni, F., Pari, E., Fonti, P., Gnes, A., and Speranza, A., 2007. "Active biomonitoring of heavy metal pollution using Rosa rugosa plants." *Environmental Pollution*, vol. 149, pp. 239–245. Available: https://www.sciencedirect.com/science/article/abs/pii/S0269749107000036

[4] Cui, S., Zhang, T., Zhao, S., Li, P., Zhou, Q., Zhang, Q., and Han, Q., 2013. "Evaluation of three ornamental plants for phytoremediation of Pb-contaminated soil." *International Journal of Phytoremediation*, vol. 15, pp. 299–306. Available: https://doi.org/10.1080/15226514.2012.694502

[5] Esringu, A., Kulekci, E. A., Turan, M., and Ercisli, S., 2015. "Phytoremediation of some heavy metals by different tissues of roses grown in the main intersections in Erzurum city Turkey." *Fresenius Environmental Bulletin*, vol. 24, pp. 2787–2791. Available: https://www.researchgate.net/publication/285512245

[6] Krämer, U., 2010. "Metal hyperaccumulation in plants." *Annual Review of Plant Biology*, vol. 61, pp. 517–534. Available: https://doi.org/10.1146/annurev-arplant-042809-112156

[7] Maslennikov, P. V., Dedkov, V. P., Kurkina, M. V., Vashcheykin, A. S., Zhuravlev, I. O., and Bavtruk, N. V., 2015. "Accumulation of metals in plants of urboecosystems." *Bulletin of the Baltic Federal University. I. Kant.*, vol. 7, pp. 57-69. Available: https://journals.kantiana.ru/vestnik/3035/8536/

[8] Medveckiene, B., Kulaitiene, J., Vaitkeviciene, N., Levickiene, D., and Buneviciene, K., 2022. "Effect of harvesting in different ripening stages on the content of the mineral elements of Rosehip (Rosa spp.) fruit flesh." *Horticulturae*, vol. 8, p. 467. Available: https://www.mdpi.com/2311-7524/8/6/467

[9] Rascio, N. and Navari-Izzo, F., 2011. "Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting?" *Plant Science*, vol. 180.

[10] Saltan, Gontar, O. B., Svyatkovskaya, E. A., and Shlapak, E. P., 2015. "Assessment of the accumulation of heavy metals by woody introduced species in various conditions of the urban environment of the Kola North." *Russian Journal of Applied Ecology,* vol. 3, pp. 36-41. Available: http://dx/doi.org/10.37614/2307-5252.2021.4.21.004

[11] Stanchenko, L. Y., 2009. "Distribution of heavy metals in soils and vegetation of urban ecosystems of the Kaliningrad region." *Bulletin of the Russian State University. I. Kant,* pp. 81-85. Available: https://cyberleninka.ru/article/n/raspredelenie-tyazhelyh-metallov-v-pochvah-i-rastitelnosti-gorodskih-ekosistem-kaliningradskoy-oblasti

[12] Hall, J. L. and Williams, L. E., 2003. "Transition metal transport in plants." *Journal of Experimental Botany,* vol. 54, pp. 2601–2613. Available: https://doi.org/10.1093/jxb/erg303

[13] Williams, L. and Salt, D. E., 2009. "The plant ionome coning into focus." *Curr. Opin. Plant Boil.,* vol. 12, pp. 247–249. Available: https://doi.org/10.1016/j.pbi.2009.05.009

[14] Hassan, Z. and Aarts, M. G. M., 2011. "Opportunities and feasibilities for biotechnological improvement of Zn, Cd or Ni tolerance and accumulation in plants." *Environ. Exp. Biol.,* vol. 72, pp. 53–63. Available: https://doi.org/10.1016/j.envexpbot.2010.04.003

[15] Duffus, J. H., 2002. "Heavy metals – a meaningless term? (IUPAC Technical Report)." *Pure Appl. Chem.,* vol. 74, pp. 793–807. Available: http://doi.org/10.1351/pac200274050793

[16] Sharma, R. K. and Agrawal, M., 2005. "Biological effects of heavy metals: An overview." *J. Environ. Biol.,* vol. 26, pp. 1–13. Available: http://www.geocities.com/Lenviron_biol/

[17] Bogdanovsky, G. A., 1994. *Chemical ecology*. Moscow: MGU. p. 237.

[18] Dobrovolsky, V. V., 1992. *The main features of the geochemistry of zinc and cadmium. Zinc and cadmium in the environment*. Moscow: Nauka. pp. 7–18.

[19] Kabata-Pendias, A. and Pendias, H., 2010. *Trace elements in soils and plants*. 4th ed. Boca Raton: CRC Press. p. 548.

[20] Vodyanitsky, Y. N., 2009. *Heavy and superheavy metals and metalloids in contaminated soils*. Mscow: GNU Soil Institute. V.V. Dokuchaev of the Russian Agricultural Academy. p. 182.

[21] Grant, C. A., Buckley, W. T., Bailey, L. D., and Selles, F., 1998. "Cadmium accumulation in crops." *Can. J. Plant Sci.,* vol. 78, pp. 1–17. Available: https://cdnsciencepub.com/doi/pdf/10.4141/P96-100

[22] Dobrovolsky, V. V., 1983. *Geography of microelements. Global dispersion*. Moscow: Mysl. p. 272.

[23] Dobrovolsky, V. V., 2004. *Global system of mass flows of heavy metals in the biosphere. Scattered elements in boreal forests*. Moscow: Nauka. pp. 23–30.

[24] Report, 2019. *On the environmental situation in St. Petersburg in 2018, Edited by I.A. Serebritsky*. St. Petersburg: LLC "Sesam-print, p. 264.

[25] Titov, A. F., Kaznina, N. M., and Talanova, V. V., 2014. *Heavy metals and plants*. Petrozavodsk: Karelian Scientific Center of the Russian Academy of Sciences. p. 194.

[26] Polesskaya, O. G., 2007. *Plant cell and reactive oxygen forms*. Textbook. Moscow: KDU. p. 140.

[27] Kreslavskii, V. D., Los', D. A. S. I., Allahverdiev, S. I., and Kuznetsov, V. V., 2012. "Signaling role of reactive oxygen species during stress in plants." *Plant Physiology,* vol. 59, pp. 163-178. Available: https://naukarus.com/signalnaya-rol-aktivnyh-form-kisloroda-pri-stresse-u-rasteniy

[28] Rocha, C. S., Rocha, D. C., Kochi, L. Y., Carneiro, D. N. M., Dos, R. M. V., and Gomes, M. P., 2021. "Phytoremediation by ornamental plants: a beautiful and ecological alternative." *Environmental Science and Pollution Research,* vol. 29, pp. 3336–3354. Available: https://link.springer.com/article/10.1007/s11356-021-17307-7

[29] Kapelyan, A. I., 2011. "Rosa rugosa Thunb. in St. Petersburg, Biological diversity. Plant introduction." In *Proceedings of the international scientific conference November 15-17, 2011, St. Petersburg), St. Petersburg.* pp. 79-81.

[30] Tkachenko, K. G., Kapelyan, A. I., Gryaznov, A. Y., and Staroverov, N. E., 2015. "The quality of reproductive diasporas of Rosa rugosa Thunb., Introduced in the Botanical Garden of Peter the Great. Bull. BSI FEB RAS [Electronic resource]: Presiding of the Botanical garden-institute of FEB RAS." *Vladivostok,* pp. 41-48. Available: http://botsad.ru/media/cms/3205/41-48.pdf

[31] Tkachenko, K. G., Staroverov, N. E., Varfolomeeva, E. A., Kapelyan, A. I., and Gryaznov, A. Y., 2019. "X-ray method for quality control of nuts of the genus rosa l. Introduced in the peter the great botanical garden." *Bulletin of the Botanical Garden FEB RAS,* pp. 39-57. Available: https://botsad.ru/menu/activity/izdaniya-bsi-dvo-ran/byulleten-bsi-dvo-ran/arhiv-nomerov/21/4/

[32] Al-Yafeai, A., Malarski, A., and Böhm, V., 2018. "Characterization of carotenoids and vitamin E in R. rugosa and R. canina: Comparative analysis." *Food Chem.,* vol. 1, pp. 435-442. Available: https://doi.org/10.1016/j.foodchem.2017.09.070

[33] Keys, J. D., 1976. "Chinese herbs: Their botany, chemistry, and pharmacodynamics. Charles e. Tuttle company." p. 390.

[34] Shreter, A. I., 1970. *Medicinal plants of the Far East and their application*. Vladivostok: Dalnevost: Book. Publishing House. p. 136.

[35] Shreter, A. I., 2004. *Natural raw materials of chinese medicine* vol. 1-3. Moscow.

[36] Zhao, Z. and Chen, H., 2014. "Chinese Medicinal Identification." *Paradigm Publications,* p. 560. Available:

https://scholar.google.ru/scholar?q=Zhao+Z.,+Chen+H.+Chinese+Medicinal+Identification.+Paradigm+Publications%3B+2014.+560+p.&hl=en&as_sdt=0&as_vis=1&oi=scholart

[37] Ohwi, J., 1965. *Flora of japan (translated and edited by f.G. Mayer and e.H. Walker)*. Washington DC, USA: Smithsonian Institution.

[38] Fu, L. G., 1992. *The red data book of Chinese plants- rare and endangered plants* vol. 1. Beijing, China: Science Press.

[39] Bruun, H. H., 2005. "Rosa rugosa thunb. Ex murray." *Journal of Ecology*, vol. 93, pp. 441-470. Available: https://doi.org/10.1111/j.1365-2745.2005.01002.x

[40] Stefanowicz, A. M., Zubek, S., Stanek, M., Grześ, I. M., Rożej-Pabijan, E., Błaszkowski, J., and Woch, M. W., 2019. "Invasion of Rosa rugosa induced changes in soil nutrients and microbial communities of coastal sand dunes." *Science of The Total Environment,* vol. 677, pp. 340-349. Available: https://doi.org/10.1016/j.scitotenv.2019.04.408

[41] Jørgensen, R. H. and Kollmann, J., 2009. "Invasion of coastal dunes by the alien shrub Rosa rugosa is associated with roads, tracks and houses." *Flora - Morphology, Distribution Functional Ecology of Plants,* vol. 204, pp. 1–297. Available: https://doi.org/10.1016/j.flora.2008.03.002

[42] Kollmann, J., Jørgensen, R. H., Roelsgaard, J., and Skov-Petersen, H., 2009. "Establishment and clonal spread of the alien shrub Rosa rugosa in coastal dunes—A method for reconstructing and predicting invasion patterns." *Landscape and Urban Planning,* vol. 93, pp. 0–200. Available: https://doi.org/10.1016/j.landurbplan.2009.07.006

[43] Alpert, P., Bone, E., and Holzapfel, C., 2000. "Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. Perspectives in Plant Ecology." *Evolution and Systematics,* vol. 3, pp. 1–66. Available: https://www.sciencedirect.com/science/article/abs/pii/S1433831904700293

[44] Isermann, M., 2008. "Expansion of rosa rugosa and hippophaë rhamnoides in coastal grey dunes: Effects at different spatial scales." *Flora - Morphology, Distribution Functional Ecology of Plants,* vol. 203, pp. 273-280. Available: https://doi.org/10.1016/j.flora.2007.03.009

[45] Muñoz-Vallés, S. and Cambrollé, J., 2015. "The threat of native-invasive plant species to biodiversity conservation in coastal dunes." *Ecological Engineering,* vol. 79, pp. 32–34. Available: http://doi:10.1016/j.ecoleng.2015.03.002

[46] Bortolini, D. G., Barros, L., Maciel, G. M., Brugnari, T., Modkovski, T. A., Fachi, M. M., Pontarolo, P., Pinela, J., Ferreira, I., *et al.*, 2022. "Bioactive profile of edible nasturtium and rose flowers during simulated gastrointestinal digestion." *381,* Available: https://doi.org/10.1016/j.foodchem.2022.132267

[47] Hummer, K. E. and Janick, J., 2009. *Rosaceae: taxonomy, economic importance, genomics. In: Genetics and genomics of rosaceae* vol. 2009. Eds: Springer, pp. 1–17.

[48] Matyjaszczyk, E. and Śmiechowska, M., 2019. "Edible flowers. Benefits and risks pertaining to their consumption." *Trends in Food Science and Technology,* vol. 91, pp. 670-674. Available: https://doi.org/10.1016/j.tifs.2019.07.017

[49] Ackova, D. G., 2018. "Heavy metals and their general toxicity for plants." *Plant Sci.,* vol. 5, pp. 14-8. Available: https://doi.org/10.14719/pst.2018.5.1.355

[50] Saltan, Natalia, S., Natalia., Sviatkovskaya, Ekaterina, S., and Ekaterina, 2020. "Bioecological features of Rosa rugosa Thunb. in urban ecosystems of the Kola North." In *BIO Web of Conferences.* p. 24.

[51] Singh, B., Samiksha, Parihar, Parul, Singh, Rachana, Singh, V. P., and Prasad, S. M., 2016. "Heavy metal tolerance in plants: Role of transcriptomics, proteomics, metabolomics, and ionomics." *Frontiers in Plant Science*, vol. 6,

[52] Hashidoko, Y., Tahara, S., and Mizutani, J., 1989. "Antimicrobial sesquiterpene from damaged Rosa rugosa leaves." *Phytochemistry,* vol. 28, pp. 425-430. Available: https://doi.org/10.1016/0031-9422(89)80026-3

[53] Achuthan, C., Babu, B., and Padikkala, J., 2003. "Antioxidant and hepatoprotective effects of rosa damascena." *Pharm Biol.,* vol. 41, pp. 357–361.

[54] Basim, E. and Basim, H., 2003. "Antibacterial activity of rosa damascena essential oil." *Fitoterapia,* vol. 74, pp. 394-396. Available: https://pubmed.ncbi.nlm.nih.gov/12781814/

[55] Baydar, N. G. and Baydar, H., 2013. "Phenolic compounds, antiradical activity and antioxidant capacity of oil-bearing rose (Rosa damascena Mill.) extracts." *Industrial Crops and Products,* vol. 41, pp. 375-380 Available: https://doi.org/10.1016/j.indcrop.2012.04.045

[56] Brian, C. Y., Cheng, Xiu-Qiong, Fu, Hui., Guo, T., Li, Zheng-Zhi, Wu, K., *et al.*, 2016. "The genus Rosa and arthritis: Overview on pharmacological perspectives." *Pharmacological Research,* vol. 114, pp. 219-234. Available: https://doi.org/10.1016/j.phrs.2016.10.029

[57] Ercisli, S., 2007. "Chemical composition of fruits in some rose (Rosa spp.) species." *Food Chemistry,* vol. 104, pp. 1379–1384. Available: https://doi.org/10.1016/j.foodchem.2007.01.053

[58] Grajzer, M., Wiatrak, B., Gębarowski, T., Matkowski, A., Grajeta, H., Rój, E., Kulma, A., and Prescha, A., 2021. "Chemistry, oxidative stability and bioactivity of oil extracted from Rosa rugosa (Thunb.) seeds by supercritical carbon dioxide." *Food Chemistry,* vol. 335, Available: https://doi.org/10.1016/j.foodchem.2020.127649

[59] Ying, J. F., Lu, Z. B., Fu, L. Q., Tong, Y., Wang, Z., Li, W. F., and Mou, X. Z., 2021. "The role of iron homeostasis and iron-mediated ROS in cancer." *American Journal of Cancer Research*, vol. 11, pp. 1895–1912. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8167679/

[60] Zhang, Z., Wang, M., Xing, S., and Zhang, C., 2022. "Flavonoids of Rosa rugosa Thunb. inhibit tumor proliferation and metastasis in human hepatocellular carcinoma HepG2 cells." *Food Science and Human Wellness*, vol. 11, pp. 374-382. Available: https://doi.org/10.1016/j.fshw.2021.11.016

[61] Frontasyeva, M., 2011. "Neutron activation analysis for the life sciences. A review." *Physics of Particles and Nuclei*, vol. 42, pp. 332-378. Available: http://www.springerlink.com/content/f836723234434m27/

[62] Pavlov, S. S., Dmitriev, A. Y., Chepurchenko, I. A., and Frontasyeva, M. V., 2014. "Automation system for measurement of gamma-ray spectra of induced activity for neutron activation analysis at the reactor IBR-2 of Frank Laboratory of Neutron Physics at the Joint Institute for Nuclear Research." *Physics of Elementary Particles and Nuclei.*, vol. 11, pp. 737–742. Available: https://link.springer.com/article/10.1134/S1547477114060107

[63] Aparin, B. F. and Rusakov, A. V., 2003. "Soils and soil cover of the zone of the eastern semicircle of the ring road (kad) around St. Petersburg." *Bulletin of St. Petersburg State University. Series 3 Biology*, vol. 2, pp. 103-116. Available: https://cyberleninka.ru/article/n/pochvy-i-pochvennyy-pokrov-zony-vostochnogo-polukoltsa-koltsevoy-avtodorogi-kad-vokrug-sankt-peterburga-

[64] Aparin, B. F. and Sukhacheva, E. Y., 2013. "Methodological bases for the classification of soils of megacities on the example of St. Petersburg." *Bulletin of St. Petersburg University. Series 3: Biology*, pp. 115-122. Available: https://biocomm.spbu.ru/article/view/2647/2462

[65] Gerasimova, M. I., Stroganova, M. N., Mozharova, N. V., and Prokofieva, T. V., 2003. *Anthropogenic soils*. Moscow, p. 266.

[66] Ufimtseva, M. D. and Terekhina, N. V., 2014. "Ecological and geochemical assessment of the state of soils in the historical center of St. Petersburg." *Bulletin of St. Petersburg University. Sariah 7: Geology. Geography*, pp. 122-136. Available: https://yaznanie.ru/a/nuBw0sSf

[67] Markert, B., 1992. "Establishing of "Reference plant" for inorganic characterization of different plant species by chemical fingerprinting." *Water, Air, and Soil Pollution*, vol. 64, pp. 533-538. Available: https://link.springer.com/article/10.1007/BF00483363

[68] Frydrych, A., Krośniak, M., and Jurowski, K., 2023. "The role of chosen essential elements (zn, cu, se, fe, mn) in food for special medical purposes (fsmps) dedicated to oncology patients-critical review: State-of-the-art." *Nutrients*, vol. 15, p. 1012. Available: https://doi.org/10.3390/nu15041012

[69] Hänsch, R. and Mendel, R. R., 2009. "Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl)." *Current Opinion in Plant Biology*, vol. 12, pp. 259–266. Available: http://doi:10.1016/j.pbi.2009.05.006

[70] Merchant, S. S., 2010. "The elements of plant micronutrients." *Plant Physiology*, vol. 154, pp. 512–515. Available: http://doi:10.1104/pp.110.161810

[71] Shikhova, L. and Egoshina, T., 2004. "Heavy metals in soils and plants of the North-East of the European part of Russia." *Kirov*, p. 264. Available: https://www.dissercat.com/content/soderzhanie-i-dinamika-tyazhelykh-metallov-v-pochvakh-severo-vostoka-evropeis

[72] Ali, Khan, E., and Sajad, M. A., 2013. "Phytoremediation of heavy metals-Concepts and applications." *Chemosphere*, vol. 91, pp. 869-881. Available: https://doi.org/10.1016/j.chemosphere.2013.01.075

[73] Ali, Vajpayee, P., Tripathi, R., Rai, U., and Singh, S., 2003. "Phytoremediation of lead, nickel, and copper by Salix acmophylla Boiss: role of antioxidant enzymes and antioxidant substances." *Bulletin of Environmental Contamination and Toxicology*, vol. 70, pp. 0462–0469. Available: https://doi.org/10.1007/s00128-003-0009-1

[74] Boriŝev, M., Pajević, S., Nikolić, N., Pilipović, A., and Krstić, B., 2009. "Phytoextraction of Cd, Ni, and Pb using four willow clones (Salix spp.)." *Polish Journal of Environmental Studies*, vol. 18, pp. 553–561. Available: https://www.researchgate.net/publication/236841366_Phytoextraction_of_Cd_Ni_and_Pb_Using_Four_Willow_Clones_Salix_spp#fullTextFileContent

[75] Cheng, S., 2003. "Heavy metal pollution in China: origin, pattern and control." *Environmental Science and Pollution Research*, vol. 10, pp. 192-198. Available: https://link.springer.com/article/10.1065/espr2002.11.141.1

[76] Evangelou, M. W., Deram, A., Gogos, A., Studer, B., and Schulin, R., 2012. "Assessment of suitability of tree species for the production of biomass on trace element contaminated soils." *Journal of Hazardous Materials*, vol. 209, pp. 233–239.

[77] Jensen, J. K., Holm, P. E., Nejrup, J., Larsen, M. N., and Borggaard, O. N., 2009. "The potential of willow for remediation of heavy metal polluted calcareous urban soils." *Environmental Pollution*, vol. 157, pp. 931–937.

[78] Kachenko, A. G., Singh, B., and Bhatia, N. P., 2007. "Heavy metal tolerance in common fern species." *Australian Journal of Botany*, vol. 55, pp. 63–73.

[79] Mehmood, T., Chaudhry, M., Tufail, M., and Irfan, N., 2009. "Heavy metal pollution from phosphate rock used for the production of fertilizer in Pakistan." *Microchemical Journal*, vol. 91, pp. 94–99. Available: https://doi.org/10.1016/j.microc.2008.08.009

[80] Okieimen, F. E., 2011. "Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation." *ISRN Ecology*, pp. 1–21. Available: https://doi.org/10.5402/2011/402647

[81] Shufeng, W., Xiang., Shi, H., Sun, Y., Chen, H., Pan, X., and Yang, T. R., 2014. "Variations in metal tolerance and accumulation in three hydroponically cultivated varieties of salix integra treated with lead." *PLoS One,* vol. 9, p. e108568.
[82] Tőzsér, D., Magura, T., and Simon, E., 2017. "Heavy metal uptake by plant parts of willow species: A meta-analysis." *Journal of Hazardous Materials,* pp. 1-25.
[83] Yoon, J., Cao, X., Zhou, Q., and Ma, L. Q., 2006. "Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site." *Science of the Total Environment,* vol. 368, pp. 456–464.
[84] Liu, J., Fan, Y., Zou, J., Fang, Y., Wang, L., Wang, M., Jiang, X., Liu, Y., Gao, J., *et al.*, 2017. "A rhabf2/ferritin module affects rose (rosa hybrida) petal dehydration tolerance and senescence by modulating iron levels." *The Plant Journal,* vol. 92, pp. 1157–1169. Available: https://doi.org/10.1111/tpj.13751
[85] Afanas'eva, L. V. and Ajushina, T. A., 2021. "Features of microelements and low-molecular weight antioxidants accumulation in plants of the genus Rosa L." *Chemistry of Plant Raw Materials,* vol. 2, pp. 209-216. Available: http://journal.asu.ru/cw/article/view/7440