COMPARATIVE ANALYSIS OF CHEMICAL ELEMENTS CONTAINED IN VARIOUS ORGANS OF THE NITREBUSH (NITRARIA SCHOBERI L.) GROWING IN THE ARALKUM AREAS

Amanova Guzal Ikromovna[1], Abdirahimova Sayora Shodiyorovna[2], Saitova Azima Qaljanovna[3], Ziavitdinov Jamoliddin Fazlitdinovich[4], Sherimbetov Sanjar Gulmirzoevich[5]

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Abstract

For the first time, concentrations of chemical elements contained in the vegetative and generative organs of the nitrebush (Nitraria schoberi), a species of flowering plant in the family Nitrariaceae, widely spread in the Southern Aralkum, on the Ustyurt plateau and Vozrozhdeniya Island were determined. In the process of the study, concentrations of 32 chemical elements found in the samples of soil the plant grows on, and those of 37 elements found in the underground organs of the plant (roots) and the above-ground ones (leaves and fruits) were determined. Significant differences in the concentrations of macro- and microelements contained in the underground organs of Nitraria schoberi and those in the above-ground organs of the plant widely spread in the arid areas of the Aral Sea were demonstrated. Some elements were found in high concentrations. Due to their high tolerance to the arid conditions, the Nitraria schoberi L. species were found demanded in the soil amendment to be used for reduction of the soil salinization degree, and as the potent sand stabilizers.

Keywords: the Aral Sea**,** Nitraria schoberi, element, salt, neutron activation analysis

[1]Doctoral student, Laboratory of technologies of vegetable and plant growing, A.S. Sadykov Institute of Bioorganic Chemistry, Uzbekistan Academy of Sciences
[2]Junior researcher**,** Laboratory of technologies of vegetable and plant growing, A.S. Sadykov Institute of Bioorganic Chemistry, Uzbekistan Academy of Sciences
[3]Candidate of biological sciences, Karakalpak State University named after Berdakh
[4]Doctor of Sciences (Chemistry)**,** head of Laboratory of technologies of vegetable and plant growing, A.S. Sadykov Institute of Bioorganic Chemistry, Uzbekistan Academy of Sciences
[5]Professor, Doctor of Sciences (Biology), Laboratory of technologies of vegetable and plant growing, A.S. Sadykov Institute of Bioorganic Chemistry, Uzbekistan Academy of Sciences

Email: [1]guzal.amanova.87@mail.ru, [2]sayoraabdirahimova@gmail.com, [3]s_azima@karsu.uz

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1. Introduction

Various biometals and minerals occurring in the nature are known to play their special roles in the biochemical processes taking place in the cells and tissues of a living organism. In their tissues and organs, living organisms, especially plants, tend to accumulate elements essential for normalization of physiological, biochemical and genetic processes. The identification of element compositions of plants is the key aspect in both theoretical and practical studying of their chemical compositions. Any study on roles these critical elements play in the life cycles of plants makes possible deeper understanding of molecular mechanisms underlying biological and ecological peculiarities of taxons belonging to the specific group.

Today, biological diversity of the Aral Sea's dessicated bed, chemical compositions of vegetation cover and plant species, as well as biochemical processes taking place in them are the aspects poorly explored. The region greatly differs from the nearby desert areas by unique structures of its vegetation, soil and climate. Geographically, the Aral Sea region is the continuation to the Turan Depression, a desert basin region stretching from the southern Turkmenistan through Uzbekistan to Kazakhstan. From the administrative view, its southern part constituting more than half of its territory is in the Republic of Uzbekistan (Karakalpakstan), and the northern one is in the Republic of Kazakhstan. It borders on the Lower Amu Darya State Biosphere Reserve in Uzbekistan in the south, on the Karakum desert in the north and on the spurs of the eastern Ustyurt in the west [1,7].

A halophytic bush, Nitraria schoberi L. is a typical species of deserts and semi-deserts growing on the saline gypsum soils of the foothills and lowlands, as well as on the salty lake shores. Roots of the plant growing in the areas of interest may reach the depth of 3.5m approaching the ground water. Due to their high tolerance to the arid conditions, the Nitraria schoberi L. species are the demanded instruments in the soil reclamation used for reduction of the soil salinization degree, and as the potent sand stabilizers [3,4,16,20]

Prof. S. Sherimbetov examined not only ecological groups of the promising plant species widely spread in the region, but also the concentrations of 38 chemical elements constituting the plants with due attention to high concentrations of the soil salts in the Aral Sea region. Some rare metals were found to accumulate in the generative organs of the plants [7].

In view of high concentrations of the soil salts in the Aral Sea region, the screening of chemical compositions of promising plant species widely spread in the region, isolation of bioactive agents they contain, identification of their biological and pharmaceutical practice are of current scientific and practical value.

Aim: The study was initiated to identify chemical compositions of the underground plant organs, such as roots, and the above-ground ones, to name leaves and fruits of Nitraria schoberi widely spread in the Southern Aralkum, on the Ustyurt plateau and Vozrozhdeniya Island, as well as chemical compositions of soils the plant grows on.

Background

Facing the problems associated with the soil reclamation, a lot of countries use vegetation to amend the soils, including the sandy ones, by their stabilization. The concept of soil stabilization is that the soil is being locked in place to prevent it from moving. There are trees or bushes used to stabilize the sandy soils. Nitraria schoberi L. is an accepted name of a species in the genus Nitraria (family Nitrariaceae) discovered by Gottlieb Schober, Chief Physician of Peter I and one of the first Russian researchers of flora and fauna, who gave it the name of Nitraria from Latin "nitrum" (nitre) specifying its distribution near bitter-salty lakes. Farther of modern taxonomy Carl Linnaeus gave the name Nitraria schoberi to the plant thus commemorating the name of G. Schober. Having an Irano-Turanian distribution, Nitratia schoberi, the nitrebush is a species of flowering plant in the family Nitrariaceae. Nearly ten Nitraria L. species are widely spread in the steppe, semi-desert and desert areas of the Central Asia, Europe, North Africa and South-Eastern Australia. Due to their uniqueness as the salt-resistant objects, and in view of global desertification, the species belonging to the genus are considered as the promising ones in the soil reclamation as a soil amendment and for decorative purposes [8]. The Nitraria schoberi fruits were found to contain sugars, proteins, amino acids, vitamins, pectins and mineral elements, making them suitable for production of juices, jams and food dyes in the food industry. The extracts from the fruits have both anti-oxidant and anti-bacterial properties making possible their use in treatment of fungal and inflammatory diseases. Both freshly cut and dried fruits of the plant are edible [2,6,9,11]. Banaev et al. found 19 phenol compounds in the leaves of N. sibirica growing in Siberia [15]; a group from the Central Siberian Botanical Garden found flavonols, tannins, catechins, anthocyanins, pectin and glucose in the

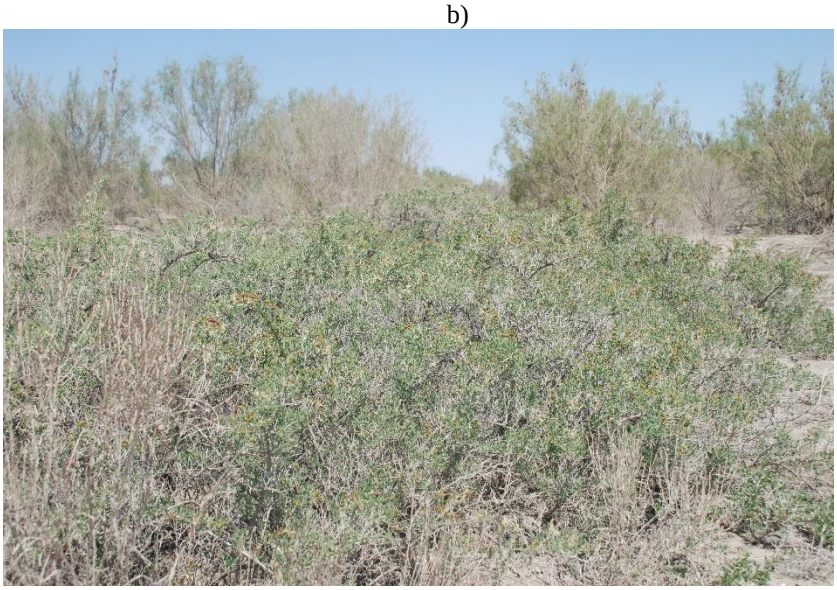
leaves and fruits of both N. schoberi and N. sibirica [17]. Upon analysis of variability taking place in the features of the vegetative and generative organs of N. schoberi, such as the plant shoots, leaves, fruits and seeds collected in 2013-2015 in various regions of Dagestan (the Russian Federation), high coefficient of variability in features of leaves was demonstrated in the Botlikh (3.9cm), Atlausk (4.5cm) and Sulaksk (6.7cm) populations. N. schoberi was shown to become more adaptive to the environmental variability [18,19]. Starting from 1960 s, alkaloids isolated from N. schoberi, N. komarovii and N. sibirica species belonging to the Nitraria genus have been studied and analyzed by a scientific group from the Institute of Chemistry of Plant Substances headed by Professor S.Yu. Yunusov[12,13,14], methods for chemical synthesis of the alkaloids isolated from the Nitraria species were generated. Concentrations of protein-peptide fractions, free amino acids, vitamins, carbohydrates and total polyphenols contained in the stems, leaves, fruits and seeds of N. schoberi widely spread in the Southern Aralkum were determined by the scientists from the Laboratory of technologies of vegetable and plant growing, Institute of Bioorganic Chemistry, Uzbekistan Academy of Sciences, headed by Professor S.G. Sherimbetov [21,22,23]. Chemical compositions of various organs of N. schoberi widely spread in the desert areas of Uzbekistan has been barely explored, since research neither on concentrations of its high molecular weight and nutritious constituents nor on isolation of bioactive substances has been ever conducted. Studies aiming at the determination of concentrations of chemical elements contained in the underground organs (roots) and above-ground ones (leaves, fruits) of N. schoberi growing in the Southern Aralkum, on the Ustyurt plateau and Vozrozhdeniya Island, as well as concentrations of chemical elements contained in the soil the plant grows on were conducted.

2. Materials and methods

The results of scientific expeditions to the desiccated regions of the Aral Sea Basin undertaken by the Laboratory of technologies of vegetable and plant growing in 2015-2021 demonstrate the increase in the number of N. schoberi populations in the regions due to its specific bioecological adaptions, to name evolution of the root system and ability to stabilize the moving of sands and salt. During the expeditions to the Aralkum including the Southern Aralkum, the Ustyurt plateau and Vizrozhdeniya Island, undertaken in 2016-2020, biomaterials from various organs of N. schoberi were collected to be studied (Fig.1).

a)

b)



c)

Fig.1. N. schoberi growing in the desert regions of Uzbekistan: a. in the Southern Aralkum, b. on the Ustyurt plateau, c. on Vozrozhdeniya Island, July 2020

Biology. In the wild, N. schoberi grows on the vast areas forming plant communities on the Aral Sea's desiccated bed. The findings of the scientific expeditions undertaken to the Southern Aralkum demonstrated that the plant can grow in height of up to 1-2.5m, and has the branched stems of 3-5 m in length, small flowers, thick leaves 3-4cm in length; the size of the ripe fruit is 0.5-1cm. The plant starts blossoming in May and fruiting in June-July.

Ecology. N. schoberi is a bush resistant to various natural stress factors fit to grow on the sandy and salinized soils, thus adapting to the severe ecological conditions of the Aralkum. Reaching 2.5-3.5m in depth on the Aral Sea's desiccated bed its roots stabilize the moving sands.

Areal. Nitraria schoberi L. is distributed in Caspian, Turanian lowlands, China (Dzungaria), Afghanistan, Iran, Syria, Transcaucasia, Altai region, southwest of West Siberia, Kazakhstan, Crimea, spurs of southern Carpathians and Central Asia, to specify regions of low Amu-Darya, Kyzylkum, Ustyurt plateau and Aralkum in Karakalpakstan [5,10].

Methods

The neutron activation analysis performed on the water-water energetic reactor (WWER) at the Institute of Nuclear Physics, Uzbekistan Academy

of Sciences, was used to determine concentrations of elements in the plant organs and soil samples. The samples of N. schoberi, its roots and of the soil the plant grows on were collected in the field; each sample was put into a separate plastic bag with indication of the time of collection and short description of the place and area. In the laboratory, necessary quantities of the samples were ground in the porcelain mortar, dried at 60°C and passed through a 2-mm sieve. To perform the neutron activation analysis of the samples, by means of the quartering method used to determine short-lived isotopes 30-40mg of plant samples, 20-30mg of soil and roots were picked; to determine the medium- and long-lived isotopes 100mg of plant samples and 50-70mg of soil and roots were selected. Each sample was placed into the plastic appropriately numbered bag and sent to WWER at the Institute of Nuclear Physics, Uzbekistan Academy of Sciences, for the neutron activation analysis to be performed.

3. Results and discussion

For the purpose of the study, the samples of soil and roots of N. schoberi growing in the Southern Aralkum were collected in July 2020 to be tested for concentrations of chemical elements contained in them, since no research on the element compositions of underground organs of the plant was ever conducted. As the result, concentrations of 32 chemical elements found in the soil the plant grows on were tested; 37 elements were found and tested in the N. schoberi roots. The majority of the elements were found in the samples of the plant organs, as well (Table 1).

Table 1. Concentrations of chemical elements in the soil and in the N. schoberi roots, μg/g

Elements	Samples of soil and roots (July 2020)			
	At the depth of 10-20cm		At the depth of 20-40cm	
	soil	root	soil	root
Petrogenic elements				
Na	15,000	4,390	13,300	7,250
K	10,200	9,620	11,000	10,800
Ca	96,000	8,200	81,200	4,900
Mn	520	60	450	23
Fe	19,500	350	20,300	1,270
Lithophile elements				
Rb	58	1,1	57	2,7
Sr	360	53	370	98
Cs	2,7	0,04	2,8	0,12
Ba	270	5,3	320	13,6
Hf	3,9	0,55	4,1	0,18
Ta	0,49	0,0057	0,58	0,017
Siderophile elements				
Cr	42	13.7	45	63.3
Co	8.7	0.5	9.2	0.47
Ni	24	8.8	23	34.5
Chalcophile elements				
Cu	<1.0	37	<1.0	37
Zn	51	13	53	28
As	6.6	0.55	6.7	<0.1

Mo	-	2.0	-	1.9
Sb	0.43	0.081	0.41	0.12
Re	-	0.0030	-	<0.001
Hg	-	<0.001	-	0.0084
Se	-	0.43	-	0.26
Cd	-	<1.0	-	<1.0
Radioactive elements				
Th	6.0	0.074	6.2	0.31
U	2.3	1.2	3.0	3.6
Pure elements				
Au	0.0057	0.0019	<0.001	0.0037
Rare earth elements				
Sc	8.3	0.011	8.7	0.38
La	21	1.1	23	0.45
Ce	36	0.46	39	2.2
Nd	18	1.2	17	<1.0
Sm	3.2	0.32	3.5	0.44
Eu	0,8	0.011	0.81	0.044
Tb	0.53	<0.01	0.55	<0.01
Yb	1.7	0.091	2.1	<0.01
Lu	2.3	0.0089	0.22	0.0037
Halogen elements				
Cl	2,230	3,740	6,400	7,310
Br	3.7	17	<1.0	34

For the first time, concentrations of chemical elements found in the soil N. schoberi grows on in the desiccated southern regions of the Aral Sea, and in the roots of the plant were measured. Concentrations of some elements, to name sodium, potassium, calcium, manganese and iron were found high. As to concentrations of chemical elements found in various layers of the soil the plant grows on, they were found to differ significantly by the depth of sampling; thus, concentrations of iron, rubidium, barium, strontium, cobalt, nickel, scandium, samarium, chlorine and bromine were found higher at the depth of 20-40cm than those at the depth of 10-20cm. Concentrations of the chalcophile elements, such as rhenium and selenium, were found higher in the plant roots taken at the depth of 10-20cm than those taken at the depth of 20-40cm. The findings demonstrate that the plant does not accumulate the elements above from the soil layers of various depths. As no analysis was undertaken to compare concentrations of chemical elements found in the organs of N. schoberi growing in the Southern Aralkum and those in populations from other regions, concentrations of chemical elements in the above-ground organs of N. schoberi, to name its leaves and fruits of the plant growing in the Southern Aralkum, on the Ustyurt plateau and Vozrozhdeniya Island were tested. There were 37 elements found and tested in the above-ground organs of the plant (Table 2).

Table 2. Concentrations of chemical elements in leaves and fruits of N. schoberi growing in the areas of Southern Aralkum, on Ustyurt plateau and Vozrozhdeniya Island, μg/g

Elements	**Southern Aralkum (2016)**	**Southern Aralkum (2020)**	**Ustyurt plateau (2020)**	**Vozrozhdeniya Island (2020)**

	Leaves	**fruits**	**leaves**	**Fruits**	**Leaves**	**fruits**	**leaves**	**Fruits**
Ag	<0.1	<0.1	-	-	-	-	-	-
As	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Au	0.0084	0.0048	0.0032	0.0018	0.0025	0.0059	0.0019	0.0016
Ba	6.6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Br	108	9.6	53	5.3	4.1	1.7	34	7.0
Ca	9,770	1,860	15,400	2,170	14,900	4,700	14,500	3,280
Cd	-	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Ce	0.65	0.13	0.47	0.12	<0.1	<0.1	0.1	<0.1
Cl	78,100	11,800	36,000	4,690	25,700	10,700	39,900	2,390
Co	0.47	0.15	0.29	0.093	0.08	0.068	0.095	0.065
Cr	0.88	<0.1	3.2	1.4	0.6	0.69	0.3	0.59
Cs	0.071	<0.001	0.045	0.0093	0.02	0.007	0.013	<0.01
Cu	6,300	580	835	50	500	250	830	250
Eu	0.017	<0.001	0.011	0.0021	0.0046	<0.001	<0.001	<0.001
Fe	510	85	370	68.3	162	87.4	79.9	54.4
Hf	0.069	0.017	0.07	0.014	0.011	0.0082	0.013	<0.001
Hg	0.017	<0.01	0.056	<0.001	<0.001	<0.001	<0.001	0.019
K	22,900	13,000	30,800	14,900	20,600	17,600	20,800	13,200
La	0.45	0.033	0.30	0.055	0.12	0.040	0.099	<0.1
Lu	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mn	48	13	54	8.4	39	15	41	13
Mo	18	3.6	1.6	<0.1	1.9	0.63	6.2	0.68
Na	75,000	13,400	37,800	4,920	30,700	13,500	39,800	10,100
Nd	-	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Ni	6.5	<1.0	5.5	3.8	<1.0	<1.0	1,1	1,7
Rb	1.9	0.69	1.9	0.37	1.4	1.5	1.7	1,6
Re	-	-	0.018	<0.001	0.15	0.030	0.068	0.0048
Sb	0.024	<0.01	<0.001	<0.001	0.015	0.013	0.0093	0.015
Sc	0.16	0.022	0.11	0.019	0.044	0,019	0.015	0.0092
Se	0.59	0.076	0.33	<0.1	18.6	6,5	0.37	0.33
Sm	0.054	0.0083	0.057	0.0060	0.013	<0.001	0.014	0.0043
Sr	210	45	225	33	130	43	94	39
Ta	<0.1	<0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tb	<1.0	<1.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Th	0.11	0.037	0,086	0.015	0.034	0,012	0.014	<0.01
U	<0.1	<0.1	0,070	<0.01	<0.01	<0.01	0.062	<0.01
Yb	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Zn	20	26	16	12	26	28	8.7	25

As it can be seen from Table 2, concentrations of some chemical elements in the leaves and fruits of the plant are substantially high; thus, there were 15,400 µg/g and 30,800 µg/g of calcium and potassium, respectively, in the samples of the N. schoberi leaves collected in the areas of the Southern Aralkum in 2020, 18.6 µg/g of selenium in the samples of leaves collected on the Ustyurt plateau, 39,900 µg/g of chlorine in the samples of leaves collected in the areas of the Southern Aralkum in 2016 and 39,800 µg/g of sodium in the samples of leaves collected on Vozrozhdeniya Island. High concentrations of calcium, potassium, sodium and chlorine were found in the N. schoberi above-ground organs growing in the Southern Aralkum, on Ustyurt plateau and Vozrozhdeniya Island (Fig.2). Calcium is known to regulate transport of other nutrients to the plant participating in the activation of some enzymes of plant origin. The roles of potassium, sodium and chlorine both in the development of plant and in the equilibrium of photosynthesis are incomparable.

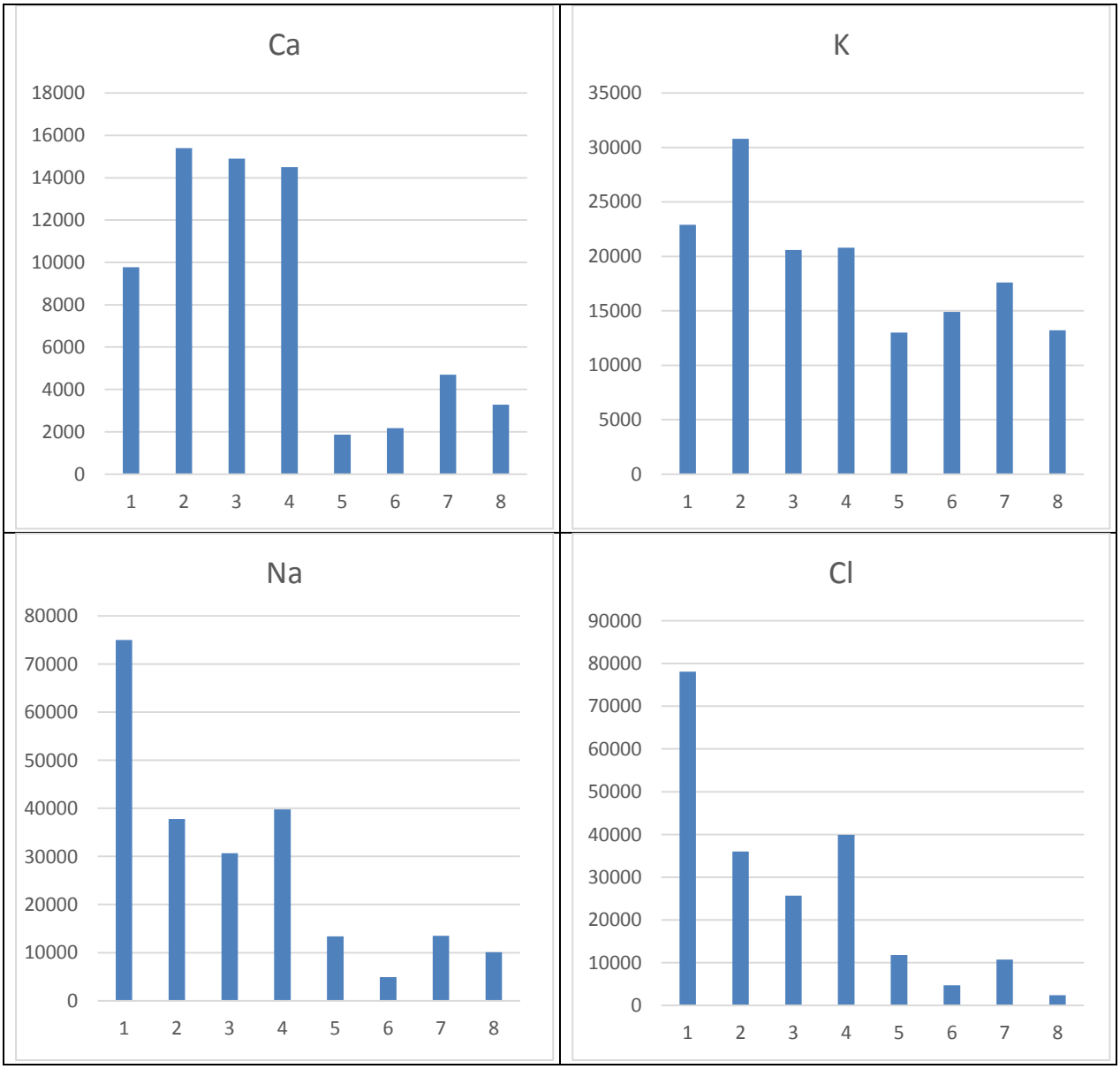


Figure 2. Concentrations of minerals (Ca, K, Na) and halogen element (Cl) in the above-ground organs of N. Schoberi taken in various parts of the Aral Sea region, µg/kg.

In: leaves taken in the Southern Aralkum in 2016 and in 2020 (1,2), leaves taken on the Ustyurt plateau and Vozrozhdemiya Island in 2020 (3,4), fruits taken in the Southern Aralkum in 2016 and in 2020 (5,6), fruits taken on the Ustyurt plateau and Vozrozhdemiya Island in 2020 (7,8). As to biogenic elements contained in the N. schoberi above-ground organs, concentrations of copper, iron, manganese and strontium are substantially high. Cu, Fe and Mn are essential for photosynthesis. The roles these elements play in the physiological and biochemical processes in the plants are dramatic (Fig.3).

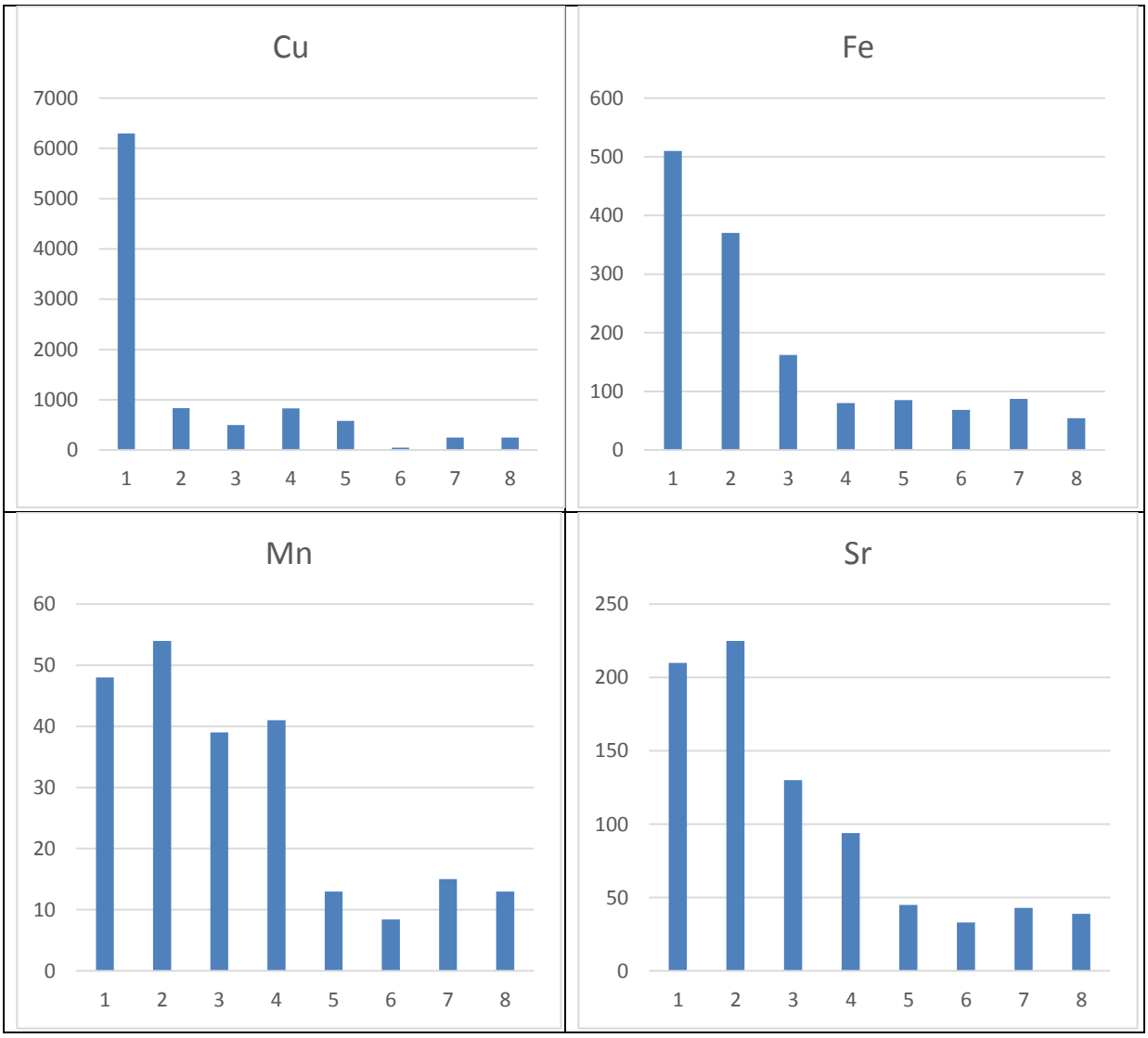


Figure 3. Concentrations of biogenic elements (Cu, Fe, Mn, Sr) in the above-ground organs of N. Schoberi taken in various parts of the Aral Sea region, µg/kg.

In: leaves collected in the Southern Aralkum in 2016 and in 2020 (1,2), leaves collected on the Ustyuart plateau and Vozrozhdemiya Island in 2020 (3,4), fruits collected in the Southern Aralkum in 2016 and in 2020 (5,6), fruits collected on the Ustyuart plateau and Vozrozhdemiya Island in 2020 (7,8). Our findings demonstrate significant differences in the concentrations of various chemical elements in the leaves and fruits of N. schoberi growing in the Southern Aralkum, on the Ustyurt plateau and Vozrozhdeniya Island. Thus, there were higher concentrations of sodium and chlorine in samples of plants collected in the Southern Aralkum in 2016 than those collected in 2020, while concentrations of barium, bromine, cobalt, iron, molybdenum and other chemical elements were found to decrease with time.

4. Conclusion

The neutron activation analysis was used to determine concentrations of 37 chemical elements

in the samples of roots, leaves and fruits of N. schoberi widely spread in the Southern Aralkum, on the Ustyuart plateau and Vozrozhdeniya Island, as well as those of 32 chemical elements found in the samples of soil taken at the various depths in the soil layers the plant reaches while growing. Our findings demonstrate significant differences in concentrations of chemical elements found in the samples tested. Some chemical elements were found only in specific samples. For instance, for the first time, rhenium (Re), according to literature occurring in the bowels of the earth, was found in the samples of roots and soil collected in 2020.

In addition, our findings demonstrate significant differences in concentrations of macro- and microelements found in samples of the above-ground and underground organs of N. schoberi growing on the desiccated bed of the Aral Sea, as well as unusually high concentrations of some chemical elements. Our findings suggest that macro- and microelement compositions of the plant are determined by the physiological processes taking place in the plant organism, as well as by the harmful environmental situation in the Aral Sea areas due to its desiccation and increase of earth mineralization. The data gathered in the course of the study can serve as a real proof that the Nitraria schoberi species populations growing in the Aral Sea areas are fit enough to grow on the soils with various degrees of salinity, and play a significant role in the stabilization of the quicksand and salt flats. It is recommended that the land reclamation should be performed by increasing the number of the species aiming at recovery of the ecosystem formed and existing on the Aral Sea's dessicated bed and in the Aral Sea areas for the land to be improved. Chemical composition, biological and pharmacological features of the Nitraria schoberi species should be further analyzed considering the plant as the promising one for the plant breeding, elimination of ecological problems, land improvement and decoration, as well as the unique raw material for the food and pharmaceutical industries.

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