Advances in Biological Sciences Research, volume 7
1st International Symposium Innovations in Life Sciences (ISILS 2019)

Accumulation of artificial and natural radionuclides in medicinal plant material in the Central Black Soil Region of Russia

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***Abstract*—Levels of strontium-90, cesium-137, thorium-232, potassium-40, and radium-226 were studied in medicinal plant species, along with the accumulation of these elements from soils. Medicinal plant raw materials from ten plant species were collected in 36 sampling points in the Voronezh Region. Findings indicate that the main accumulators of cesium-137 isotopes were the leaves of the broadleaf plantain, the grass of the common motherwort, the grass of the common wormwood, and the leaves of the common nettle (accumulation coefficients were greater than 1.5). Cesium-137 was most prevalent in the leaves and grass, and to the least extent in flowers and underground organs. Strontium-90 was most evident in the roots of the greater burdock and the roots of the common dandelion. Isotopes of radioactive strontium-90 accumulated more in underground plant organs, and less in aerial plant organs. The leaves of the broadleaf plantain, the leaves of the common nettle, the roots of the common dandelion and the roots of the greater burdock showed the highest ability to accumulate natural and artificial radionuclides fixated by soil.**

Keywords*—medicinal plant material, Voronezh Region, strontium-90, cesium-137, thorium-137, potassium-40, radium-226

I. Introduction

A significant part of the procurement of medicinal plant materials in Russia is concentrated in the Black Soil Region, particularly in Voronezh Oblast. The development of mineral resources, intensive agricultural practices associated with the usage of pesticides and herbicides, the consequences of the Chernobyl catastrophe – all of these factors exacerbate the problem of providing the medical and pharmaceutical industries with a variety of safe plant materials to meet their needs. Phyto remedies derived from contaminated plant materials are one of the sources of pollutants entering the human body [1-3]. Radionuclides with their ability to migrate along biological chains are one of the most dangerous pollutants of the Biosphere [4-6].

The aim of the research was to assess levels of radioactive contamination of upper soil layers and medicinal raw materials in Voronezh Region, and to identify the accumulative abilities of different wild medicinal plants species in relation to radionuclides.

II. Experimental

The research was conducted in Voronezh Region, which is typical of Russia's Central Black Soil Region. The choice of upper soil layer sampling areas reflected the character of specific anthropogenic impacts (Fig.1): chemical rubber plant “GSE-Giprokauchuk” (28), Joint-Stock Company “Minudobreniya” (23), “Borisolglebsk Engineering” («Bormash») (24); combined heat and power plant “Voronezh 1” (“VOGRES”) (27), Novovoronezh nuclear power plant (NPP) (8), Voronezh Airport (30), a city street (Street Leningradskaya) (31), high voltage power lines (HVPL) (9), Voronezh water reservoir (29), small towns with developed light industry (Kalach (26), Borisoglebsk (25)), intended nickel mining zone (4), areas of intensive agricultural activity (Districts: Liskinsky (10), Olkhovatsky (11), Podgorensky (12), Petropavlovsky (13), Gribanovsky (14), Khokholsky (15), Novokjopersky (16), Repyovsky (17), Vorobyovsky (18), Paninsky (19), Ertilsky (20), Verkhnekhavsky (21), Rossoshansky (22)), areas affected by radionuclide contamination as a result of the Chernobyl nuclear power plant disaster (Nizhnedevitsky (5), Ostrogozhsky (6), and Semiluksky (7) districts) and for comparison, natural conservation areas (Voronezh Nature Reserve (1), Khopersk State Nature Reserve in Novokhopersk (2) and Borisoglebsk Districts (3)). Additional medicinal raw materials were collected near highways and railways (highway M4 «Don» in Ramon’ (32) and Pavlovsk (34) Districts, highway A144 in Anna District (33), a non-speed road in Boguchar District (35) and a railway line in Ramon’ District (36)).

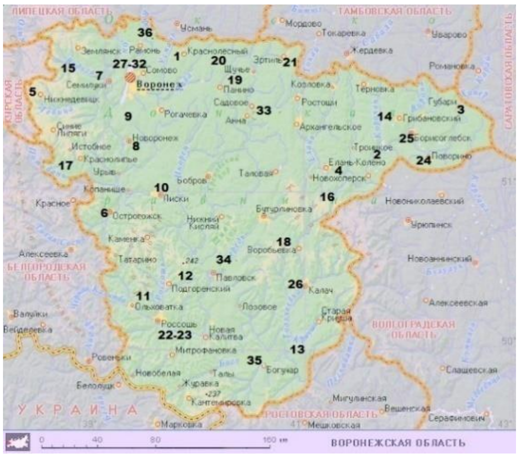

Fig. 1. Map of the sampling points of soil and medicinal plant materials (symbols are explained in the text).

In all areas, we sampled upper soil layers (0-10 cm deep) and different species and parts of these medicinal plants: prostrate knotweed grass (Polygonum aviculare L.), common wormwood grass (Artemisia absinthium L.), yarrow grass (Achillea millefolium L.), common motherwort grass (Leonurus quinquelobatus Gilib.), broadleaf plantain leaves (Plantago major L.), common nettle leaves (Urtica dioica L.), small leaved linden flowers (Tilia cordata Mill.), tansy flowers (Tanacetum vulgare L.), common dandelion roots (Taraxacum officinale F.H. Wigg), greater burdock roots (Arctium lappa L.). We used shadow drying at temperature 40-45 °C under fair ventilation. The accumulation coefficient (AC) characterizes the intensity of the transfer of radionuclides from the soil to the plant, and is equal to the ratio of the specific activity of the radionuclide in the air-dried sample of medicinal plant materials to the specific activity of the radionuclide in the soil. The calculations were carried out according to the formula (1):

$$CA = C_{MPM} / C_{soil}, \qquad (1)$$

where C_{MPM} is the specific activity of a radionuclide in air-dried sample of the medicinal plant material (Bq/kg); and C_{soil} isthe specific activity of the radionuclide in the upper soil layers (Bq/kg) [7-9].

The analysis of soil samples and medicinal vegetable raw materials was carried out using a MKGB-01 RADEK γ-β-α-spectrometer/radiometer with ASW programming. We measured levels of the main long-life artificial radionuclides (Sr-90, Cs-137) and common naturally occurring radionuclides (K-40, Th-232, Ra-226).

III. Results and discussion

An analysis of the existing regulatory documentation showed that the maximum permissible concentration of radionuclides in the soil has not been defined. However, it is still possible to assess the degree of radionuclide contamination of the samples. The districts of the north-western part of the region (Ramonsky, Verkhnekhavsky, Nizhnedevitsky, Semiluksky, Repyovsky, Khokholsky and Voronezh-city) are characterized by a higher specific activity of Cs-137 relative to the average for the region. However, these values are small - about 50-60 Bq/kg. The slightly increased level of specific activity in these areas can be attributed to the fact that they were all inside the zone of Chernobyl radioactive fallout in 1986. Values of specific radioactivity of natural radionuclides are close to the world average. Specific activities of K-40 and Th-232 slightly exceeded the world average (by 12% and 19%, respectively). This can be explained by the fact that the chernozem (black) soils of the Voronezh Region are characterized by high specific activity values of natural radionuclides (500 Bq/kg for K-40 and 44 Bq/kg for Th-232).

Analysis of plant raw materials showed that the specific activity of radionuclides does not exceed the maximum permissible values [10] in all collected samples. In order to assess the ability of different plant species to accumulate artificial and natural radionuclides, accumulation coefficients were calculated. Average accumulation coefficients for radionuclides in different plant species in the Voronezh Region are represented in the Table I.

An analysis of the data showed that thorium-232 is the least accumulated by plants (AC varies from 0.15 in small leaved linden flowers to 0.49 in greater burdock roots, with an average of 0.28 for all studied plants).

Accumulation of cesium-137 and potassium-40 occurred to a high degree (AC averages were 1.36 for Cs-137 and 1.34 for K-40). At the same time, AC values vary significantly depending on raw plant material type: for cesium-137 they range from 0.39 in small leaved linden flowers to 2.55 in broadleaf plantain leaves, and for potassium-40 from 0.90 in tansy flowers to 1.85 in common motherwort grass. The transition and accumulation of Cs-137 and K-40 from

TABLE I. Accumulation Coefficients for Radionuclides in Different Medicinal Plant Species

Medicinal plant material	Accumulation coefficients for radionuclides				
	Strontium-90	Cesium-137	Thorium-232	Potassium-40	Radium-226
Prostrate knotweed grass (Polygonum aviculare L.)	0.55	1.09	0.17	1.36	0,50
Common wormwood grass (Artemisia absinthium L.)	0.76	1.70	0.23	1.68	0,74
Yarrow grass (Achillea millefolium L.)	0.59	1.02	0.13	1.04	0,59
Common motherwort grass (Leonurus quinquelobatusGilib.)	0.61	1.87	0.20	1.85	0,56
Broadleaf plantain leaves (Plantago major L.)	1.12	2.55	0.37	1.47	0,93
Common nettle leaves (Urtica dioica L.)	1.07	1.41	0.42	1.59	1,06
Small leaved linden flowers (Tilia cordata Mill.)	0.39	0.39	0.15	0.98	0,47
Tansy flowers (Tanacetum vulgare L.)	0.59	0.70	0.17	0.90	0,46
Common dandelion roots (Taraxacum officinale Wigg)	1.86	1.01	0.37	1.05	1,24
Greater burdock roots (Arctium lappa L.)	1.98	1.11	0.49	1.04	1,93
Average	0.99	1.36	0.28	1.34	0.85

soil to plants is connected with metabolic potassium. Plants that contain more metabolic potassium usually accumulate more Cs-137. K-40 accumulates in plants in direct proportion to concentrations of its non-radioactive isotope. Cesium and potassium are elements of the same group in Mendeleev's periodic table, and their mechanisms of capture from the soil and transportation in plant tissues do not differ. The distribution of Cs within individual plant organs and its movement inside the plant is associated with K, in particular, with K-40.

Accumulation of strontium-90 and radium-226 has a similar pattern for the studied plant species. Average AC values were 0.99 and 0.85, respectively. The AC values for Sr-90 varied from 0.39 in small leaved linden flowers to 1.98 in greater burdock roots, and AC values for Ra-226 ranged from 0.46 in tansy flowers to 1.93 in greater burdock roots. The similarity in the accumulation of these radionuclides can be explained by their similar chemical structures, as well as by another biologically important element – calcium. The mechanism of absorption of strontium, radium and calcium from the soil is almost identical. In terms of transportation, all three elements accumulate in the same plant organs and tissues.

IV. Conclusion

The main wild medicinal plant accumulators of radioactive isotope cesium-137 are broadleaf plantain leaves, common motherwort grass, common wormwood grass, and common nettle leaves. Cs-137 accumulates to a greater extent in leaves and grass, and to a lesser extent in flowers and underground organs. Highest accumulation of Sr-90 was found in greater burdock roots and common dandelion roots. Radioactive isotopes of strontium-90 accumulate to a greater extent in roots (underground plant organs), and to a lesser extent in the grass of plants. Medicinal raw plant materials with the greatest capacity for accumulating natural and artificial radionuclides fixed by soil are: broadleaf plantain leaves, common nettle leaves, common dandelion roots, and greater burdock roots. With the exception of Radioactive isotope K-40, none of the radionuclides studied accumulated appreciably in the flowers (AC values fluctuated from 0.39 to 0.70).

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