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THE STUDY OF GROSS BETA-RADIOACTIVITY OF *ELEUTHEROCOCCUS SENTICOSUS* AND SOME OTHER MEDICINAL PLANTS THAT HAD BEEN GROWN IN HYDROPONICS AND ON SOILS IN THE ARARAT VALLEY AND DILIJAN FOREST ZONE

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Abstract. *It is known that natural and technogenic radionuclides (RN) along the biogeochemical chains of agrocenoses can enter the human body through irrigation water-soil-plants, as well as through nutrient solution-substrate-plants in a hydroponic system, leading to the development of dangerous diseases. Monitoring and obtaining radioactively safe medicinal raw materials are priority issues. Research has been conducted in the Ararat Valley and at the Dilijan Forest Experimental Station (DFES) since 1996 to understand and control the levels of radionuclides in water, soil, and plant ecosystems. The investigations of RN in agricultural ecosystems are important because they can lead to the development of protection measures to be used in polluted areas and improve the safety of agricultural products. The radio-chemical studies have shown that certain medicinal plants, such as Eleutherococcus senticosus, Withania somnifera, Rosmarinus officinalis, Lavandula angustifolia, and Cichorium intybus, cultivated in outdoor hydroponics and soils of Ararat Valley and DFES, have gross β-radioactivity levels that do not exceed the threshold of 1.0 Bq/g, making them radioecologically safe for use as medicinal raw materials. The research demonstrates that E. senticosus grown in the conditions of the biogeocenosis of the DFES accumulated two times less RN in its leaves than it did in the hydroponic vegetative vessels situated in the Ararat Valley. Medicinal plants grown in hydroponics and soil show a similar gross β-radioactivity decreasing pattern, with only slight deviations, as follows: W. somnifera > L. angustifolia > C. intybus > R. officinalis > E. senticosus. The content of controlled technogenic RN (^{90}Sr, ^{137}Cs) in natural waters, soils, and medicinal plants of the Ararat Valley and DFES did not exceed the maximum allowable concentrations (MAC).*

Keywords: *hydroponics, medicinal plants, gross β-radioactivity, technogenic radionuclides*

1. Introduction

Armenia is known for its diverse and unique vegetation, as it falls within two different climatic zones: continental and temperate-subtropical. There are around 4000 species of plants found in the country, many of which have been used for their medicinal properties for centuries. The healing properties of the plants in the Armenian highlands have been known since ancient times. Many plants have medicinal properties, and they can accumulate natural and technogenic RN in certain organs, such as leaves, stems and roots. These RN can then pass through the ecological chain (irrigation water-soil-plant material-dosage form-person, and nutrient solution-substrate-plant material-dosage form-person) and eventually into the human body through dosage forms. It is important to note that the accumulation of RN in plants can have negative impacts on human health, therefore, it needs to be studied and understood before plants can be used for medicinal purpose [1-12].

Our long-term studies have found that the levels of technogenic RN, specifically ^{90}Sr and ^{137}Cs (^{90}Sr - $T_{1/2}$ = 28.6 years; ^{137}Cs - $T_{1/2}$= 30.1 years), in the Ararat Valley, where the Armenian Nuclear Power Plant (ANPP) is located, did not exceed the MAC in the systems of irrigation water-soil-plant and nutrient solution-substrat-plant of the agrocenoses [13, 14]. This suggests that the technogenic RN present in these systems does not pose a significant health or environmental risk. Consequently, it is important to study the gross β-radioactivity of medicinal plants in the specific conditions of the Ararat Valley and DFES to ensure the safety of plant raw materials intended for medicinal use. This research has both scientific and practical significance as it helps to understand the levels of radioactivity in these plants and identify which plants are safe to use for medicinal purposes. Monitoring of the radioecological safety of these medicinal plants can help mitigate any potential risks to human health or the environment.

2. Materials and methods

The studies were carried out between 2018 and 2021 at the Institute of Hydroponics Problems (IHP) located in the Ararat Valley (city of Yerevan, zone with a 30 km radius from the ANPP) and in the DFES (zone with a 100 km radius from the ANPP). The Ararat Valley is located at an elevation of about 850-900 m above sea level, and it is surrounded by the Greater and Lesser Ararat from the south and south-west, Mount Aragats from the northwest, Urts and Gegham ridges from the northeast. The climate in this area is severe and dry with average monthly temperatures reaching 25-26 °C during July and August, and an average annual

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precipitation of 200-300 mm. DFES is located near the city of Dilijan, at an elevation of 1400-1500 m above sea level. The average annual temperature is 8.1 °C, and the average annual precipitation is 660-750 mm. The upper horizons of the soils in the DFES are brown and rich in humus (9.0-9.3 %). They are also rich in potassium but poor in nitrogen and phosphorus [15, 16]. It is important to consider these environmental factors when assessing the radioecological safety of medicinal plants in this region. In hydroponics, the plants were nourished with a nutrition solution provided by G.S. Davtyan (N=200 mg/L, P=65 mg/L, K=350 mg/L), 1-2 times a day in spring and autumn, and 2-3 times a day in summer [14, 17]. The hydroponic substrate used in the study was a mixture of gravel and volcanic slag in a 1:1 ratio of those materials with particles of 3-15 mm in diameter. This substrate was disinfected prior to use with a 0.05% solution of potassium permanganate ($KMnO_4$). The soil in the region where the study was conducted is classified as semi-desert, irritable, carbonate, with 1.5-2.5% humus content, and rich in phosphorus and potassium. Agrotechnical rules such as spudding, weed removal, periodic irrigations (once every 3-4 days), and manuring were kept in the soil culture. For the study the samples were taken from the artesian water (irrigation water), nutrient solution, soil layers with depth of 0 - 30 cm and from the above-ground mass of a number of herbs introduced into Armenia: Siberian ginseng – *Eleutherococcus (E.) senticosus* (Rupr.&Maxim.), Ashwagandha – *Withania (W.) somnifera* L. Dunal, Rosemary – *Rosmarinus (R.) officinalis* L., English lavender – *Lavandula (L.) angustifolia* L. and from the root of Common chicory – *Cichorium (C.) intybus* L.. The gross β-radioactivity of samples and content of ^{90}Sr and ^{137}Cs in them were determined with radio-chemical extraction methods using a radiometer UMF-1500 (made in Russia) with low background [18]. ^{90}Sr was determined by the oxalate method with ^{90}Y. Radionuclides were determined in the dry sediments of water, nutrient solution, ash of plants and soils. The following chemical reagents were used for the analysis: $C_2H_2O_4$, HNO_3, HCl, CH_3COOH, CsCl, Y_2O_3, YCl_3, K_2SO_4, KI, $Sr(NO_3)_2$, $CeCl_3$, $Ni(NO_3)_2$, $SbCl_3$, $K_4[Fe(CN)_6]\bullet 3H_2O$, etc. Statistical analysis of the results was done using GraphPad Prism 8. The obtained results were compared to the MAC [19-21].

E. senticosus (Rupr.&Maxim.), commonly known as Siberian ginseng, is a medicinal plant that has been traditionally used to improve physical and mental performance and to treat a variety of conditions, including diabetes, cancer, neurological disorders, and infections (Figure 1). Studies have shown that it has adaptogenic, antioxidant, anti-tumor, neuroprotective, immunomodulatory, antibacterial, and antiviral properties [22, 23, 25].

a b c d

Figure 1. *E. senticosus* in hydroponics (a, b) and soil of DFES (c, d)

C. intybus L. is a perennial medicinal plant that belongs to the Asteraceae family (Figure 2). The whole plant, including the leaves, stem, and root, has been traditionally used for medicinal purposes. The root of the plant is commonly roasted and used as a coffee substitute and additive, while the leaves are often used as a salad green or cooked as a vegetable. The medicinal properties of chicory include antioxidant, anti-inflammatory, and anti-cancer effects. The root of the plant is also a source of inulin and a type of dietary fiber that is probiotic and can help to improve digestion and gut health [24].

a b c

Figure 2. *C. intybus* L. in hydroponics (a - flowers, b - root) and soil (c - root)

W. somnifera L. is a medicinal plant that has been used for centuries in Ayurvedic medicine (Figure 3). It is commonly referred to as Indian ginseng and is known for its adaptogenic properties, which means it helps the body adapt to stress. Additionally, it has anti-inflammatory, antioxidant, immune-boosting, neuroprotective, and cardioprotective properties. It is used to treat a wide range of conditions, including anxiety, stress, insomnia, and chronic pain. It has also been shown to have potential benefits for cognitive function, fertility, and as an anti-cancer agent [25-27].

Figure 3. *W. somnifera* L. in the vegetative vessels of hydroponic system

a b

Figure 4. *R. officinalis* (a) and *L. angustifolia* (b) in hydroponics

The healing properties of the medicinal plant *R. officinalis* L. are thought to be due to its bioactive compounds, particularly phenols and phenolic acids.

Similarly, *L. angustifolia* L. has been used for a long time in medicine and cosmetics production (Figure 4). It has been traditionally used for a wide range of conditions such as anxiety, insomnia, depression, headaches, and to promote wound healing [28].

3. RESULTS AND DISCUSSION

The results of the study have shown that the activity concentration of technogenic RN (^{90}Sr, ^{137}Cs) in the hydroponics nutrient solution used for the cultivation of medicinal plants was 10 times higher than in the artesian water. This suggests that the increase in radioactivity is likely due to the presence of RN in the chemicals used to prepare the nutrient solution. The study was revealed also that the content of ^{90}Sr exceeded the content of ^{137}Cs in artesian water, tap water, and brown soil in the DFES area by 14.6, 18.5, and 1.7 times, respectively. This suggests that the radioactivity of RN in natural waters and soils is significantly lower than the MAC. The results indicate that in hydroponics the source of RN in plants is the nutrient solution, while in soil culture – the irrigation water and soil (Table 1). It is suggested that in the Ararat Valley, the RN entered the medicinal plants through the above-ground organs from the air basin (precipitations, dust, smoke, ash and aerosols) [1]. DFES is located in an area with high precipitation, and the RN entered the plants simultaneously from precipitation through the above-ground organs and from the soil through the roots.

Table 1. The content of ^{90}Sr, ^{137}Cs and ^{40}K in natural waters, nutrient solution and soils in Ararat valley and DFES

Samples were taken from	Sample type	^{90}Sr	^{137}Cs	^{40}K
		Bq/L, Bq/kg*		
IHP	artesian water	0.044±0.002	0.003±0.0001	0.1
	nutrient solution	0.44±0.030	0.030±0.001	9.4
	gray soils*	6.9*±0.27	8.0* ±0.25	421*
DFES	drinking water	0.037±0.002	0.002±0.0001	0.08
	forest brown soils*	11.9*±0.30	7.0*± 0.20	540*
MAC [19, 21]	for drinking water	5.0	11.0	-

Bq/kg-for soils*

The study found that the accumulation of RN in medicinal plants in the Ararat Valley varies depending on the cultivation method (Figure 5). The gross β-radioactivity of herbs grown in hydroponics ranges from 450 to 740 Bq/kg, while in the soil it ranges from 210 to 690 Bq/kg. Additionally, it has been observed that plants grown in hydroponics tend to accumulate more RN than those grown in soil, with a difference of 1.1 to 2.1 times. It is possible that, this difference is conditioned by the ability of crops in hydroponics to absorb more RN. One of them is ^{40}K, a radioactive isotope of natural potassium being 0.0119 % of the total K (350 mg/L) in the Davtyan's nutrient solution [17]. It is known that the gross β-radioactivity of plants is mainly conditioned with amount of K, since the highest β-radioactivity (89.33%) and γ-radioactivity (10.67 %) from the RN has a natural radionuclide ^{40}K. In higher plants, the share of ^{40}K in the gross β-radioactivity of ash can reach 50 – 60 % [12].

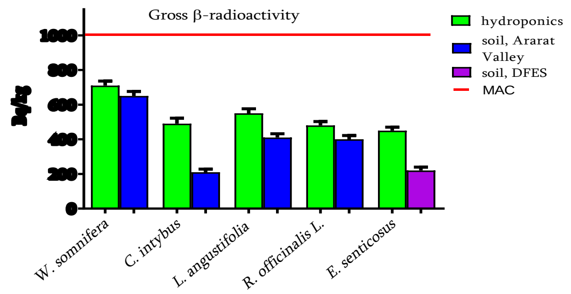

Figure 5. Gross β-radioactivity of medicinal plants in hydroponics and soil of Ararat Valley and Dilijan forest zone

The results of our long-term studies demonstrated that the proportion of ^{90}Sr and ^{137}Cs in gross β-radioactivity in various plant species (vegetables, fruits, etc.) grown in hydroponics is between 2.3-6.8 %, while in the soil it is between 2.9-12.8 %. Thus, the content of ^{90}Sr and ^{137}Cs in hydroponic plants is 1.1-2.1 times less than in soil plants [13, 14]. This difference is thought to be due to the lower concentration of ^{90}Sr and ^{137}Cs in the nutrient solution used in hydroponics compared to soil (Table 1).

Table 2. The share of ^{90}Sr, ^{137}Cs in gross β–radioactivity in raw materials of medicinal plant

Sample type	Culture conditions	^{90}Sr	^{137}Cs	Other RN
		share in gross β-radioactivity, %		
E. senticosus	hydroponics	0.7	1.1	98.2
	soil	1.6	2.9	95.5
W. somnifera	hydroponics	0.4	0.4	99.2
	soil	0.7	0.8	98.5
R. officinalis	hydroponics	0.6	0.7	98.7
	soil	0.9	1.1	98.0
L. angustifolia	hydroponics	0.3	0.6	99.1
	soil	0.8	1.2	98.0
C. intybus	hydroponics	0.4	0.8	98.8
	soil	1.9	2.5	95.6

Additionally, the study found that *E. senticosus* grown in the soil of DFES accumulated two times less RN in leaves than those grown in hydroponic vegetative vessels located in Ararat Valley (Figure 5). This suggests that the specific growing conditions and location may also play a role in the accumulation of RN in plants.

The studies suggest that the concentration of RN in medicinal plants mainly depends on the ability of the specific plant to selectively absorb mineral nutrients, rather than the activity of RN in the root environment (soil or nutrient solution). This is consistent with the literature data [29]. The studies also found that in the gross β-radioactivity of herbs (other than ^{90}Sr and ^{137}Cs), the share of natural and technogenic RN in hydroponics is 98.2-99.2 %, and in the soil is 95.5-98.5 % (Table 2). This means that in the gross β- radioactivity of plants grown in hydroponics, the share of ^{90}Sr is 2.3-2.7 % and ^{137}Cs is 2.0-2.6 % lower than in soil-grown plants.

The RN relative indices presented in Table 3 show that the observed ratio (OR) of ^{90}Sr/^{137}Cs (OR = ^{90}Sr/^{137}Cs in plant ÷ ^{90}Sr/^{137}Cs in nutrition solution, OR = ^{90}Sr/^{137}Cs in plant ÷ ^{90}Sr/^{137}Cs in soil, transfer factor (TF) = RN content in plant ÷ RN content in nutrition solution, TF = RN content in plant ÷ RN content in soil) in plants is less than 1 (OR<1) in both hydroponics and soil. In soil it is strongly expressed near *E. senticosus* (OR = 0.3), and in hydroponics - near *L. angustifolia and C. intybus*, whose OR = 0.03. The TF for ^{137}Cs ranges from 13-163 in hydroponics and 0.6-0.9 in soil, while the TF for ^{90}Sr ranges from 0.7-7.0 in hydroponics and 0.3-0.6 in soil. The ^{137}Cs TF is greater than the ^{90}Sr TF in hydroponics by 18.5-23.2 times and in soil by 2.0-1.5 times.

Table 3. Values of relative indices (OR, TF) of ^{90}Sr – ^{137}Cs couple in nutrient solution–plant and soil-plant systems for medicinal plant

Sample type	OR		TF			
	hydroponics	soil	hydroponics		soil	
			^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs
E. senticosus	0.04	0.3	7.0	163	0.3	0.9
W. somnifera	0.07	0.9	0.9	13	0.6	0.7
R. officinalis	0.05	0.9	1.4	23	0.6	0.6
L. angustifolia	0.03	0.8	0.7	20	0.5	0.6
C. intybus	0.03	0.9	0.9	26	0.6	0.7

The medicinal plants grown in hydroponics and soil show a similar pattern of decreasing gross β-radioactivity, with *W. somnifera* having the highest levels, followed by *L. angustifolia*, *C. intybus*, *R. officinalis*, and *E. senticosus* having the lowest levels. Comparing to our previous results of investigation [14], the hydroponic medicinal plants show the following decreasing series in terms of gross β-radioactivity: *Asparagus officinalis* > *W. somnifera* > *Artemisia annua* > *Teucrium polium* > *Melissa officinalis* > *L. angustifolia* > *Lycium Barbarum* > *C. intybus* > *R. officinalis* > *Thymus marschallianus* > *Stevia rebaundiana* > *E. senticosus* > *Thymus serpyllum* > *Hypericum perforatium*. Regardless of the cultivation method, the obtained plant raw material can be considered ecologically safe because the gross β-radioactivity of the plant raw material did not exceed 1000 Bq/kg.

4. Conclusion

The levels of the controlled radioactive isotopes ^{90}Sr and ^{137}Cs in the natural waters, soils, and medicinal plants of the Ararat Valley and DFES are below the MAC and are considered safe from a radioecological perspective. Additionally, it is mentioned that medicinal raw materials grown in hydroponic settings and soil in both regions are also radioecologically safe.

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