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The study of gross beta-radioactivity of some medicinal plants in conditions of outdoor hydroponics and soil culture in Ararat Valley

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ABSTRACT

Background: Technogenic and natural radionuclides (RN) along the biogeochemical chains of agrocenoses may enter the human body through irrigation water- soil- plants- agricultural animals, likewise in hydroponic systems through nutrient solution substrate plants, leading to the development of dangerous diseases. Thus, control of herbal raw material's gross β-radioactivity and obtaining radioactively safe medicinal raw material are priority issues. Since 1996 we have carried out radio monitoring research in the Ararat valley (where the Armenian Nuclear Power Plant (ANPP) is located) in water, soil, and plant systems in zones of the ANPP with a radius of 2-15, 20 (the territory of Ashtarak city), 30 km (Yerevan, territory of Institute of Hydroponics Problems) (IHP), as well as Dilijan Forest Experimental Station (DFES) (the zone of ANPP with 90 km radius). Studies have shown that in natural waters (artesian water, Hrazdan, Qasakh, Metsamor rivers), soils and in various crops (vegetables, fruit of trees, etc.) of Ararat Valley the content of technogenic RN ^{90}Sr ($T_{1/2}$=28.6 years) and ^{137}Cs ($T_{1/2}$=30.1 years) did not exceed maximum allowable concentrations (for drinking water MAC ^{90}Sr=5.0 Bq/L, MAC ^{137}Cs=11.0 Bq/L; for vegetables and fruits MAC ^{90}Sr=50 Bq/kg, MAC ^{137}Cs=130 Bq/kg). Based on these studies, a complex of practical recommendations in this region will give the opportunity of obtaining ecologically pure agricultural products.

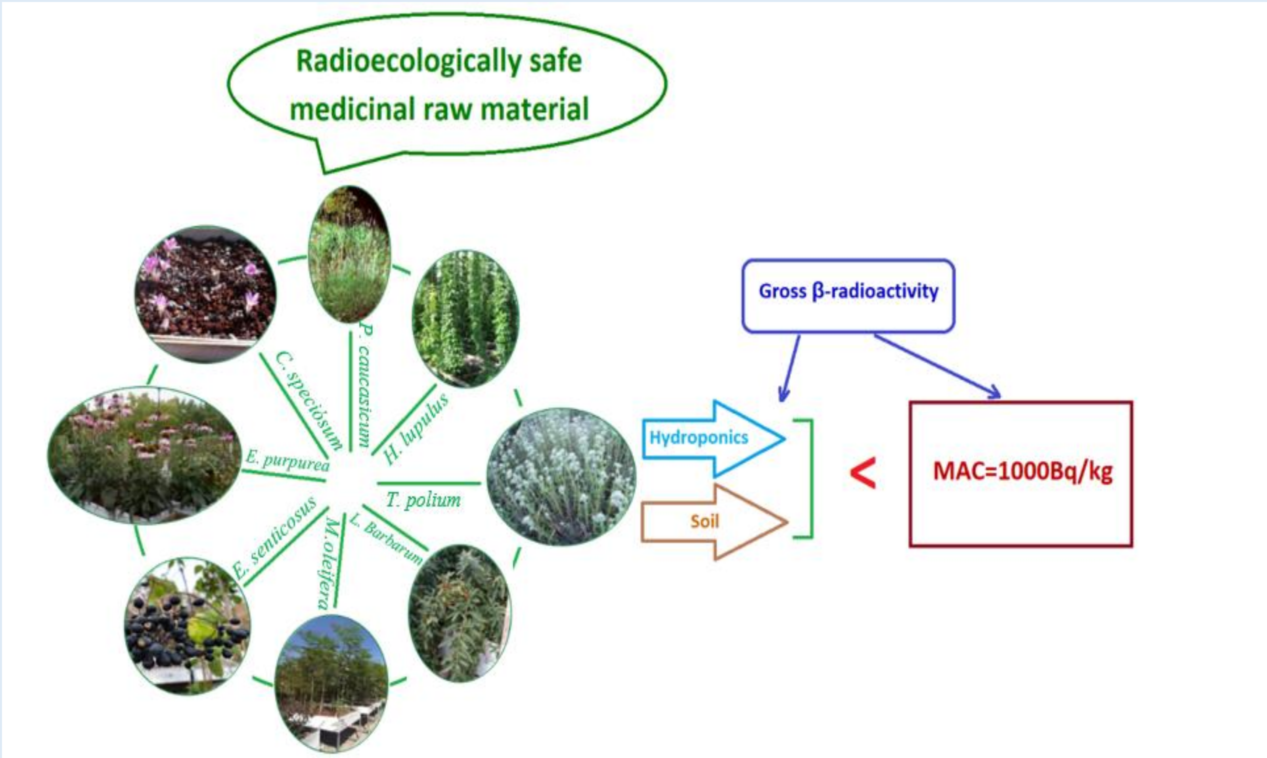
Objective: Considering that the accumulation of RN in medicinal plants poses a particularly great threat to obtaining radioecologically safe medicinal raw materials, during 2017-2022 we studied the specificities of gross β-radioactivity and accumulation of controlled technogenic RN (^{90}Sr and ^{137}Cs) in medicinal plants under hydroponics and soil conditions in the Ararat valley (the zone of ANPP with 30 km radius). This has a specific practical significance, as it will enable to obtain the most radio-ecologically safe plant material.

Methods: Gross β-radioactivity and content of ^{90}Sr and ^{137}Cs of samples (artesian water (irrigation water), nutrient solution, soil layers with depth of 0 - 30 cm and number of medicinal plants) in it were defined with radio-chemical extraction methods through the radiometer UMF-1500 (made in Russia) with low background. ^{90}Sr was determined by the oxalate method with ^{90}Y. RN were determined in dry sediments of waters, nutrient solution, the 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, $Sr(NO_3)_2$, $CeCl_3$, $Ni(NO_3)_2$, $SbCl_3$, $K_4[Fe(CN)_6]$ $3H_2O$ and others.

Results: The radio-chemical studies showed that the gross β-radioactivity of herbs in hydroponics fluctuated between 250 – 740 Bq/kg, and in soil: 140 – 690 Bq/kg. Thus, the medicinal raw material from the medicinal plants cultivated in outdoor hydroponics and soil, is radioecologically safe, since its gross β-radioactivity does not exceed the threshold of 1.0 Bq/g. Medicinal plants grown in hydroponics and soil, with a slight deviation, show the same gross β-radioactivity decreasing pattern as follows: *Peucedanum caucasicum* (M.Bieb.) K. Koch. > *Lycium barbarum* > *Eleutherococcus senticosus* (Rupr. & Maxim.) > *Teucrium polium* = *Humulus lupulus*, variety "Crystal" > *Echinacea purpurea* (L.) Moench > *Humulus lupulus*, variety "Chinook" > *Humulus lupulus*, variety "Newport" > *Colchicum speciosum* Stev. > *Moringa oleifera* Lam. Our studies have shown that the proportion of ^{90}Sr and ^{137}Cs together in gross β-radioactivity in different medicinal plants fluctuated between 1.0-7.4 % of dry mass in hydroponics and 1.7-10.1 % of dry mass in soil. In the gross β-radioactivity of medicinal plants the share of ^{90}Sr and ^{137}Cs in hydroponics was 1.4-1.7 and 1.3-1.5 times lower than that of soil plants.

Conclusion: In artesian waters, gray soils and different medicinal plants grown in hydroponic settings and soil of Ararat Valley the content of controlled technogenic RN (^{90}Sr and ^{137}Cs) did not exceed MAC. Both medicinal raw materials grown in hydroponic settings and soil in Ararat Valley are radioecologically safe.

Keywords: technogenic radionuclides, nutrient solution, herbal raw materials, ^{90}Sr, ^{137}Cs



INTRODUCTION: The contents of natural (^{40}K, ^{234}Th, ^{231}Th, ^{210}Pb, etc.) and technogenic (^{90}Sr, ^{89}Sr, ^{137}Cs, ^{134}Cs, etc.) radionuclides (RN) in plants' raw materials is an important indicator characterizing the quality, which must meet the accepted radioecological safety standards. It is known that many natural and technogenic RN are released to ecosystems because of human influence in the field of nuclear energetics. Armenia has an operating Nuclear Power Plant (NPP), a spent nuclear fuel repository, and regional low and intermediate level waste repositories. Plant food is an important link in the penetration of RN into the human body. RN can penetrate the human organism through the "irrigation water – soil – plants – agricultural animal'' biogeochemical chain of agrocenosis and likewise through the "nutrient solution - substrate - plant root'' in the hydroponic system. This process is especially typical in the Ararat Valley, where the Armenian NPP (ANPP) is located (Fig. 1). Different aspects of the environmental impact of ANPP are considered in detail [1, 2]. Since 1996 we have carried out radiomonitoring research in irrigation water – soil – plant systems of agrocenosis in different zones of the ANPP with a radius of 2 – 15 km (area of Taronik village), 20 km (area of Ashtarak city), 30 km (Yerevan city, area of Institute of Hydroponics Problems (IHP)), 90 km (area of the Dilijan Forest Experiment Station (DFES) of IHP), (Fig. 1). Based on these studies, practical radioprotective recommendations for obtaining the most radioecologically safe plant raw material have been developed [3].

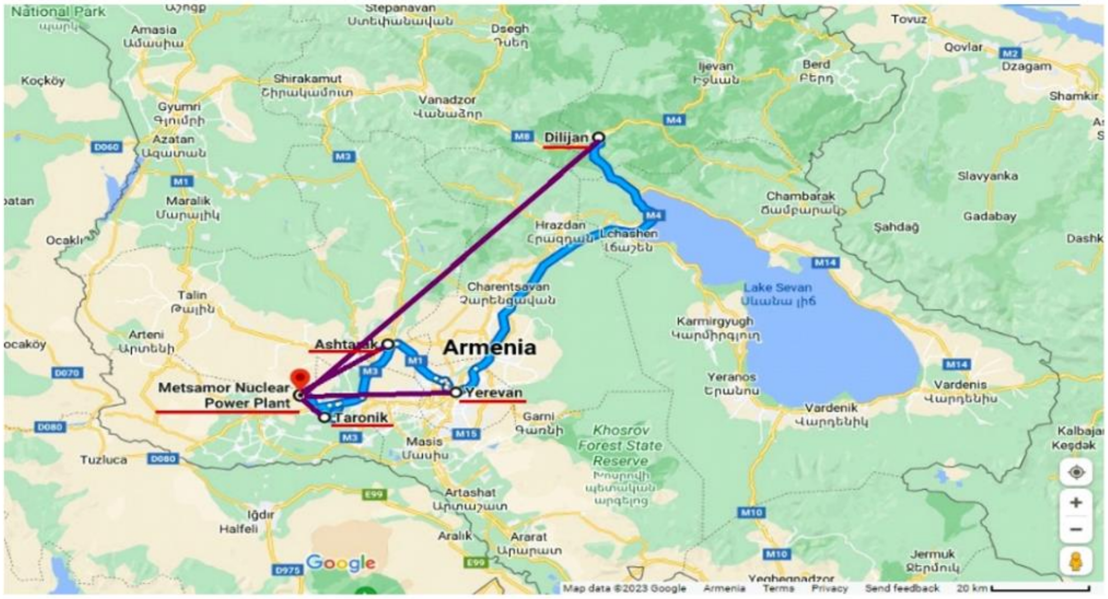


Figure 1: The map of RA taken from Google Maps. Purple lines show the distance of the radiomonitoring research zones from the ANPP.

a b c

Figure 2: *E. senticosus* (Rupr. & Maxim.) berries (a), in hydroponics (b) and soil (c)

Medicinal plants have been used in Armenia since time immemorial. Valuable medicinal *E.senticosus* (Rupr. & Maxim) from the *Araliaceae* family has an anti-radiation activity [4]. Preparations of this plant have adaptogenic property, and are endowed with antidiabetic, antioxidant, antitumor, neuroprotective, immunoregulatory, antibacterial and antiviral properties [5, 6], (Fig. 2).

The next plant with anti-radiation activity is *H. lupulus*. L. Due to the content of bioactive compounds (essential oil, resins, bitters, etc.) *H. lupulus*. L. is widely used in brewing and medicine. It has anticancer, antioxidant, and antimicrobial effects [7, 8], (Fig. 3).

M. oleifera Lam. is used in traditional medicine. It has hepatoprotective, anti-tumor, cholesterol lowering, anti-hypertensive, and anti-diabetic activities. Seeds

a b

Figure 3: *H. lupulus* L."Chinook" (a) *and M. oleifera* L. (b) in hydroponics

have an anti-inflammatory influence, leaves are effective against scurvy and osteomalacia [9-13], (Fig. 3). Moringa enhances of the antioxidant defense mechanisms of the organisms. Its protective effect against γ-radiation-induced hepatotoxicity and nephrotoxicity was shown [14]. *E. purpurea* (L.) Moench belongs to the family of Asteraceae or Compositae. It is used in medicine for a number of diseases, including disorders of the gastrointestinal tract, genitourinary, and respiratory systems, and it has strong immunomodulatory properties [15-17], (Fig. 4). The use of E. purpurea suppresses radiation-induced leukopenia, especially affecting lymphocytes and monocytes, and leads to a more rapid recovery of the number of blood cells [18].

L. barbarum L. has a radioprotective function, which is may be conditioned by immunomodulation and the synergistically modulating effect on the gut microbiota [19]. The homeland of *L. barbarum* L. (Goji) is China. In Buddhist monasteries, its fruits are called "a remedy for 1000 diseases". Goji berries lower cholesterol and sugar in the blood, and normalize blood pressure, work of the cardiovascular system. They have also antiviral and antitumor properties and are powerful antioxidants. Goji is used as an anti-stress agent [20], (Fig. 4).

C. *speciosum* Stev. belongs to the Colchicaceae family. Only 6 – 7 of its 160 species are found in Armenia. The preparations of *C. speciosum* Stev. have diuretic, choleretic, and emetic properties. The plant contains colchicine alkaloid, which is used in medicine for the treatment of periodic disease (Familial Mediterranean fever). Colchicine is greatly used in medicine for treating periodic disease [21]**.** Colchamine of *C. speciosum* Stev. is used in the treatment of malignant blood neoplasms [22, 23], (Fig. 5).

a b c

Figure 4: *L. barbarum* L. in fruiting phase (a), berries (b), and *E. purpurea* (L.) Moench. in flowering phase (c) in hydroponics

Figure 5: *C. speciósum* Stev. (a) in hydroponics, *P. caucasicum* (Bieb.) K. Koch. (b) and *T. polium* L. (c) in soil

T. polium L. has been used in Armenian traditional medicine since ancient times. In traditional Iranian medicine, it is used for treating many diseases, including abdominal pain, indigestion, and type 2 diabetes [24, 25], (Fig. 5). The use of *T. polium* L. extract attenuates oxidative stress, regulates brain-derived eurotrophic factor and by this ameliorate γ-radiation-induced brain injury [26].

P. caucasicum (Bieb.) K. Koch*.* belongs to the Umbelliferae family. There are 4 species in Armenia. Preparations of this plant are used as diuretics. *P. caucasicum* has an anti-microbial activity. The plant is registered in the Red Book of RA [27-29], (Fig. 5).

In recent years, there has been a growing demand for medicinal plants and the share of preparations obtained from medicinal plants is noticeably increasing in the pharmaceutical market. The latter can be justified by the fact that the preparations obtained from medicinal plants show a mild therapeutic effect, low toxicity, few expressed side effects and, finally, are economically beneficial. The broad spectrum of effects of preparations made from herbs is explained by the simultaneous existence of many biologically active substances in herbs. Herbal medicines are usually prescribed for preventive purposes in chronic diseases. Medicinal plants are widely used in the world to prevent or treat various diseases. Currently, more than 40% of preparations in pharmaceutical industry are of plant origin [27, 30]. Therefore, the control of the level of the gross β-radioactivity and the content of the most dangerous controlled technogenic RN (^{90}Sr - $T_{1/2}$ = 28.6 years, ^{137}Cs - $T_{1/2}$ = 30.1 years) in medicinal plants, as well as the assessment of the plant radioecological safety are considered actual issues [1, 2, 27, 30-40].

Considering the information above, we studied the characteristics of gross β-radioactivity and controlled technogenic RN (^{90}Sr, ^{137}Cs) accumulation in the above-mentioned medicinal plants under outdoor hydroponics and soil culture conditions in the area of IHP to obtain a radioecological safe medicinal raw material. These studies have both scientific and practical importance.

MATERIALS AND METHODSS

Study area and conditions: These studies were carried out during 2017 – 2022 in the territory of the IHP located in Yerevan, in Ararat Valley (ANPP technogenic influence zone with 30 km radius) (Fig. 1). Ararat Valley is in the south-western part of Armenia, about 850 - 900 m above sea level. The area has dry continental climate; the average annual temperature is 11.0 – 11.8 °C and average annual precipitation 200 – 300 mm [41].

Hydroponic plants were nourished with the G.S. Davtyan's nutrient solution (N = 200 mg/L, P = 65 mg/L, K = 350 mg/L, S = 150 mg/L, Ca = 150 mg/L, Mg = 50 mg/L, Fe = 2.8 mg/L, I = 0.76 mg/L, B = 0.5 mg/L, Mn= 0.49 mg/L, Zn = 0.38 mg/L, Mo = 0.09 mg/L, Cu = 0.05 mg/L, Co = 0.02 mg/L), [3], made on the base of artesian water. Gravel, volcanic slag and their mixture in a 1:1 ratio with particles 3 - 15 mm in diameter were used as a substrate. The soils of IHP territory are semidesert, irrigated, carbonate, and rich in phosphorus and potassium, with 1.5 - 2.5 % of humus content. Agrotechnical rules were kept in soil culture.

Radiochemical Measurement: RN (^{90}Sr, ^{137}Cs) were determined in dry sediments of waters, nutrient solution, the ash of plants, and soils. The following chemical reagents were used for the analysis: C_2H_5OH, $C_2H_2O_4$, HNO_3, HCl, CH_3COOH, CsCl, Y_2O_3, YCl_3, K_2SO_4, KI, $KMnO_4$, $Sr(NO_3)_2$, $CeCl_3$, $Ni(NO_3)_2$, $SbCl_3$, $K_4[Fe(CN)_6]\bullet 3H_2O$ and others.^{90}Sr was determined by the oxalate method with ^{90}Y. Gross β-radioactivity of samples and concentrations of RN (^{90}Sr and ^{137}Cs) in it were defined with radio-chemical methods through the radiometer UMF-1500 *(*made in RF*)* with low background [42]. Each plant measurement was repeated 3 times (n=3).

Statistical Analysis: The statistical analysis was done using GraphPad Prism 5 and Excel. $P < 0.05$ was considered statistically significant [43]. The received results were compared with Maximum Allowed Concentration (MAC) [1, 44, 45, 46].

Table 1: The content of ^{90}Sr, ^{137}Cs in artesian water, nutrient solution, and soils of IHP territory

Sample type	^{90}Sr	^{137}Cs
	Bq/L, Bq/kg*	
Artesian water (irrigation water)	0.044 ± 0.002	0.003 ± 0.0001
Nutrient solution	0.44 ± 0.030	0.030 ± 0.001
Gray soils*	6.9 ± 0.27*	8.0 ± 0.25*
MAC for drinking water [1, 44, 45]	*5.0*	11.0

General Features and Sampling: For the study the samples were taken from the artesian water (irrigation water), nutrient solution, soil layers with depth of 0 - 30 cm (Table 1) and from the up-ground mass of a few different herbs introduced to Armenia: Siberian ginseng – *Eleutherococcus (E.) senticosus* (Rupr. & Maxim.), moringa – *Moringa (M.) oleifera* Lam., Echinacea purpurea – *Echinacea (E.) purpurea* (L.) Moench, matrimony vine (goji) berries – *Lycium* (*L.*) *barbarum* L. *(*of Tibetan origin), hop cones – *Humulus (H.) lupulus* L. (American imported varieties “Chinook”, “Newport”, “Crystal”), Colchicum bulbs – *Colchicum (C.) speciosum* Stev., aboriginal: felty germander – *Teucrium (T.) polium* L., *Peucedanum caucasicum* – *Peucedanum (P.) caucasicum* (Bieb.) K.Koch.

Table 2: Concentrations of medicinal plants biologically active substances in different growing media

ulture	Growing media	α-acid content, %w/w	Essential oil, ml/100g	Tannins, %	Extractive substances, %	Flavonoids, %
Chinok [7]	Hydroponics	12,6±0,21	1,3±0,03	4,8±0,59	-	-
	Soil	12,5±0,13	1,5±0,14	5,4±0,45	-	-
Crystal[7]	Hydroponics	5,5±0,48	0,6±0,05	4,3±0,97	-	-
	Soil	5,6±0.51	0,75±0.04	6,19±0.98	-	-
Newport [7]	Hydroponics	12,9±0,49	0,9±0,07	2,8±0,22	-	-
	Soil	14,5±0,87	0,81±0,24	4,2±0,17	-	-
L. barbarum[47]	Hydroponics	39,8	-	2,3	65,1	1,2
	Soil	38,2	-	2,6	67,8	0,70
E. purpurea [48]	Hydroponics	-	-	-	29,1	2,4
	Soil	-	-	-	37,8	3,3
T. polium L. [49]	Hydroponics	-	-	-	20,0	2,6
	Soil	-	-	-	16,0	2,3

RESULTS: Our long-lasting experiments results show that the growing conditions influence the content of biologically active substances in medicinal plants (Table 2). According to our results the gross β-radioactivity of medicinal plants fluctuated between 250 – 740 Bq/kg in hydroponics, and between 140 – 690 Bq/kg in soil (Fig. 6). The gross β-radioactivity of medicinal plants cultivated in hydroponics exceeds those cultivated in soil by 1.1 – 1.8 times. In any case no result exceeded MAC. There are significant differences between hydroponic and soil variants for *E. senticosus* and *L. barbarum*.

Medicinal plants grown in hydroponics and soil show the same gross β-radioactivity decreasing pattern with a slight deviation: *P. caucasicum (M.Bieb.) K. Koch.* > *L. barbarum* L.> *E. senticosus (Rupr. & Maxim.)* > *T. polium* L.= *H. Lupulus* L., *"Crystal"* > *E. purpurea* (L.) Moench > *H. lupulus* L., *"Chinook"* > *H. lupulus* L., *"Newport"* > *C. Speciosum* Stev. > *M. oleifera* Lam. It should be noted that in hydroponics and soil, with minor exceptions "Newport" variety of hops is inferior to "Chinook" and "Crystal" varieties with gross β-radioactivity 1.1, and 1.3 times, respectively.

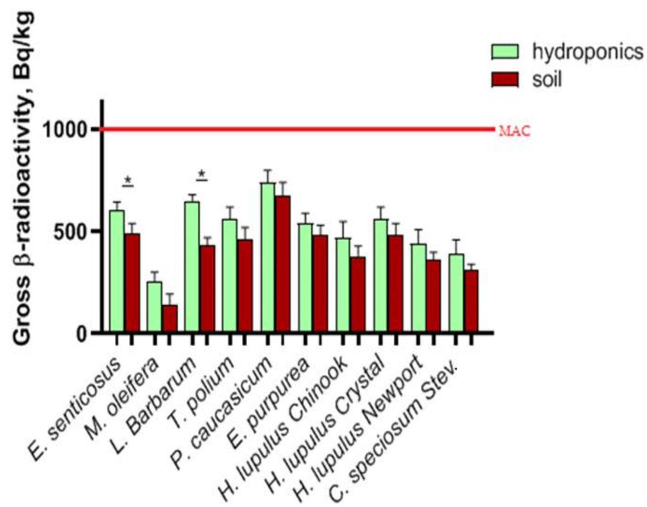


Figure 6: Gross β-radioactivity of medicinal plants in hydroponics and soil: * – $p < 0.05$.

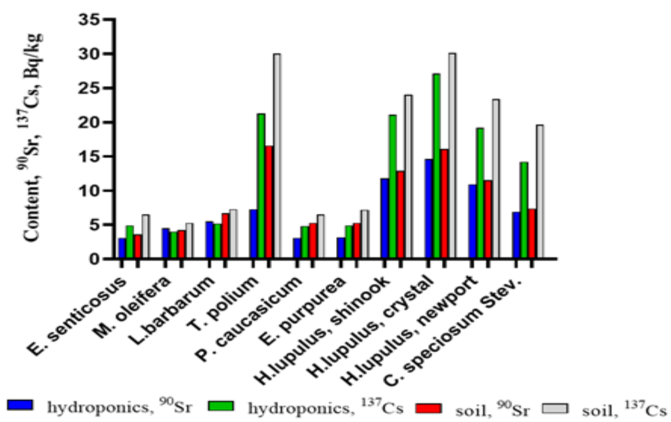


Figure 7: The content of ^{90}Sr, ^{137}Cs in medicinal plants in hydroponics and soil (MAC ^{90}Sr = 200 Bq/kg, MAC ^{137}Cs = 400 Bq/kg) [1, 44, 46]

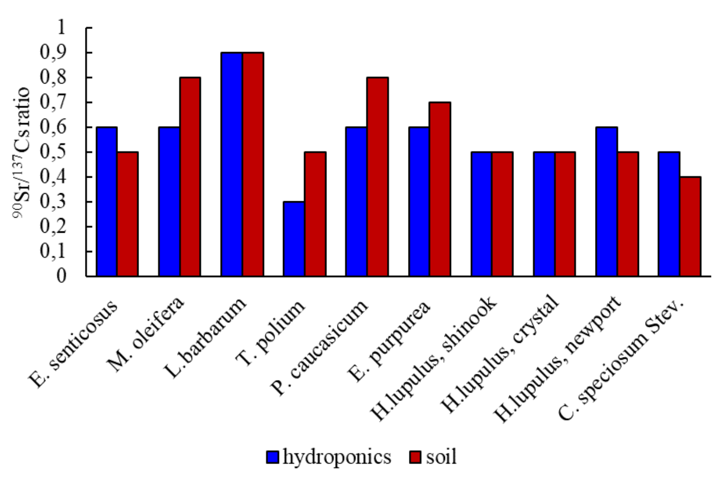


Figure 8: ^{90}Sr/ ^{137}Cs ratio in medicinal plants in hydroponics and soil

^{90}Sr in hydroponic plants ranged from 2.5 to 14.6 Bq/kg, and in soil from 3.6 to 16.1 Bq/kg, and ^{137}Cs from 4.0 to 27.1 Bq/kg and 5.3 to 30.1 Bq/kg, respectively (Fig. 7). "Newport" variety of hops is inferior to "Chinook" and "Crystal" varieties with content of ^{90}Sr, ^{137}Cs, 1.1; 1.4 times, respectively. So, although hydroponic plants exceeded soil plants in gross β-radioactivity, they are inferior to soil plants by the content of controlled technogenic RN: ^{90}Sr 1.1 – 1.4; ^{137}Cs 1.1 – 1.3 times. This is due to the fact that the concentration of ^{90}Sr and ^{137}Cs in the nutrient solution used in hydroponics is incomparably lower (16 and 267 times, respectively) than in soil (Table 1).

Figure 8 illustrates the ^{90}Sr/ ^{137}Cs ratio in medicinal plants in hydroponics and soil. Although the ratio of ^{90}Sr/^{137}Cs = 15 in nutrient solution and ^{90}Sr/^{137}Cs = 0.9 in soil, the ratio of ^{90}Sr/^{137}Cs in medicinal plants in both hydroponics and soil is the same and varies between 0.3 and 0.9.

As shown in Figure 9 the proportion of ^{90}Sr and ^{137}Cs in gross β-radioactivity of different medicinal plants fluctuated between 0.4 – 2.6 % and 0.6 – 4.8 % in hydroponics and 0.7 – 3.6 % and 0.9 – 6.5 % in soil, respectively. It means that in the gross β - radioactivity of medicinal plants the share of ^{90}Sr and ^{137}Cs in hydroponics was 1.4 – 1.7 and 1.3 – 1.5 times lower than that of soil plants.

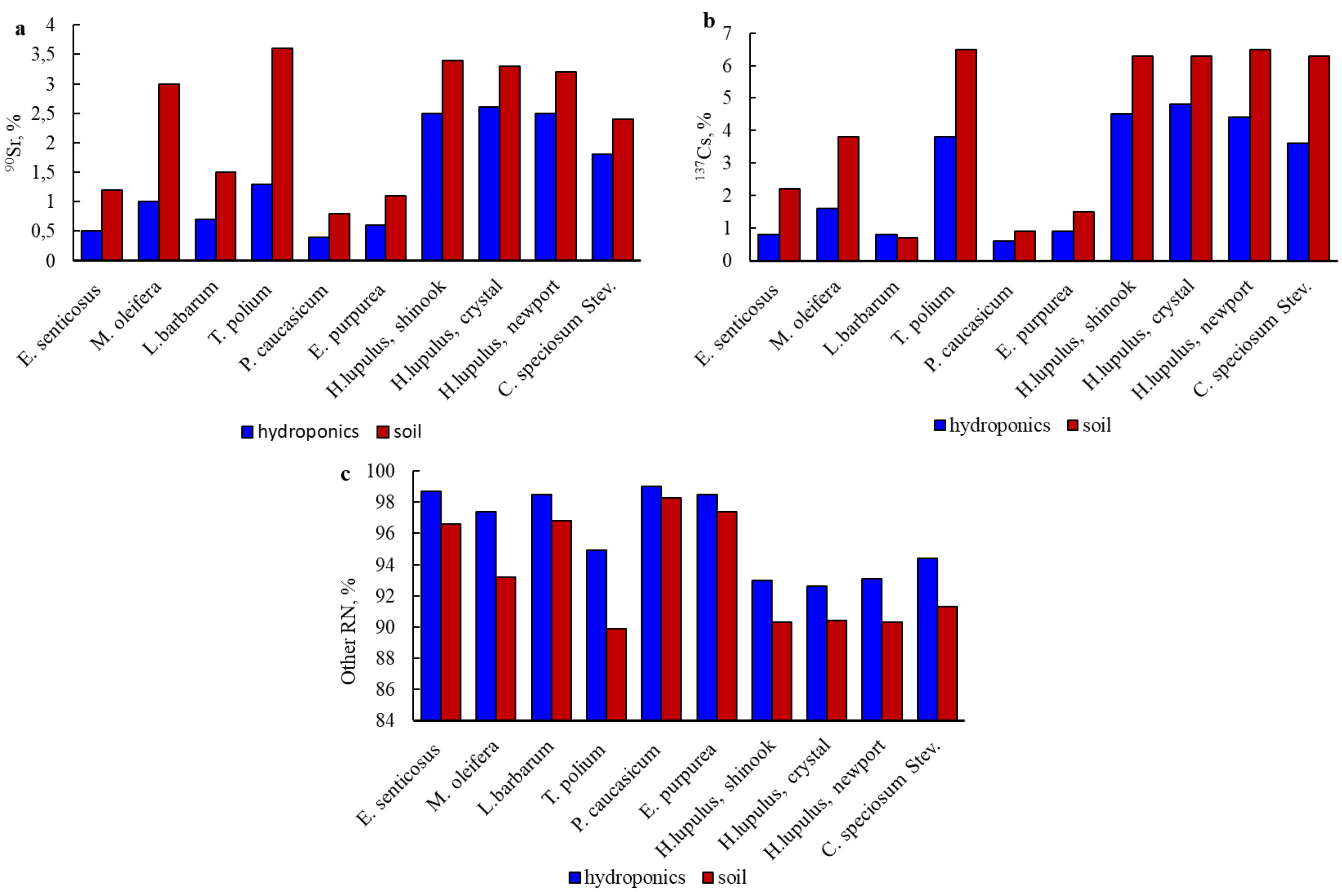


Figure 9: The share of ^{90}Sr (a), ^{137}Cs (b), and other RN (except ^{90}Sr, ^{137}Cs) (c) in gross β-radioactivity in medicinal plants in hydroponics and soil

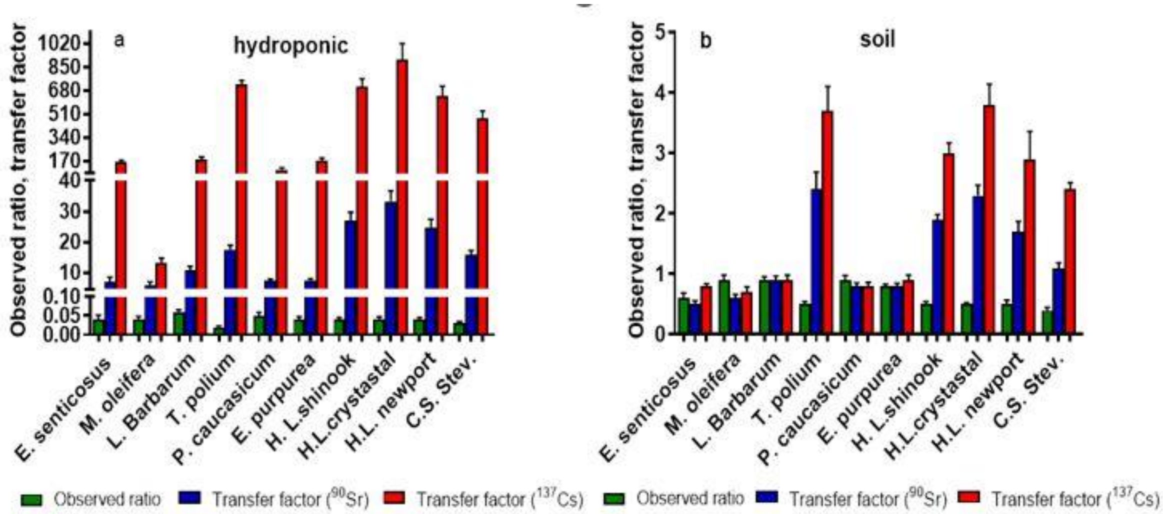


Figure 10: Observed ratio and transfer factor of ^{90}Sr - ^{137}Cs couple in nutrient solution - plant (a) and soil - plant (b) systems for s medicinal plants

Figure 10 illustrates values of relative indices of ^{90}Sr - ^{137}Cs couple (observed ratio, $OR = \frac{\frac{90Sr_{in\ plant}}{137Cs_{in\ plant}}}{\frac{90Sr_{in\ nutrient\ solution}}{137Cs_{in\ nutrient\ solution}}}$, $\boldsymbol{OR} = \frac{\frac{90Sr_{in\ plant}}{137Cs_{in\ plant}}}{\frac{90Sr_{in\ soil}}{137Cs_{in\ soil}}}$, **transfer factor,** $\boldsymbol{TF} = \frac{RN\ content\ in\ plant}{RNcontent\ in\ nutrient\ solution}$, $\boldsymbol{TF} = \frac{RN\ content\ in\ plant}{RN\ content\ in\ soil}$) in nutrient solution-plant and soil-plant systems for medicinal plants.

It should be noted that when calculating the TF of RN, we accounted for the amounts of RN that penetrated plant roots from the soil or nutrient solution and from the air basin into the above-ground organs of plants at the same time. OR values ranged from 0.02 to 0.06 in hydroponics and 0.4 – 0.9 in soil. That is, the OR value in hydroponics is 15 – 20 times smaller than in soil**.** OR is used to quantitatively express the preferential absorption of one radionuclide over another radionuclide by a plant.

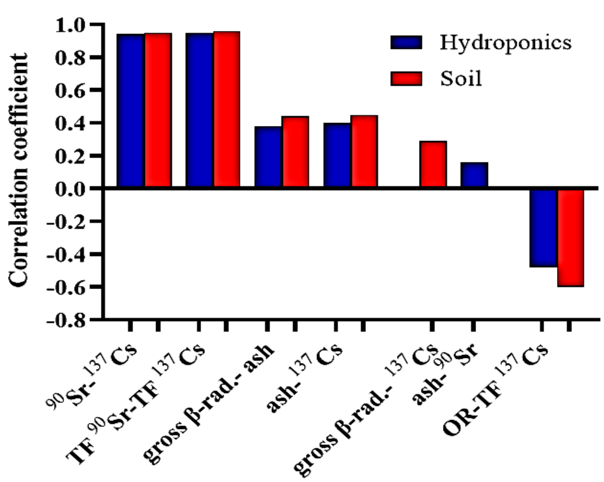


Figure 11: Correlation coefficients between agro-radiochemical indices of medicinal plant in hydroponics and soil. The correlation between the pairs (^{90}Sr - ^{137}Cs couple, TF ^{90}Sr - TF ^{137}Cs couple) is significant, since $t_{actual} > t_{theoretical}$, t_{05} = 2,23.

The values of correlations coefficients between the agro-radiochemical indices of medicinal plants are shown in Figure 11. It turned out that there are positive strong (TF ^{90}Sr - TF ^{137}Cs couple r = 0.96 ± 0.09; t_f = 10,6 in soil, ^{90}Sr - ^{137}Cs couple r = 0.95 ± 0.10; $t_{f =}$ 8,6 in soil, TF ^{90}Sr - TF ^{137}Cs couple r = 0.95 ± 0.11; $t_{f =}$ 8,6 in hydroponics, ^{90}Sr - ^{137}Cs couple correlation coefficient r = 0.94 ± 0.12; $t_{f =}$ 7,8 in hydroponics), positive average (ash - ^{137}Cs couple r = 0.45 ± 0.31; $t_{f =}$ 1,4 in soil, gross β-radioactivity - ash couple r = 0.44 ± 0.31; t_f = 1.4 in soil, ash -^{137}Cs couple r = 0.40 ± 0.32; $t_{f =}$ 1,2 in hydroponics, gross β-radioactivity - ash couple r = 0.38 ± 0.32; $t_{f =}$ 1,18 in hydroponics), negative average (OR- TF ^{137}Cs couple r = - 0.60 ± 0.28; $t_{f =}$ 2,1 in soil, OR - TF ^{137}Cs couple r = - 0.48 ± 0.31; $t_{f =}$ 1,5 in hydroponics), positive weak (gross β-radioactivity - ^{137}Cs couple r = 0.29 ± 0.33; $t_{f =}$ 0,87 in soil, ash - ^{90}Sr couple r = 0.16 ± 0.34, $t_{f =}$ 0,47 in hydroponics) comparative connections between plant indicators [43].

DISCUSSION: The results of radiochemical analyzes showed that at the dry hot soil climatic zone of the Ararat Valley in the same radioecological tension medicinal plants grown in hydroponics exceeded the plants cultivated in the soil by gross β-radioactivity**.** That is, the growing environment of medicinal plants (hydroponics, soil) had a certain effect on the accumulation of RN in plants. The growth conditions have influenced the content of the biologically active compounds in medicinal plants. It is possible that the excess of hydroponic plants over soil ones in gross β - radioactivity is due to a larger intake of K (due to ^{40}K). It can be assumed that controlled hydroponic conditions have a beneficial effect on plant mineral nutrition, resulting in higher biological activity of hydroponic plants compared with the soil ones. A mechanized and automated closed system is used to irrigate and to apply mineral fertilizers in case of soilless production. In this case, some ecological abiotic factors are being regulated in a monitored hydroponics environment. This facilitates nutrient and water-air regime improvement providing high biological efficiency. As a result, in hydroponics plant roots absorb mineral elements (for example, K) from the nutrient solution more intensively than from the soil. Both in hydroponic and soil, the various medicinal plants have accumulated different amounts of RN. Apparently, the biological characteristics of the type of plants (including height, duration of vegetation, peculiarities of mineral nutrition and water regime, depth of root spread in soil and substrate, size of leaves, their anatomical structure, shape, etc.) and properties to selectively absorb mineral elements determined it.

Possibly in hydroponics RN is penetrated the medicinal plants from the nutrient solution, and in soil culture from the irrigation water and soil simultaneously. According to the data of Table 1, the content of the technogenic RN (^{90}Sr, and ^{137}Cs) is incomparably low in hydroponic nutrient solution, than in soil. Because of that hydroponic plants are always inferior to the soil plants in a content of technogenic RN. It can be assumed that both in hydroponics and in soil RN penetrated the medicinal plants from the air basin (atmospheric precipitations, hydrosol and aerosols, dust, smoke, soot) through aboveground organs. [1, 2]. It is important to note that in the hot dry soil-climatic conditions of the Ararat Valley, frequent watering of plants promotes the migration of RN from irrigation water, soil, and nutrient solution into plant roots.

At the same time, it is important to note that although hydroponic medicinal plants exceeded soil plants in gross β-radioactivity, they are inferior to soil plants by the content of controlled technogenic RN (^{90}Sr, ^{137}Cs). This is confirmed by the results of our previous studies [3]. Regardless of the medicinal plants type and cultivation way, received plant raw material may be considered radioecologically safe, because gross β-radioactivity of plant raw material did not exceed the border of 1000 Bq/kg [46].

According to our results it can be suggested that the biological characteristics of medicinal plants to selectively absorb mineral nutrients have been observed. It can be assumed that the concentration of RN in medicinal plants mainly depends on the type of plants and not on the activity of RN in the rhizosphere (soil or nutrient solution). This partially coincides with literature data [31]. Our previous studies have shown that the proportion of ^{90}Sr and ^{137}Cs together in gross β-radioactivity in different plant species (herbs, vegetables, fruits, etc.) fluctuated between 2.3 – 6.8 % in hydroponics and 3.0 – 12.8 % in soil [3]. In gross β-radioactivity of medicinal plants the share of natural (^{40}K, ^{234}Th, ^{210}Pb, etc.) and technogenic other RN (^{89}Sr, ^{134}Cs, ^{141}Ce, etc., except ^{90}Sr, ^{137}Cs), in hydroponics is 92.6 – 99.0 %, and in soil - 89.9 – 98.4 %.

In hydroponics and soil the OR of ^{90}Sr - ^{137}Cs couple for plants is less than 1. This means that the migration of ^{137}Cs to plant roots exceeded the migration of ^{90}Sr in both hydroponics and soil, with hydroponics predominant. In soil, it is strongly expressed in *C. speciosum* Stev. (OR = 0.4), and in hydroponics, *T. polium* L. (OR = 0.02), and *C. speciosum* Stev. (OR = 0.03). This is confirmed by the values of TF RN. Thus, in plants, TF ^{137}Cs exceeded TF ^{90}Sr by 1.1 – 2.2 times in soil, and by 2.2 – 41.3 times in hydroponics.

The comparative connections between the agro-radiochemical indices of medicinal plants are more pronounced in soil than in hydroponics.

CONCLUSION: In Ararat Valley the sources of RN penetration into medicinal plants were irrigation waters, soil and air basin in soil culture, and nutrient solution and air basin in hydroponics. The content of controlled technogenic RN (^{90}Sr and ^{137}Cs) in artesian waters, gray soils and various medicinal plants grown in hydroponics and soil in the area of IHP did not exceed the MAC. Grown hydroponically and in soil, the "Newport" variety of hops is radioecologically safer than the "Chinook" and "Crystal" varieties. Regardless of the type of medicinal plants and the method of cultivation (hydroponic, soil) in Ararat Valley the obtained medicinal raw material can be assessed as radioecologically safe.

Abbreviations: ANPP - Armenian Nuclear Power Plant; DFES - Dilijan Forest Experimental Station; IHP – Institute of Hydroponics Problems; MAC - Maximum Allowed Concentration; OR - observed ratio, RN – radionuclides; TF - transfer factor.

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