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Radiometric Measurements in of Japanese barberry (*Berberis thunbergii* DC.), Boxwood (*Buxus sempervirens* L.) and Gold tassel (*Euonymus japonica* Thunb.) Under Cadmium and Zinc Stress

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Abstract: In this study, the effects of Cd and Zn applications on the activity concentration and transfer factors in the Japanaesebarberry, Boxwood, and Gold tassel leaves were investigated using gamma-ray spectrometry. The mean concentrations (in Bq kg-1) of radionuclides in the studied soil samples were found to be 289.40±32.47 for 238U, 241.76±27.47 for 232Th, 783.63±83.46 for 40K, and 31.44±5.63 for R 137Cs while the respective values in the studied species were 168.6±20.1- 288.8±34.5, 145.9±19.1-250.3±32.4, 434.6±52.2-828.4±99.4, and 16.1±1.8-28.3±3.3. The activity concentrations were found to be at the lowest in the control group and 400 µM Zn for all three species, and at the highest level at 25 µM Cd in general in the species. The order of radionuclides by the highest activity concentrations was 40K>238Uz232Th>137C, whereas the order of species was Gold tassel>Boxwood>Japanaese barberry. TF (232U, 232Th, 40K, and 137Cs) values were found to be between 0.583 and 0.998, between 0.604 and 1.036, between 0.555 and 1.057, and between 0.513 and 0.899. And also, while the order of species by the activity concentration was Gold tassel>Boxwood>Japanaese barberry the order of species by the TF values was Boxwood>Gold tassel>Japanaese barberry. In conclusion, plants' radionuclide activity concentrations were found to be at the highest level in 25 µM Cd group and at the lowest level in the control group. Considering all the data, it can be stated that a low dose of Cd was effective on the radioactivity concentrations and Gold tassel could be used as the indicator plant in radiation pollution.

Keywords: Cadmium, Zinc, Radioavtivity, Transfer factor

Öz: Bu çalışmada, kadın tuzluğu, şimşir ve altuni taflan bitkilerinde Cd ve Zn uygulamalarının radyoaktivite konsantrasyon değişiklikleri ve topraktan yaprağa taşınma faktörü üzerindeki etkileri gama ışını spektrometresi kullanılarak araştırılmıştır. İncelenen toprak örneklerinde radyonuklitlerin ortalama konsantrasyonları (Bq kg-1) 238U için 289.40±32.47, 232Th için 241.76±27.47, 40K için 783.63±83.46 ve R 137Cs için 31.44±5.63 olarak bulunurken, bitki türlerinde bu değerler sırası ile 168.6±20.1- 288.8±34.5, 145.9±19.1-250.3±32.4, 434.6±52.2-828.4±99.4, ve 16.1±1.8-28.3±3.3 (Bq kg-1) olarak bulunmuştur. Türlerde aktivite konsantrasyonları her üç bitki türünde kontrol grubu bitkilerde ve 400 µM Zn dozlarında en düşük ve 25 µM Cd dozunda ise genel olarak en yüksektir. Rayonuklitlerin en yüksek aktivite konsantrasyolarına göre sıralaması 40K>238Uz232Th>137C ve türlerin sıralaması ise Altuni taflan>Şimşir>Kadın tuzluğu olmuştur. Türlerde TF (232U, 232Th, 40K ve 137s) değerleri sırası ile 0.583-0.998, 0.604-1.036, 0.555-1.057 ve 0.513-0.899 arasında bulunmuştur. TF değerlerine göre radyonuklitlerin sıralaması 40K>232Th>238U>137Cs ve türlerin sıralaması ise Şimşir>Altuni taflan>Kadın tuzluğu şeklindedir. Sonuç olarak bitkilerde radyonuklit aktivite konsantrasyonları 25 µM Cd dozunda en yüksek, kontrol grubu bitkilerde ise en düşüktür. Tüm veriler göz önünde bulundurulduğunda düşük dozda Cd'ın radyoaktivite konsantrasyonlarında etkili olduğu ve Altuni taflanın radyasyon kirliliğinde indikatör bitki olarak kullanılabileceği söylenebilir.

Anahtar Kelimeler: Kadmiyum, Çinko, Radyoaktivite, Transfer faktörü

1. Introduction

As in other organisms, plants are inevitably subjected to radiation effect because the radioactive elements having a very long lifetime have created a natural radiation surface in the ecosystem throughout the history of the world [1]. However, the rapid development of industry, rapid growth of population, industrial and domestic wastes caused by unplanned urbanization, and mining and nuclear energy wastes do cause and have caused radiation pollution in air, water, and soil. Moreover, fossil fuels, nitrogenous fertilizer industry, and synthetic fertilizer technology might cause the release of natural radionuclides into the environment [1, 2]. Natural radiation sources consist of natural radionuclides naturally existing in nature such as 238U, 232Th, and 40K and the 238U and 232Th degradation series products (226Ra and 222Rn), while the artificial radionuclides such as 90Sr, 137Cs, and 131I are released to the environment through nuclear accidents and nuclear weapon trials [3, 4]. Natural and artificial radionuclides bind to the inorganic matter in soil and sediments through air and water and accumulate in herbal tissues via the roots. Moreover, radionuclides accumulating in aerosols from the atmosphere might penetrate the plant tissues via leaves and barks [3, 5]. Intake of radionuclides from soil to the plant is defined as transfer factor (TF) and it varies depending on soil characteristics such as pH, clay mineral, Ca, K, and organic matter content [6, 7], leaf characteristics of plants, developmental status of organs, and plant species [8], and climatic parameters such as wind speed, precipitation, and humidity [6-9]. Radionuclides' activity concentrations in plant tissues might vary depending on plant genotype and developmental status of organs, as well as the concentration of radionuclides and their chemical behaviors [10]. In literature, it was emphasized that plants took large amount of 40K and 226Ra, low amount of 238U2u, and very low amount of 232Th from the soil [7, 11]. In plants, it was reported that the intake of 40K and 137Cs occurJapanaesethrough the same mechanism as fundamental element K that 40K and K+ were analogous and 238U and 226Ra were analogous to Ca, and that concentrations of 40K and 232U in plant tissues might be higher than those of other radionuclides. Besides that, it is also asserted that application of phosphatic fertilizers increased the 238U activity concentration in soil and plant tissues [12]. Until now, in studies on the effects of heavy metal stress in plants, the changes in the amount of necessary molecules in plant growth and development such as photosynthetic pigments, nitrogenous compounds, carbonaceous compounds, secondary metabolites [13], enzymatic and non-enzymatic defense systems [14, 15] and nutrients have been investigated [16, 17]. And also, radioactivity measurements were performed on organs of many plant species such as leaf, stem, and flower [11, 15, 18], various food sources [19, 20], mushrooms [21], soils [2, 22] and water samples [23] from different regions, in Turkey. However, there is no study carried out on the effects of heavy metal stress on the radionuclide activity concentrations in plant leaves. In the present study, it was aimed to investigate the capacity of Cd and Zn treatments to accumulate 238U, 232Th, 40K, and 137Cs radionuclides in Japanaesebarberry, Boxwood, and Gold tassel plant species widely grown in parks, gardens, and roadsides in the city center of Kastamonu.

2. Material and Method

In the present study, 2-year-old Japanaesebarberry (*Berberis thunbergii* DC. var. *atropurpurea* Chenault), Boxwood (*Buxus sempervirens* L. var. *rotundifolia* Baill.), and Golden Tassel (*Euonymus japonicus* Thunb. var. *aureomarginatus* Rehder) plants obtained from Kastamonu Municipality's Department of Parks and Gardens were used. Plants were removed out of the plastic tubes, in which they were grown (S1), and planted into 5L pots containing turf and garden soil (Soil 2; 2:1) and irrigated for 4 weeks by using tap water. Then, the plants were grouped as control, cadmium (Cd: 25 µM and 50 µM-$CdSO_4H_2O$), and zinc (Zn: 200 µM and 400 µM-$ZnCl_2$) and they were subjected to metal stress applications by using soil (300 ml) depending on the water retention capacity of soil. The concentrations determined for Cd and Zn were dissolved in Hoagland-Arnon's nutrient solution. While the plants in the control group were given only the nutrient solution, the metal stress application was performed using with the nutrient solution. Metal stress application on plants was performed for 8 weeks (twice a week).

Characteristics of soil samples used in the experiment

pH value of soil samples (S1, S2) was found to range between 6.88 and 6.96 and that of irrigation water was found to be 8.60. Of the soil samples used, K, P, S, Mg, and Ca contents (mg kg^{-1}) were found to vary between 27540- 29681, between 5195-3228, between 3074-2712, between 12950-17580, and between 111700- 27880, respectively (Table 1). Fe, Mn, Cu, Zn, Ni, and Cd contents were found to range between 34960- 38490, between 460.5- 709.2, between 36.8- 37, between 71- 80.7, between 58.8 - 74.80, and between 0.41-3.45 (Table 1).

Table 1. Characteristics of soil mixture used in the experiments

	pH	K	P	S	Mg	Ca	Fe	Mn	Cu	Zn	Ni	Cd
S1	6.88	27540±30	5195±2.8	3074±3	12950±60	111700±100	34960±30	460.5±2.0	36.8±0.7	71±0.7	58.8±20.6	3.45±0.3
S2	6.96	29681±6.5	3228 ±2.4	2712 ±	17580 ±	27880± 32	38490 ±30	709.2 ±1.8	37 ±0.6	80.7±1.4	74.80± 1.1	0.41 ±0.1
W	8.60	2894±4.7	11.96±0.3	-	15951±60	14782.86±60	7.82±0.4	0.322±	20.24±0.4	14.70±0.8	10.23±	1.63±0.1

Preparation of leaf and soil samples for the radioactivity measurements

Leaf samples harvested from the plants were dried in an environment without direct sunlight exposure. The samples were kept in a drying oven at 85°C for 24 hours and then pulverized using a blender. The soil samples used in the experiment were dried at room temperature and then pulverized using the laboratory blender. In order to ensure the homogeneity of samples, they were passed through a sieve with 80 Mesh and left for drying in a drying oven at 85°C temperature for 48 hours.

pH measurements in soil samples

pH values of samples were determined using the method of Gülçur [24]. The samples were kept in 1/2.5 pure water for 24 hours and the pH was measured using a digital pH-meter.

Elemental analysis of soil and leaf samples

Some of the dried soil and leaf samples were used in the elemental analysis in Kastamonu University's Central Research Laboratory by using SPECTRO brand XEPOS model XRF device. Some of samples were put into polyethylene containers with 6 cm diameter and 5 cm height and the lids were closed tightly. In order for samples to reach radioactive balance, they were kept for 1 month [11].

Method for the activity concentrations of radionuclides

Gamma-ray spectrometry was performed with FoodGuard-1 3 x 3-inch NaI (Tl) model radiation detector (ORTEC, Oak Ridge, USA) in the Central Research Laboratory of Kastamonu University. The ground leaves were placed into plastic boxes having a diameter of 8 cm and a height of 8 cm and designed to fit the geometry of the detector. Then, the boxes were tightly closed and kept for 1 month. Thus, the formation of radioactive equilibrium between ^{238}U and ^{232}Th and their decay products was allowed and the samples were prepared for counting. The detector was calibrated before the analysis. To analyze the spectra collected in computer memory, the channel corresponding to the input energy must be known. Thus, the types of radioactive nuclei present in the sample can be found. To accomplish the energy calibration, a standard source(s) consisting of nuclei with previous energies is needed. Standard point sources including the peaks of ^{109}Cd, ^{57}Co, ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn, and ^{60}Co, with energies ranging between 80 and 1400 keV were used for the calibration. After the calibration, each sample was counted in the gamma spectrometer for 50000 sec. Activities of radionuclides obtained at end of the measurements were determined using the following equation:

$$\textbf{Activity} = \frac{\textbf{Net area}}{\textbf{Counting time} \times \textbf{Sample amount} \times \textbf{Abundance} \times \textbf{Yield}} \tag{1}$$

The net areas under the peaks were calculated by subtracting the background from the total area. The radioactivity concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs in the samples were determined by making use of the gamma peaks of natural radionuclides, which were the degradation products of these radionuclides. After determining the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K, the activity concentration of ^{137}Cs isotope in the samples was also determined. The activity concentrations of radionuclides (^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs) were expressed as Bq kg^{-1} dry weight.

Calculation of Transfer Factor

The rate of radionuclides, which are present in the soil, to transfer from the plant tissues is named transfer factor (TF). Using the equation given below, TF values were calculated with the mean radionuclide activity concentrations found in the leaves of Red barberry, Boxwood, and Gold tassel plants and the soil samples used in growing the plants [11, 25].

TF=Activity concentration of plant (Bq kg^{-1})/Activity concentration of soil (Bq kg^{-1}) (2)

3. Result and Discussion

Plants illustrate an important link in the transport and distribution of radionuclides and other pollutants in the environment and are often consideJapanaeseas biomonitors of atmospheric pollution [3, 6,7, 15]. Naturally occurring and fallout radionuclides were investigated in samples of Japanaese barberry, Boxwood, and Golden tassel plants.

Changes in 238U, 232Th, 40K, and 137Cs activity in soil samples

The elemental contents of soil samples used in growing the plants are presented in Table 1. The mean values found in the soil samples were 289.40±32.47 for 238U activity concentration, 241.76±27.47 for 232Th activity concentration, 783.63±83.46 for 40K activity concentration, and da 31.44±5.63 for 137Cs activity concentration (Table 2). The 238U, 232Th, 40K, and 137Cs activity concentrations of the tap water used in the experiment were 1.48±0.1, 1.17±0.1, 2.65±0.3, and 0.42±0.04, respectively (Table 2). Study results were found to overlap with the activity concentrations reported by Kaya et al. [22] for the soil samples collected from different regions of Gümüşhane province. Researchers found the 232Th, 40K, and 137Cs activity concentrations in the soil samples to range between 9.7±1.15 and 32.52±2.65, between 236.83±7.53 and 889.65±17.63, and between 7.63±1.26 and 39.44±8.57. In another study, Adesiji & Ademola [25] found the 238U, 232Th, and 40K activity concentrations of soil samples they used in growing corn plant to be in the range of 242.13 ± 429.10-2763.90 ± 2345.77, 15294.77 ± 6924.46-26211.90 ± 7178.22, and 374.01 ± 590.51-5008.18 ± 2427.165 Bqkg-1, respectively, and those values are much higher than the results achieved in the present study. 40K activity concentration was similar to the value reported by Bilgici Cengiz et al. [2-20] (245.6±34.6 Bqkg-1 and 814.2±35.7 Bqkg-1) but 232Th (22.2±6.8-44.6±7.5 Bqkg-1) activity concentration was much lower than the value found in the present study.

Table 2. Radioactivity concentration changes in the soil samples used in the experiment

	^{238}U	^{232}Th	^{40}K	^{137}Cs
Soil 1	236.35±26.20	196.87±16.60	678.64±68.52	22.44±2.70
Soil 2	322.45±38.73	286.64±38.33	876.62±98.40	38.44±8.56
Mean	289.40±32.47	241.76±27.47	783.63±83.46	31.44±5.63
Water	1.48±0.1	1.17±0.1	2.65±0.3	0.42±0.04

137Cs activity concentration found in the present study was confirmed by the results achieved by Lamarque et al. [26] (0-5 cm: 61-280 Bqkg^{-1}; 10-15 cm: 14-224 Bq kg^{-1}). But Absar et al. [27] reported the 232Th, 40K, and 137Cs activity concentrations in soil to be in the ranges of 50 ±19-65± 21, 245 ±30-635 ±35, and 137Cs 3±1-9±1, respectively. In the present study, 232Th and 137Cs values were lower than those values but 40K was found to be in a similar range.

Radionuclide activity concentration changes in plant samples

The activity concentrations for 238U, 232Th, 40K, and 137Cs radionuclides found in leaves of Japanaese barberry, Boxwood, and Gold tassel plants subjected to Cd and Zn application are presented in Table 3. Given the results, although the activity concentrations of those radionuclides varied by the species and concentration, radioactivity concentrations were found to be higher than in control for all three plants (Table 3).

238U activity concentration changes and TF values in plants subjected to Cd and Zn

238U, a natural radionuclide, exists in nature generally in form of uranium minerals with elements such as Ca, Mg, and P. Since it has low solubility in soil solution, its intake by the plants is also at a low level. However, since its chemical behavior is similar to that of Ca, it was reported to have positive effects on metabolic reactions, in which Ca is effective [6, 12, 26]. In the present study, 238U activity concentrations found in leaves of Red barberry, Boxwood, and Gold tassel were found to be 168.6±20.1-223.7±26.4 1 Bq kg^{-1}, 171.0±20.6-265.9±31.7 1 Bq kg^{-1}, and 176.5±21.2-288.8±34.5 Bq kg^{-1} (Table 3). In comparison to the control group, the highest level of 238U activity concentration was found at 25 µM Cd dose in all three species. The lowest activity concentration was found in the control group plants. The second-highest activity concentration was achieved at 50 µM Cd dose for Red barberry and Gold tassel leaves and 200 µM Cd dose for Boxwood leaves (Table 3). Among the plant species, the highest 238U activity concentrations were found in Gold tassel leaves and with Cd doses (288.8±34.5; 270.1±32.1 Bq kg^{-1}), whereas the lowest activity concentration was found in the control group samples of Red barberry leaves (168.6±20.1 Bq kg^{-1}). 238U accumulation capacities of plants were found to be Gold tassel>Boxwood>Red barberry. In these plants, TF (238U) value was reported to be 0.583-0.773 for Red barberry, 0.591-0.919 for Boxwood, and 0.610-0.998 for Gold tassel. In comparison to the control group, the highest TF value was achieved at 25 µM Cd dose for all three plants. TF values reached the maximum levels in Red barberry and Gold tassel leaves with Cd doses and in Boxwood leaves with 25 µM Cd and 200 µM Zn doses (Table 3).

Table 3. Effects of Cd (25 µM and 50 µM) and Zn (200 µM and 400 µM) applications on 238U and 232Th activity concentrations and TF changes in Red barberry, Boxwood, and Gold leaves (Bq kg^{-1})

Plant	Group	238U	232Th	238U	232Th
Japanaese barberry	Control	168.6±20.1	148.0±19.1	0.583	0.612
	25 µM Cd	223.7±26.4	232.5±30.1	0.773	0.962
	50 µM Cd	214.5±25.3	173.4±22.4	0.742	0.718
	200 µM Zn	198.2±23.4	218.1±28.1	0.685	0.903
	400 µM Zn	184.7±22.1	168.5±21.7	0.638	0.697
Boxwood	Control	171.0±20.6	151.9±19.6	0.591	0.628
	25 µM Cd	265.9±31.7	244.2±31.4	0.919	1.010
	50 µM Cd	217.8±26.2	179.4±23.3	0.753	0.742
	200 µM Zn	245.4±29.4	211.9±27.4	0.848	0.877
	400 µM Zn	200.9±24.3	167.7±21.6	0.695	0.694
Gold tassel	Control	176.5±21.2	145.9±19.1	0.610	0.604
	25 µM Cd	288.8±34.5	250.3±32.4	0.998	1.036
	50 µM Cd	270.1±32.1	211.7±27.3	0.933	0.876
	200 µM Zn	259.1±31.5	222.0±28.6	0.896	0.919
	400 µM Zn	201.4±24.7	161.6±21.0	0.696	0.669

The 238U activity concentration found in the present study was higher in comparison to the results reported in the literature. Examining several tree species and epiphyte plants, Manigandan et al. [4] reported the mean 238U activity concentration to range between 9.6 ± 0.4 and 11.4 ± 0.4 and TF value to range between 0.249 and 0.313. However, Tshivhase et al. [28] reported the 238U activity concentration to be 31.36±9.40, 0.02±0.01, and 0.16 ±0.14 Bq kg^{-1} and TF value to be 0.19±0.06, 0.307±0.89, and 0.11±0.01 Bq kg^{-1}, respectively. In the present study, the finding that 238U activity concentration in experimental groups was higher than in the control group was related to the P concentration in soil and low Cd and Zn doses stimulating the 238U absorption of species. In literature, it was reported that the mean P concentration in soil was 500-800 mg kg^{-1}, that P values in soils in Turkey ranged between 146.2 and 3125 mg kg^{-1}, and that the P concentration required for plant was 0.3-3 kg ha^{-1} [29, 30].

232Th activity concentration changes in plants treated with Cd and Zn

232Th activity concentration was found to be within the ranges of 148.0±19.1-232.5±30.1 Bq kg^{-1} in Japanese barberry leaves, 151.9±19.6-244.2±31.4 Bq kg^{-1} in Boxwood leaves, and 145.9±19.1-250.3±32.4 Bq kg^{-1} in Gold tassel leaves. In the control group plants, the highest activity concentration was achieved in Boxwood leaves and in Gold tassel. 232Th activity concentrations that were the highest in comparison to the control group were observed at 25 µM Cd and 200 µM Zn doses for all three species. Among the plant species, the highest 232h activity concentration was found in Gold tassel leaves (250.3 ± 32.4 Bq kg^{-1}) and the lowest one in Gold tassel control group (145.9 ± 19.1 Bq kg^{-1}). In the samples, TF(232Th) values were in the ranges of 0.612-0.962 for Japanaese barberry leaves, 0.628-1.010 for Boxwood leaves, and 0.604-1.036 for Gold tassel leaves. TF values were generally at the highest levels in low Cd and Zn doses (Table 3). 232Th activity concentration changes achieved in the present study overlapped with the results reported by Adesiji & Ademola [25]. Examining two different corn leaves which they grew in two different soil samples, researchers reported the 232Th activity concentration to vary between 238.05 ± 64.64 and 826.37 ±1182.03 Bq kg^{-1}, activity concentration in soil samples to range between 1776.08 ± 4164.89 and 26211.90 ± 7178.22 Bq kg^{-1}, and TF value to range between 0.02 ± 1.27 and 0.08 ± 3.70. However, Chakraborty et al. [31] examining grass and Bilgici Cengiz & Çağlar [32] analyzing 45 wheat flour samples reported 232Th activity concentration values that were much lower than in the present study. Similarly, Absar et al. [27] reported the 232Th activity concentration of tea plant leaves to be 2.4 ±0.5-5.8 ±0.9 Bq kg^{-1} and that of soil to be 50±13-63±5 Bq kg^{-1}, whereas TF (232Th) was found to be 0.05±0.04. Bilgici Cengic & Çağlar [20] analyzed various herbs widely used in the Eastern Anatolian region and reported the 232Th activity concentration to be 55.99±4.32 Bq kg^{-1} and TF value to be 0.88.

40K activity concentration changes in plants treated with Cd and Zn

40K activity concentration was found to be 434.6±52.2-536.2±64.3 Bq kg^{-1} in Japanaesebarberry leaves, 529.8±63.6-828.4±99.4 Bq kg^{-1} in Boxwood leaves, and 534.9±64.2-821.4±98.6 Bq kg^{-1} in Gold tassel leaves. In comparison to the control group, the highest activity concentration was found to be 828.4±99.4 in Boxwood leaves treated with 25 µM Cd, followed by Gold tassel leaves treated with 200 µM Zn (821.4 ± 98.6 Bq kg^{-1}). The lowest activity concentration was found in the control group Japanaese barberry leaves, followed by Japanaese barberry leaves treated with 400 µM Zn (Table 4). Similar to 232Th activity concentration, 40K activity concentration reached the highest levels with low Cd and Zn doses. Among the plants, the highest activity concentration was found in 40K and the order of plants was found to be Boxwood > Gold tassel >Japanaese barberry (Table 3). TF(40K) values were found to range between 0.555 and 0.685 in Japanaese barberry leaves, between 0.676 and 1.057 in Boxwood leaves, and between 0.683 and 1.048 in Gold tassel leaves. TF (4K) was found to be high in low Cd and Zn treatments in comparison to the control group and other treatments and the highest value was found in Boxwood leaves. Besides that, the order of species by the TF (40) values was Gold tassel>Boxwood>Japanaese barberry (Table 3). The 40K activity concentrations found in plants are in corroboration with the literature. 40K is a naturally rich radionuclide in plants. The fact that we found high concentrations of 40K in the leaves of sample plants is not surprising given that plants obtain their nutrients and water through root uptake from the soil, in which there are high 40K concentrations. The amount of potassium in plants is high because of its essential role in most physiological processes needed to maintain plant growth and development. Potassium has an important role in photosynthesis, translocation of starches and sugars, plant-water relations, protein synthesis, activation of plant enzymes, resistance to plant diseases [8, 29]. Similar results were reported in the studies examining the herbaceous and woody plants [7, 15, 27]. Manigandan et al. [3] reported the 40K activity concentration in some plant species grown in rain forests of India to vary between 160.4 ± 12.3 and 206.4 ± 13.4 Bq kg^{-1} and TF value to vary between 0.802 and 0.954. Similar to the present study, Shayeb et al. [33] determined the 40K activity concentration in date samples to be 181 ± 17 Bq kg^{-1}, the activity concentration in soil samples to be 329 ± 87 Bq kg^{-1}, and TF value to be 0.51 ± 2.0. In another study examining the medicinal plants used in traditional medicine in Thailand, the mean 40K activity concentration was found to be 610±260 Bq kg^{-1} and TF value to be 2.0±1.4 and it was determined that the activity concentration was at a higher level in leaves in comparison to flowers and stem Saenboonruang et al. [7]. In their study carried out on forests in Southwestern Serbia region, Hadrovıć et al. [34] reported the 40K activity concentration of evergreen species to be 102 ± 25 Bq kg^{-1}, that of non-evergreen species to be 140 ± 26 Bq kg^{-1}, and that of samples from the soil, where the plants were grown, to be 62±5-970±60 Bq kg^{-1}. TF (40K) was found to be 0.022-0.22 in non-evergreen species and 0.007-0.19 in coniferous species. Much higher level of 40K activity concentrations in soil and plant tissues in comparison to other radionuclides was related to the chemical behaviors of 40K and essential element K+. Researchers reported that the intakes of K^+ and 40K occurJapanaesethrough similar mechanisms and their roles in metabolic reactions were also the same [8, 29, 35].

137Cs activity concentration changes in plants treated with Cd and Zn

The 137Cs activity concentration changes found in the plant samples were in the ranges 16.1±1.8-26.2±3.1 Bq kg^{-1} in Japanaesebarberry leaves, 17.7±2.3-26.3±3.2 Bq kg^{-1} in Boxwood leaves, and 17.3±2.1-28.3±3.3 Bq kg^{-1} in Gold tassel leaves (Table 4). The highest activity concentration was found at 200 µM Zn dose in Golden Tassel (28.3±3.3 Bq kg^{-1}) leaves, followed by 25 µM Cd dose in Japanaese barberry (26.3 ± 3.2 Bq kg^{-1}) and Gold tassel leaves (26.3±3.2 Bq kg^{-1}). 137Cs activity concentration was found to be higher in Boxwood and Gold tassel leaves at 25 µM Cd and 200 µM Zn doses, whereas it was high in Japanaese barberry leaves at Cd (25-50 µM) doses. The lowest activity concentration in plants was found in 137Cs radionuclide and the order of plants by this parameter was found to be Gold tassel>Boxwood>Japanaese barberry (Table 4).

TF (137Cs) values were found to be between 0.550 and 0.899 in Japanaese barberry, 0.563 and 0.836 in Boxwood, and 0.513 and 0.835 in Gold tassel leaves. TF (137Cs) was found to be high at low Cd and Zn doses in the first two species and at Cd doses in Gold tassel leaves. The order of species by TF value was Japanaese barberry>Boxwood>Gold tassel (Table 4). 137Cs activity concentration data were in corroboration with the literature. In previous studies, the lowest activity concentration in soil and plant organs was reported to belong to 137Cs [36]. Lamarque et al. [26] monitoJapanaesethe seasonal activity concentration changes of 137Cs in *Fagus sylvatica* and *Picea abies* grown in forests, which were polluted because of the Chernobyl disaster, in Franche-Comté region in Northeastern France. Researchers determined that 137Cs activity concentration in soil samples ranged between 61 and 280 Bq kg^{-1} (0-5 cm) and between 14 and 224 Bq kg^{-1} (10-15 cm), that TF values in leaves varied seasonally, and that TF (137Cs) was 0.0074 for *F. sylvatica* and 0.0179 for *P. Abies*. Researchers also reported that there was no direct relationship between cesium activity in soil and cesium activity in plant organs and that it might be because the intake of 137Cs might have occurJapanaesethrough roots from the soil and through leaves from aerosols in the air. 137Cs activity concentrations in soil and grass in Bangladesh were reported to be 0.17 ± 0.02 Bq kg^{-1} and 2.41 ± 0.18 Bq kg^{-1}, respectively, whereas TF value was found to be 0.061 [31]. Shayeb et al. [34] compaJapanaesethe 137Cs activity concentrations in date and soil samples collected from different regions of Saudi Arabia and they reported the activity in soil to be 10.2 ± 2.1 Bq kg^{-1} and the activity in date samples to be below the limit of detector. In a study carried out using tea leaves, 137Cs activity concentration was found to be <0.4 Bq kg^{-1} in the leaves and 3±1-10±1 Bq kg^{-1} in the soils, whereas TF (137Cs) was found to be belwo the limit of detector [4]. Hadrovıć e al. [34] examining the 137Cs activity concentration in forests of Southwestern Serbia reported the 137Cs activity concentration to be 4.9 ± 7.1 Bq kg^{-1} in some non-evergreen species and 5.9 ± 4.8 Bq kg^{-1} in evergreen samples.

Table 4. Effects of Cd (25 µM and 50 µM) and Zn (200 µM and 400 µM) treatments on 40K and 137Cs activity concentration and TF changes in Red barberry, Boxwood, and Gold leaves (Bq kg^{-1})

Plant	Group	40K	137Cs	40K	137Cs
Red barberry	Control	434.6±52.2	16.1±1.8	0.555	0.550
	25 µM Cd	536.2±64.3	26.2±3.1	0.685	0.836
	50 µM Cd	492.9±59.1	19.1±2.3	0.629	0.835
	200 µM Zn	520.3±62.4	18.7±2.4	0.664	0.899
	400 µM Zn	454.6±54.6	18.1±2.2	0.580	0.630
Boxwod	Control	529.8±63.6	17.7±2.3	0.676	0.563
	25 µM Cd	828.4±99.4	26.3±3.2	1.057	0.836
	50 µM Cd	643.9±77.3	20.2±2.4	0.822	0.641
	200 µM Zn	745.1±89.4	23.7±2.6	0.951	0.753
	400 µM Zn	581.7±69.8	19.6±2.5	0.743	0.624
Gold tassel	Control	534.9±64.2	17.3±2.1	0.683	0.513
	25 µM Cd	804.8±96.6	26.3±3.2	1.027	0.835
	50 µM Cd	792.6±95.1	26.2±3.2	1.012	0.608
	200 µM Zn	821.4±98.6	28.3±3.3	1.048	0.595
	400 µM Zn	584.3±70.1	19.8±2.5	0.746	0.575

TF (137Cs) was found to be 5.2 in non-evergreen trees and in the range between 0.021 and 0.18 in coniferous species and activity concentration and TF values were found to be at the highest in leaves. Researchers reported that 137Cs intake of plants occur Japanaese through the same mechanism as K^+ intake and it accumulated more in leaves as with the K. Moreover, it was claimed that the plants with larger leaf surface area genes need K^+ element more because of higher transpiration, stomal conductivity, and photosynthetic activity and, thus, more 40K and 137Cs might accumulate in the plants having larger leaf surface area [8, 36]. Depending on the activity concentrations of radionuclides and the changes in TF, the order of plants by the (1) activity concentration was Gold tassel>Boxwood>Japanaese barberry and the order by TF values was Boxwood>Gold tassel>Japanaese barberry and that (2) 25 µM Cd and 200 µM Zn doses yielded the highest radionuclide activity concentration and TF values. It suggests that, regarding the order of species by TF and activity concentrations, leaf characteristics were also important as well as the factor genotype. The larger leaves of Gold tassel in comparison to other two species might increase the competition for radionuclide absorption from both soil and air. Boxwood leaves have also larger surface areas when compaJapanaeseto Japanaesebarberry leaves. High 40K and 238U activity concentrations in both species confirm this conclusion. The plants having more aboveground volume have higher transpiration, hydrolytic resistance, and stoma activity and these plants necessitate more K^+ and Ca^+ elements. K+ plays important roles in stoma movements, as well as controlling the events of osmosis and turgor [29], while Ca has a specific importance in strengthening the cell wall [37, 38]. In literature, it was reported that 40K was analogous to essential element K^+ and 238U was analogous to Ca^+ [26, 36, 38]. The higher activity concentrations and TF values at lower doses were related to the possibility that low doses of (Cd-Zn) metals might stimulate the radionuclide absorption. It was stated that Cd was a very mobile element and, thus, rate of its transfer from soil to plant and its speed of transfer within the plant were high [37, 38, 39].

4. Conclusions

In the present study, in which the effects of Cd and Zn treatments on 238U, 232Th, 40K, and 137Cs activity concentrations and TF values of Japanaese barberry, Boxwood, and Gold tassel plants were examined, it was revealed that activity concentrations varied depending on plant species, metal species, and concentration. In all three species, the radionuclide activity concentrations were found to be at the lowest levels in the control group and 400 µM Zn groups, whereas the 25 µM Cd dose generally yielded the highest level. 238U and 232Th activity concentrations in Gold tassel (25 µM Cd), 40K activity concentration Boxwood (25 µM Cd), and 137Cs activity concentration in Gold tassel (400µM Zn) were found to be the highest ones in comparison to the control and other groups. Among the control group plants, the lowest activity concentrations were found in Japanaese barberry (23U, 40K, 137Cs) and Gold tassel (232Th) leaves, whereas the order of radionuclides by the highest activity concentrations was 40K>238Uz>232Th>137C and that of species by the highest radionuclide activity concentration was Gold tassel>Boxwood>Japanaese barberry. Similar to the activity concentration results, TF values of species were found to be at lower levels in control group plants. The lowest TF values were found in Japanaese barberry leaves for TF (238U) and TF (40K) and in Gold tassel leaves for TF (232Th) and TF (137C). The highest TF (238), TF (232Th), and TF (40K) were obtained at 25 µM Cd dose and the highest TF (137Cs) was achieved at 200 µM Zn dose. The order of radionuclides by the highest TF values 40K>232Th>238U>137Cs and that of species was Boxwood>Gold tassel>Japanaese barberry. Given the results obtained, it can be stated that low doses of Cd and Zn might increase the radioactivity concentrations and that Gold tassel and Boxwood plants could be used as an indicator regarding the radiation pollution.

Competing Interest / Conflict of Interest

The authors declare that they have no competing interests.

Author Contribution

We declare that all Authors equally contribute.

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