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Araştırma Makalesi / Research Article

Determination of Soil-to-Apricot Transfer Factors and Radioactivity Levels of Natural Radionuclides

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Abstract

The aim of this study was to determine the natural radionuclide concentrations and transfer factors of these radionuclides from soil to fresh apricot in agricultural lands in Malatya and in the fruits of apricot trees planted in these lands. It is also to determine the annual effective ingestion dose (AE_{ingest}) and the cancer risk (LCR) that may occur as a result of the consumption of apricots. In study, the mean concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples were calculated as 17.9±0.5 Bq/kg, 14.1±0.4 Bq/kg and 445.2±8.0 Bq/kg, respectively. The activity values of ^{226}Ra and ^{232}Th calculated for soil samples were found below limit values, while the values calculated for ^{40}K were found above the limit values except for T-2, T-4 and T-10. Transfer factors calculated for ^{226}Ra radionuclide transfer from soil to apricot samples in agricultural lands were between 0.44±0.01 and 0.78±0.06, transfer factors calculated for ^{232}Th radionuclide transfer were between 0.36±0.02 and 0.79±0.06 and transfer factors calculated for ^{40}K radionuclide transfer were between 0.24±0.02 and 0.70±0.08. All TF values were found to be less than 1. In the study, it was observed that the results and averages obtained as a result of AE_{ingest} and LCR calculations were below the permissible limit values.

Keywords: Transfer factor, Natural radioactivity, Apricot, Gamma energy, Radionuclide concentration, Soil.

Doğal Radyonüklidlerin Topraktan Kayısıya Transfer Faktörlerinin ve Radyoaktivite Düzeylerinin Belirlenmesi

Öz

Bu çalışmanın amacı, Malatya'daki tarım arazilerinde ve bu arazilere dikilen kayısı ağaçlarının meyvelerinde doğal radyonüklid konsantrasyonlarını ve bu radyonüklidlerin topraktan taze kayısıya transfer faktörlerini (TF) belirlemektir. Ayrıca, kayısının tüketilmesi sonucunda maruz kalınacak yıllık etkin sindirim dozunu (AE_{ingest}) ve oluşabilecek kanser riskini (LCR) de belirlemektir. Çalışmada, ^{226}Ra, ^{232}Th ve ^{40}K radyonüklidlerinin toprak örneklerindeki ortalama konsantrasyonları sırasıyla 17,9 ± 0,5 Bq/kg, 14,1 ± 0,4 Bq/kg ve 445,2 ± 8,0 Bq/kg olarak hesaplanmıştır. Toprak örnekleri için hesaplanan ^{226}Ra ve ^{232}Th aktivite değerleri sınır değerlerin altında bulunurken, ^{40}K için hesaplanan değerler T-2, T-4 ve T-10 hariç sınır değerlerin üzerinde bulunmuştur. Tarım arazilerindeki kayısı örneklerine topraktan geçen ^{226}Ra radyonüklidi için hesaplanan transfer faktörleri 0,44 ± 0,01 ile 0,78 ± 0,06 arasında, ^{232}Th radyonüklid geçişi için hesaplanan transfer faktörleri 0,36 ± 0,02 ile 0,79 ± 0,06 arasında ve ^{40}K radyonüklid geçişi için hesaplanan transfer faktörleri ise, 0,24 ± 0,02 ile 0,70 ± 0,08 arasında değişmektedir. Tüm TF değerleri 1'den küçük bulunmuştur. Çalışmada, AE_{ingest} ve LCR hesaplamaları sonucunda elde edilen sonuçların ve ortalamaların izin verilen sınır değerlerin altında olduğu görülmüştür.

Anahtar Kelimeler: Transfer faktörü, Doğal radyoaktivite, Kayısı, Gama enerjisi, Radyonüklid konsantrasyonu, Toprak

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1. Introduction

Radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K are naturally occurring in soil and cause the soil to become radioactive. Natural radionuclides are mostly found in high concentrations in volcanic, phosphate, granite and salt rocks. These rocks crumble over time and mix into the soil and groundwater in very small pieces with rain and runoff waters. As a result, the natural radioactivity of the soil increases (Eisenbud, 1987).

Radioactive elements in nature pass directly or indirectly into the living body. This passage occurs when radioactive elements are taken into the body through respiration or digestion. As a result of ingestion of radioactive foods into the body through digestion, the person is exposed to radiation by internal irradiation (Çelebi, 1995).

Radionuclides in the structure of soil and water pass to the plant / fruit / vegetable through the roots. When these plants, fruits or vegetables are consumed by living organisms, these radionuclides are transferred to the living body (UNSCEAR, 1993; Abdou et al., 2017).

In recent years, there have been many studies investigating the transfer of natural or artificial radionuclide from soil to various plants, fruits and vegetables and their transfer factor (Ahmad, 2007; Uchida et al., 2007; Chakraborty et al., 2013; Gaffer et al., 2014; Asaduzzaman et al., 2014; Khandaker et al., 2016; Abu Shayeb et al., 2018; Cengiz, 2019; Semioshkina and Voigt, 2021; Rout et al., 2021; Bal et al., 2023; Nurtjahya et al., 2023; Samad et al., 2024; Makki et al., 2024).

The aim of this study was to determine the natural radioactivity level of soil and apricot samples collected from different districts in Malatya province (in Turkey) and to determine the radionuclide transfer factor from soil to apricot.

2. Materials and Methods

2.1. Sampling and Preparation

2.1.1. Soil samples

In order to calculate the radionuclide transfer factor from soil to apricot samples, a total of 3 kg of soil samples were taken from 3 points, 1 kg from each point around a tree determined in each district in Malatya province (Figure 1) and mixed homogeneously. Thus, a mixture representing each measurement point was obtained. Soil samples were taken from 0-20 cm soil layer. For 10 different districts, the same procedure was repeated.

The soil samples brought to the laboratory were dried in the laboratory environment for one week. After being cleaned from foreign objects, the remaining moisture was removed by keeping in an oven at 105 °C for a few hours. Then, the samples were weighed and the dry weight was determined. The samples were filled into 250 ml polyethylene sample containers and the container was sealed airtight. The samples were kept for 30 days to ensure radioactive equilibrium between ^{226}Ra and its daughters (Agar et al., 2014).

2.1.2. Apricot samples

Turkey ranks first in the world fresh apricot production and Malatya is the province where the most apricots are produced in Turkey. Apricot is a fruit that likes deep, well-permeable, well-ventilated, warm and nutrient-rich, sandy, loamy, humus soils. It is a fruit that has positive effects on human health through the organic and inorganic substances it contains. Turkey ranks first in apricot production and the region, including Malatya, meets approximately 85-90 % of the world apricot production.

Figure 1. Districts where the samples were taken

Fresh apricot samples were collected from the area where soil samples were taken. The samples taken in equal numbers from different branches of each tree were dried at 105 °C for 4 days and then ground and sieved. In this way, homogenous mixtures were obtained (Harb and Michel, 2009; Santos et al., 2002). Each mixture was weighed and its dry weight was determined. The same procedure was repeated for all districts. As with soil samples, the samples were placed in sample containers and the container was closed airtight. The samples were kept for 30 days to ensure the radioactive equilibrium between ^{226}Ra and its daughters (IAEA, 1989; Nadal et al., 2011).

2.2. Calculation of Radionuclide Concentrations

The gamma spectroscopic measurements of the soil and apricot samples analysed in the study were performed using ORTEC, GEM50P4-83 model high purity coaxial Ge detector with 1.9 keV resolution and 50% relative efficiency at 1332.5 keV.

After one month of storage, the samples were measured for approximately 13 hours using a gamma spectrometer. In the gamma-ray spectrum, photo-peak areas were selected at specific energy levels for different isotopes. Gamma rays with energies of 351.9 keV, 609.3 keV and 1,764.5 keV for ^{226}Ra, 583.2 keV and 911.2 keV for ^{232}Th and for ^{40}K, a gamma ray with an energy of 1,460.8 keV was used. The net photo-peak fields were calculated by subtracting the photo-peak fields at the relevant energy levels obtained during periodic laboratory background measurements. In this way, more accurate results were obtained by eliminating the background effect.

Radionuclide activity concentrations (A) of soil and apricot samples were calculated using the following equation:

$$A = \frac{C}{\varepsilon\,(E_\gamma)\times P_\gamma\times M\times t} \quad (1)$$

where, C is the count (net area) of the gamma-ray of interest in the gamma-ray spectrum; $\varepsilon\,(E_\gamma)$ is the calculated yield for the gamma-ray of interest; P_γ, is the probability of emission of the gamma-ray of interest; t is the counting time and M is the mass of the sample (Abugoufa, 2019; Sultan, 2020).

2.3. Soil-To-Plant Transfer Factor (TF)

Transfer factor (TF) is used to determine how much of the natural radionuclides present in soil samples within the study areas are transferred to plants (Al-Hamarneh et al., 2016). TF is an index of the ability of a plant to take up or accumulate activity from the soil in which it grows. The soil-to-plant transfer factor is usually defined as the ratio of the activity concentration of a radionuclide in plant samples to the activity concentration in soil. For a given radionuclide, the dry weight of the sample is taken as the basis. TF values of soil and apricot samples were calculated using Equation (2) (IAEA, 2010; FAO/IAEA/IUR, 1998; Cengiz, 2019).

$$TF = \frac{C_{Apricot}\ (Bq/kg,\ \text{dry weight})}{C_{Soil}\ (Bq/kg,\ \text{dry weight})} \tag{2}$$

where $C_{Apricot}$ and C_{Soil} are the activity concentrations in dry weight of plant and soil samples, respectively. A TF value less than 1 indicates a strong binding affinity of the radionuclide to soil and less bioaccumulation in plants. TF values greater than 1 (TF>1) indicate that the transfer of radionuclides from soil to plant is high (Baker and Brooks, 1989; Hu et al., 2014; Khandaker et al., 2016).

2.4. Annual Effective Ingestion Dose Rate (AE_{ingest}) and Lifetime Cancer Risk (LCR)

The annual effective ingestion doses of ^{226}Ra, ^{232}Th and ^{40}K radionuclide in the structure of the apricot samples investigated in the study were calculated with the help of Equation (3), while the probability of developing cancer in case of a certain exposure was calculated with the help of Equation (4).

$$AE_{ingest}\,(\mu Sv/y) = C \times I_{ingest} \times IDF \tag{3}$$

In equation (3), C is the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, I_{ingest} is the consumption rate of apricot and IDF is the intake dose conversion factor for the respective radionuclides. For ^{226}Ra, ^{232}Th and ^{40}K, the intake dose conversion factor for an adult over 17 years of age is 2.8×10^{-7} Sv/Bq, 2.3×10^{-7} Sv/Bq and 6.2×10^{-9} Sv/Bq, respectively (Güven et. al., 2023). For apricot fruit, I_{ingest} was taken as 2.5 kg/year (URL1).

$$LCR = AE_{ingest}\ (Sv/y) \times LE(y) \times RF\ (1/Sv) \tag{4}$$

Here, LCR is the lifetime probability of cancer development, AE_{ingest} annual effective ingestion dose rate, LE is the life expectancy (average 70 years) and RF is the risk factor. For stochastic effects, ICRP (International Commission on Radiological Protection) uses RF as 0.05 1/Sv (ICRP, 1990).

3. Findings and Discussion

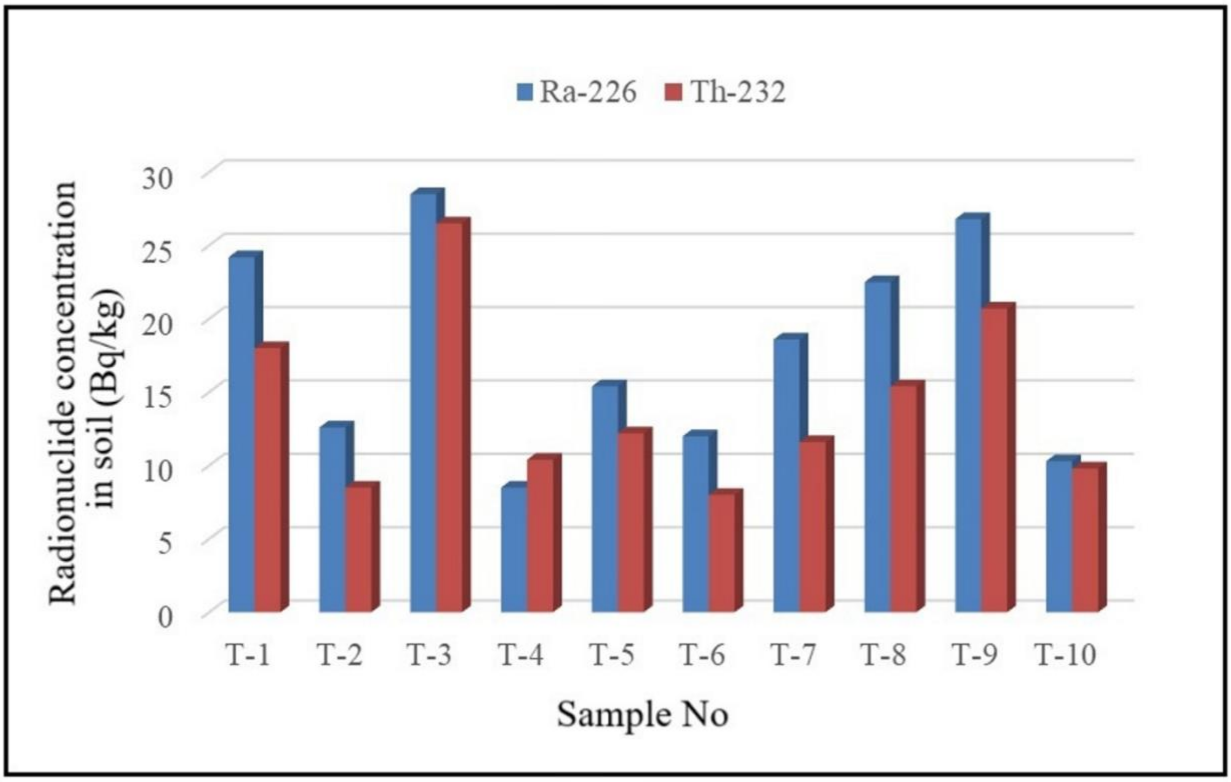
The concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil and apricot samples are given in Table 1, Table 2, Figure 2. (a) and (b), Figure 3. (a) and (b), respectively.

Table 1. ^{226}Ra, ^{232}Th and ^{40}K radionuclide concentrations in soil samples (Bq/kg d.m.)

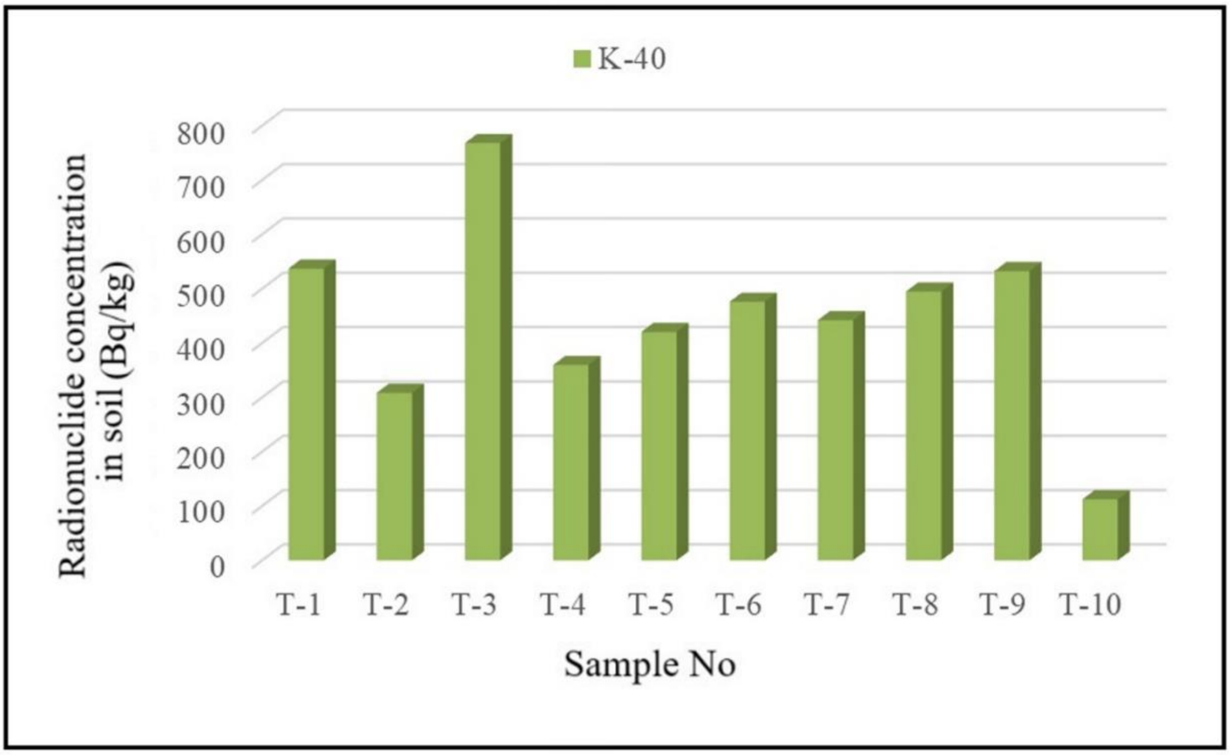
Sample No	**District**	**Activity (Bq/kg)**		
		^{226}Ra	**^{232}Th**	**^{40}K**
T-1	Doğanşehir	24.2 ± 0.6	18.0 ± 0.4	18.0 ± 0.4
T-2	Kale	12.6 ± 0.4	8.5 ± 0.3	8.5 ± 0.3
T-3	Hekimhan	28.5 ± 0.8	26.5 ± 0.6	26.5 ± 0.6
T-4	Yeşilyurt	8.5 ± 0.2	10.4 ± 0.3	10.4 ± 0.3
T-5	Battalgazi	15.4 ± 0.4	12.2 ± 0.4	12.2 ± 0.4
T-6	Pütürge	12.0 ± 0.3	8.0 ± 0.2	8.0 ± 0.2
T-7	Akçadağ	18.6 ± 0.5	11.6 ± 0.4	11.6 ± 0.4
T-8	Darende	22.5 ± 0.6	15.4 ± 0.5	15.4 ± 0.5
T-9	Kuluncak	26.8 ± 0.8	20.7 ± 0.5	20.7 ± 0.5
T-10	Doğanyol	10.3 ± 0.3	9.8 ± 0.3	9.8 ± 0.3
Mean		**17.9 ± 0.5**	**14.1 ± 0.4**	**14.1 ± 0.4**

Table 2. ^{226}Ra, ^{232}Th and ^{40}K radionuclide concentrations in apricot samples (Bq/kg d.m.)

Sample No	**District**	**Activity (Bq/kg)**		
		^{226}Ra	**^{232}Th**	**^{40}K**
A-1	Doğanşehir	16.4 ± 0.5	14.3 ± 0.5	193.4 ± 3.4
A-2	Kale	9.3 ± 0.3	3.9 ± 0.1	74.2 ± 1.5
A-3	Hekimhan	19.0 ± 0.6	11.9 ± 0.4	296.5 ± 5.6
A-4	Yeşilyurt	4.7 ± 0.2	3.7 ± 0.1	190.1 ± 3.0
A-5	Battalgazi	12.0 ± 0.4	8.5 ± 0.3	276.4 ± 4.4
A-6	Pütürge	6.2 ± 0.2	5.2 ± 0.2	266.5 ± 4.0
A-7	Akçadağ	10.8 ± 0.4	9.0 ± 0.3	140.6 ± 2.9
A-8	Darende	16.0 ± 0.5	8.6 ± 0.3	325.5 ± 5.3
A-9	Kuluncak	12.9 ± 0.4	13.5 ± 0.4	232.0 ± 4.7
A-10	Doğanyol	4.5 ± 0.2	3.7 ± 0.1	78.8 ± 1.8
Mean		**11.2 ± 0.4**	**8.2 ± 0.3**	**207.4 ± 3.7**

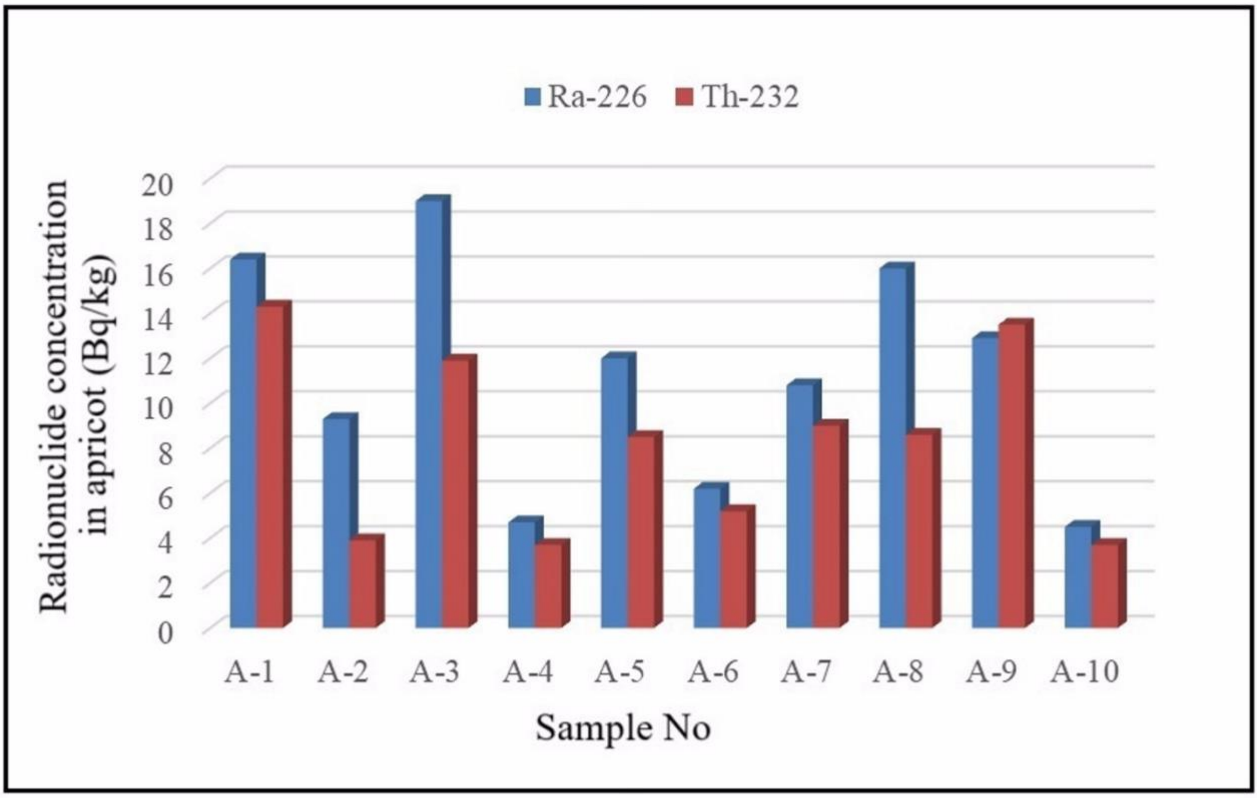


(a)

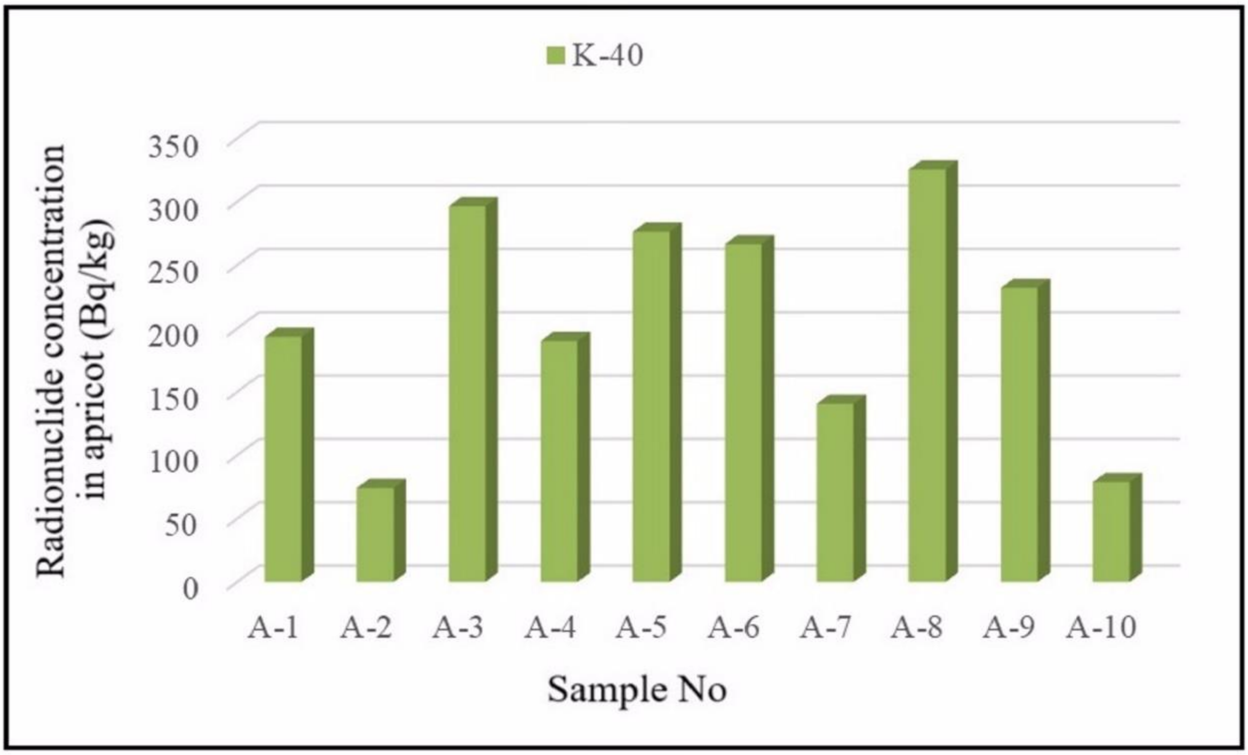


(b)

Figure 2. **a)** ^{226}Ra and ^{232}Th radionuclide concentrations in soil samples
b) ^{40}K radionuclide concentration in soil samples



(a)



(b)

Figure 3. (a) ^{226}Ra and ^{232}Th radionuclide concentrations in apricot samples

(b) ^{40}K radionuclide concentration in apricot samples

The mean concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples were calculated as 17.9 ± 0.5 Bq/kg, 14.1 ± 0.4 Bq/kg and 445.2 ± 8.0 Bq/kg, respectively, in study. The world average values ^{226}Ra, ^{232}Th and ^{40}K activity concentrations for soil samples were reported as 35.0 Bq/kg, 30.0 Bq/kg and 400.0 Bq/kg, respectively in the UNSCEAR 2000 report (UNSCEAR, 2000). In this study, the activity values of ^{226}Ra and ^{232}Th calculated for soil samples were found below these limit values, while the values calculated for ^{40}K were found above the limit values except for T-2, T-4 and T-10.

The transfer factors of ^{226}Ra, ^{232}Th and ^{40}K radionuclides from soil to apricot fruit are given in Table 3 and Figure 4.

Table 3. The transfer factors of ^{226}Ra, ^{232}Th and ^{40}K radionuclides from soil to apricot fruit

	RadionuclideTransfer Factor		
District	**^{226}Ra**	**^{232}Th**	**^{40}K**
Doğanşehir	0.68 ± 0.04	0.79 ± 0.06	0.36 ± 0.03
Kale	0.74 ± 0.05	0.46 ± 0.03	0.24 ± 0.02
Hekimhan	0.67 ± 0.04	0.45 ± 0.02	0.39 ± 0.03
Yeşilyurt	0.55 ± 0.03	0.36 ± 0.02	0.53 ± 0.04
Battalgazi	0.78 ± 0.06	0.70 ± 0.05	0.66 ± 0.05
Pütürge	0.52 ± 0.03	0.65 ± 0.04	0.56 ± 0.04
Akçadağ	0.58 ± 0.04	0.78 ± 0.06	0.32 ± 0.03
Darende	0.71 ± 0.05	0.56 ± 0.04	0.66 ± 0.06
Kuluncak	0.53 ± 0.02	0.65 ± 0.04	0.44 ± 0.05
Doğanyol	0.44 ± 0.01	0.38 ± 0.02	0.70 ± 0.08
Mean	**0.62 ± 0.04**	**0.58 ± 0.03**	**0.49 ± 0.04**

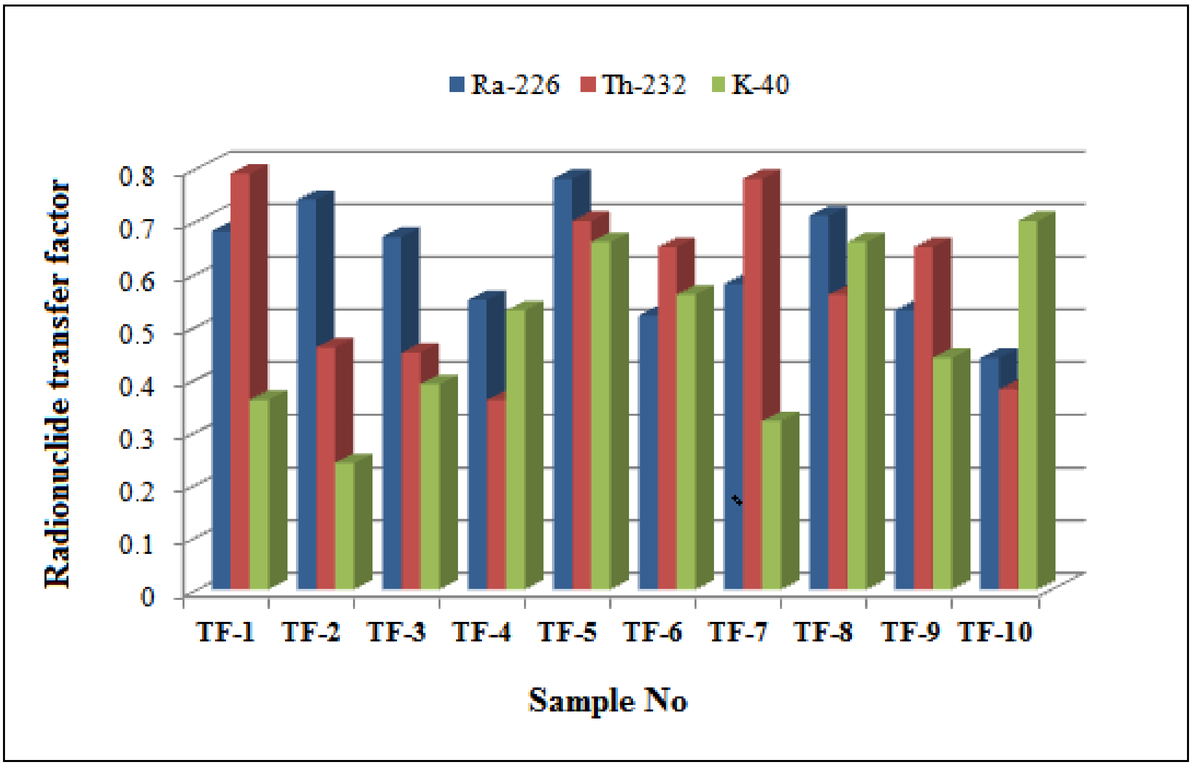


Figure 4. The transfer factors of ^{226}Ra, ^{232}Th and ^{40}K radionuclides

In this study, transfer factors calculated for ^{226}Ra radionuclide transfer from soil to apricot samples in agricultural lands were between 0.44 ± 0.01 and 0.78 ± 0.06, transfer factors calculated for ^{232}Th radionuclide transfer were between 0.36 ± 0.02 and 0.79 ± 0.06 and transfer factors calculated for ^{40}K radionuclide transfer were between 0.24 ± 0.02 and 0.70 ± 0.08. The lowest TF value was obtained in Kale district for ^{40}K and the highest value was obtained in Doğanşehir district for ^{232}Th.

Table 4. Comparison of radionuclide transfer factor results with the results obtained in similar studies

References	Studies Region	Fruits or vegatables Studies	RadionuclideTransfer Factor		
			^{226}Ra/^{238}U	^{232}Th	^{40}K
This study	Malatya, Turkey	Apricot	0.44 ± 0.01–0.78 ± 0.06	0.36 ± 0.02–0.79 ± 0.06	0.24 ± 0.02–0.70 ± 0.08
Nurtjahya et al., 2023	Bangka Belitung Province	Papaya	0.12 ± 0.10	0.28 ± 0.10	28.1 ± 8.9
Nurtjahya et al., 2023	Bangka Belitung Province	Dragon fruit (red)	0.33 ± 0.20	0.04 ± 0.01	10.6 ± 3.1
Otu, 2021	İstanbul, Turkey	Potato	0.06 ± 0.02	0.09 ± 0.04	0.8 ± 0.02
Kırış, 2019	Trabzon, Rize, Artvin, Turkey	The fruit part of cherry laurel	0.166	0.088	0.83
Abu Shayebet et al., 2018	Saudi Arabia	Palm pit	0.33	0.22	0.51
Khandaker et al., 2016	Malaysia	Vegetables	0.03–0.96	0.01–3.96	0.74–38.17
Asaduzzaman et al., 2014	Puchong, Malaysia	Sweet potato	0.50–0.74	0.73–1.4	3.0–3.5
Keser et al., 2011	Rize, Turkey	Kiwi	0.12	0.04	1.65
Keser et al., 2011	Rize, Turkey	Orange	0.08	0.01	1.15
Ahmad, 2007	Egypt	Banana	0.479 ± 0.04	0.227 ± 0.02	31.849 ± 3.14
Ahmad, 2007	Egypt	Apricot	0.690 ± 0.06	0.480 ± 0.04	8.873 ± 0.88
Ahmad, 2007	Egypt	Peach	0.350 ± 0.03	0.336 ± 0.03	1.95 ± 0.01

In this study, the TF results obtained for ^{226}Ra and ^{232}Th are in agreement with the results obtained in similar studies, while the results obtained for ^{40}K are considerably lower than the results obtained in similar studies (Table 4.).

In addition, the AE_{ingest} and LCR due to the natural radionuclides in the apricot samples were calculated in the study (Table 5).

Table 5. The AE_{ingest} and LCR due to the natural radionuclides in the apricot samples

Sample No	AE_{ingest} (^{226}Ra) µSv/y	AE_{ingest} (^{232}Th) µSv/y	AE_{ingest} (^{40}K) µSv/y	Total AE_{ingest} µSv/y	LCR × 10^{-3}
A-1	11.48 ± 0.36	8.22 ± 0.29	3.00 ± 0.05	22.70 ± 0.70	0.079 ± 0.003
A-2	6.51 ± 0.21	2.24 ± 0.06	1.15 ± 0.02	9.90 ± 0.29	0.035 ± 0.001
A-3	13.30 ± 0.42	3.93 ± 0.06	4.60 ± 0.09	21.83 ± 0.57	0.076 ± 0.002
A-4	3.29 ± 0.14	2.13 ± 0.05	2.95 ± 0.05	8.37 ± 0.24	0.029 ± 0.001
A-5	8.4 ± 0.28	4.89 ± 0.17	4.28 ± 0.07	17.57 ± 0.52	0.062 ± 0.002
A-6	4.34 ± 0.14	2.99 ± 0.12	4.13 ± 0.06	11.46 ± 0.32	0.040 ± 0.001
A-7	7.56 ± 0.28	5.18 ± 0.17	2.18 ± 0.05	14.92 ± 0.50	0.052 ± 0.002
A-8	11.2 ± 0.35	5.00 ± 0.17	5.05 ± 0.08	21.25 ± 0.60	0.074 ± 0.002
A-9	9.03 ± 0.28	7.76 ± 0.23	3.60 ± 0.07	3.60 ± 0.07	0.013 ± 0.000
A-10	3.15 ± 0.14	2.13 ± 0.06	1.22 ± 0.03	6.50 ± 0.23	0.023 ± 0.001
Arithmetic mean				**13.81 ± 0.40**	**0.048 ± 0.002**
World avarage (UNSCEAR, 2008)				**285**	**0.29**

According to Table 5, the calculated total AE_{ingest} values ranged from 3.60 ± 0.07 to 22.70 ± 0.70 µSv/y, while the LCR values ranged from (0.013 ± 0.000) ×10^{-3} to (0.079 ± 0.003) ×10^{-3}. The highest AE_{ingest} and LCR values were obtained for sample A-1 and the sample was taken from Doğanşehir district.

4. Conclusions and Recommendations

In this study, the activity levels of ^{226}Ra, ^{232}Th and ^{40}K in soil samples taken from different districts in Malatya province and apricot samples grown in these soils, as well as the transfer factors from soil to apricot were determined using the HPGe Germanium detector. The measured ^{226}Ra, ^{232}Th and ^{40}K activity concentrations were compared with the values reported in similar studies conducted in Turkey and in the world. While ^{226}Ra and ^{232}Th activity concentrations were lower than the world average values for soil samples, ^{40}K activity concentrations were higher than the world average value. The fact that ^{40}K radionuclide concentrations in the samples are above the limit values is due to the soil structure of the regions (Malatya metamorphics are the oldest formations), geological structure (in the 2nd degree earthquake zone) or fertilisation and spraying processes applied to increase productivity in agricultural lands. While the transfer values of radionuclides from soil to apricot were compatible with the existing studies in the literature for ^{226}Ra, ^{232}Th, the TF values obtained for ^{40}K were lower than the studies in the literature and all values were found to be less than 1. In the study, it is also observed that the results and averages obtained as a result of AE_{ingest} and LCR calculations are below the limit values permitted by UNSCEAR (2008). This means that the consumption of apricot samples grown in these regions will not pose a health risk.

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Authors' Contributions

All the paper is designed, created and revised by one author.

Competing of Interest

The author declared no competing interests.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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