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# Radiological assessment of internal exposure resulting from ingestion of natural radionuclides in *Arachis hypogaea* L. grown in Turkey

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**RESEARCH ARTICLE**

## Abstract

Groundnut (*Arachis hypogaea* L.) is one of the most important of all legumes and contains appreciable amounts of dietary oil and protein. Groundnut is added to many foods to enhance their levels of high-quality protein in diets lacking in nutrition. In this study, 51 groundnut samples were collected from the Mediterranean region of Turkey and analysed for naturally occurring radioactive isotopes of radium ($^{226}$Ra), thorium ($^{232}$Th) and potassium ($^{40}$K). The activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in groundnut samples varied from 2.9 ± 0.8 to 7.6 ± 1.0 Bq kg$^{-1}$ (dw), with an average of 5.4 Bq kg$^{-1}$ (dw); 4.4 ± 0.9 to 10.7 ± 1.2 Bq kg$^{-1}$ (dw), with an average of 6.9 Bq kg$^{-1}$ (dw) and 246.3 ± 18.2 to 541.8 ± 40.1 Bq kg$^{-1}$ (dw), with an average of 427.1 Bq kg$^{-1}$ (dw), respectively. The annual effective radiation dose was estimated to assess the health hazards caused by the ingestion of groundnut samples based on the measured activity concentrations of the radionuclides contained in them. The annual effective radiation dose varied from 6.5 to 10.1 μSv y$^{-1}$, with an average of 8.3 ± 0.1 μSv y$^{-1}$. The results revealed that consumption of Turkish groundnuts does not pose any radiological health hazards.

**Keywords**: groundnut, natural radioactivity, internal exposure, radiological hazards, annual effective dose, gamma-ray spectrometer

## 1. Introduction

Just as people are exposed to radioactivity in the atmosphere, they can be internally exposed to various radioactive substances by ingesting or inhaling terrestrial radionuclides. Ingested doses are mainly from the naturally occurring isotopes of the uranium ($^{238}$U) and thorium ($^{232}$Th) series radionuclides, and radioactive potassium radionuclide ($^{40}$K) found in food and drinking water (UNSCEAR, 2000). How much of these are ingested depends on the concentration of the radionuclides present and how much food and drinking water containing these types is consumed, which depend on different background levels, and prevailing climate and agricultural conditions (UNSCEAR, 2000).

Radium (Ra) is a member of the radioactive uranium series. Its isotope, $^{226}$Ra, is an important radionuclide in health physics and environment protection because it can dissolve in groundwater and enter food chain through plant roots. $^{226}$Ra is easily incorporated into the bones of mammals because its chemical and biological behaviour is similar to that of other alkaline earth metals, such as calcium (Ca), strontium (Sr) and barium (Ba) (Jia and Jia, 2012). $^{232}$Th, which is the first isotope in the series of radioactive thorium, might affect human health by weakening the immune system, which would induce various types of diseases when it accumulates in large amounts in the bones, lungs, liver and skeletal tissues. $^{232}$Th also has the ability to change genetic material (Addo *et al.*, 2013). $^{40}$K is a radioactive isotope of naturally occurring K, which has three isotopes—$^{39}$K (93.3%), $^{40}$K (0.0117%) and $^{41}$K (6.7%). $^{40}$K is the main natural source of radioactivity in animal and plant tissues as a soluble inorganic salt (UNSCEAR, 2000). Accumulation of K in the kidney causes its malfunctioning, and excess of K causes irregular heartbeats (Lenntech, 2018).

Groundnut (*Arachis hypogaea* L.), also known as peanut, is a plant of leguminous family. It is a valuable source of oil and nutrients for humans and has the potential to be used as an economic food supplement for treating malnutrition because it contains ~25–28% protein, ~48–50% oil and ~20–26% carbohydrates. Groundnut also contains 3% fibre and a large amount of Ca, thiamine and niacin (Bishi *et al.*, 2015; Sarvamangala *et al.*, 2011). Over the past 5 years, the production of groundnut in Turkey has increased by 34%, and in 2016, Turkey's total production reached 164,186 tonnes (TUİK, 2017). A large amount of groundnut produced in Turkey is usually consumed as a snack in domestic market.

Knowledge about the content levels of radionuclides in groundnut is very important in assessing the radiological health hazards of those exposed to them either directly or indirectly. Recently, several studies have been related to groundnuts grown in different regions of the world (Bianucci *et al.*, 2013; Cheng *et al.*, 2015; Guo *et al.*, 2014; Kraimat and Bissati, 2017; Liu *et al.*, 2017; Meena *et al.*, 2016; Msimbira *et al.*, 2016; Phan-Thien *et al.*, 2012; Shi *et al.*, 2014; Waliyar *et al.*, 2015; Willmon *et al.*, 2017; Zhang *et al.*, 2017; Zhao *et al.*, 2017); however, according to our literature search, there have been no detailed studies related to determining the contents of naturally occurring radionuclides in groundnut samples grown in Turkey. Given this shortcoming, we conducted this study, the results of which would contribute to the national requirement of establishing a baseline of radioactivity and internal exposure from groundnut consumption. The study aimed to (1) measure the activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K in groundnut samples grown in the Mediterranean region of Turkey; and (2) assess human health hazards by estimating the effective radiation dose rate by ingesting groundnut samples.

## 2. Materials and methods

### Experimental material

Fifty-one groundnut samples were collected from different fields located in Adana and Osmaniye in the Mediterranean region of Turkey (Figure 1), the two cities that produce most of Turkey's groundnut yield. In 2016, ~90% of the total groundnut production in Turkey was from Adana (60%) and Osmaniye (30%) (TUİK, 2017).

### Radionuclide analyses

Approximately 2 kg of groundnut samples were collected and cleaned of dust and small stones, after which each sample was coded. Then groundnuts were removed from their shells, and the samples were stored at room temperature for 2 days. Each sample was dried under controlled conditions at 100 C for 10–15 h until the moisture was completely removed; after this, each sample was ground. The homogenised samples were placed in a 5 × 6-cm sample container, weighed and sealed hermetically. Before measuring radioactivity, the sealed samples were stored for 1 month to reach a radioactive equilibrium of $^{226}$Ra and its decay products.

Radionuclide analyses were performed using a gamma-ray spectrometer with a high-resolution coaxial p-type horizontal HPGe detector. The resolution of the detector is 1.8 keV for $^{60}$Co gamma-ray energy line at 1332.5 keV and has a relative efficiency of 30%. The detector was shielded to minimise natural environmental background radiation. The certified standard calibration source, that is 1-L Marinelli beaker containing multinuclides in 1.0 g cm$^{-3}$ epoxy (Eckert & Ziegler Isotope Products) was used for absolute efficiency calibration of the system within an energy range of 122–1836 keV (Turhan *et al.*, 2015). The counting time for each groundnut sample was adjusted to obtain the best statistics of gamma-ray spectrum.

The activity concentration of $^{226}$Ra was determined directly by its own gamma-ray line at 186.1 keV, taking into account the contribution of $^{235}$U, and calculated as follows:

$$A_{226_{Ra}} = F_C \cdot A_{226_{Ra}} + 235_U, \quad (1)$$

where $F_C$ is the correction factor (0.572) (Vuong *et al.*, 2017). The activity concentration of $^{232}$Th was measured using the 911.2-keV gamma-ray line from actinium ($^{228}$Ac) and 583.2-keV gamma-ray line from thallium ($^{208}$Tl). The activity concentration of $^{40}$K was measured directly by its own gamma-ray line at 1460.8 keV (Turhan *et al.*, 2015).

### Radiological assessment

Internal exposure of radionuclide results from inhalation of contaminated air or ingestion of contaminated water and food. The estimate of effective dose in foodstuffs is useful for assessing the health hazards associated with the intake of these substances proportional to the total dose delivered in body. The annual effective dose ($D_{eff}$ in μSv y$^{-1}$) from ingestion of a radionuclide from groundnut samples was estimated using the following expression International Commission on Radiological Protection (ICRP, 1996):

$$D_{Eff} = AC \cdot R \cdot \Sigma A_i DC_i, \quad (2)$$

where AC is the average annual consumption of groundnut (1.7 kg y$^{-1}$), R is the average ratio between the dry and fresh


**Figure 1. Sampling sites of individual groundnut (G) sample.**

mass of groundnut samples (0.85 kg dw $kg^{-1}$ $fw^{-1}$), $A_i$ is the activity concentration of radionuclide i in groundnut samples and $DC_i$ is the dose conversion factors of radionuclide i. DC was measured for adults as 0.28, 0.23 and 0.0062 µSv $Bq^{-1}$ for $^{226}$Ra, $^{232}$Th and $^{40}$K, respectively (ICRP, 1996).

## 3. Results and discussion

The activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K measured in each groundnut sample and the statistical data for these activity concentrations are presented in

**Table 1. Activity concentrations of radionuclides of radium ($^{226}$Ra), thorium ($^{232}$Th) and potassium ($^{40}$K) in groundnut samples.**

| Sample code | Activity concentration (Bq kg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $^{226}$Ra | | | $^{232}$Th | | | $^{40}$K | | |
| G1 | 5.1 | ± | 2.0 | 6.9 | ± | 1.6 | 500.8 | ± | 40.1 |
| G2 | 3.8 | ± | 1.5 | 5.9 | ± | 1.2 | 526.3 | ± | 36.8 |
| G3 | 3.2 | ± | 0.9 | 6.7 | ± | 1.4 | 414.7 | ± | 27.0 |
| G4 | 6.1 | ± | 1.3 | 5.6 | ± | 2.5 | 370.0 | ± | 27.4 |
| G5 | 4.4 | ± | 1.6 | 6.8 | ± | 2.6 | 457.0 | ± | 37.0 |
| G6 | 7.4 | ± | 1.0 | 5.2 | ± | 1.6 | 451.0 | ± | 31.5 |
| G7 | 2.9 | ± | 0.8 | 4.4 | ± | 1.3 | 528.6 | ± | 37.0 |
| G8 | 4.1 | ± | 1.0 | 8.4 | ± | 2.6 | 541.8 | ± | 40.1 |
| G9 | 4.9 | ± | 1.0 | 9.2 | ± | 2.4 | 470.9 | ± | 30.4 |
| G10 | 5.6 | ± | 2.1 | 4.9 | ± | 1.2 | 522.7 | ± | 36.0 |
| G11 | 5.2 | ± | 1.0 | 5.7 | ± | 1.9 | 461.8 | ± | 43.4 |
| G12 | 5.4 | ± | 0.9 | 5.6 | ± | 1.2 | 483.0 | ± | 37.7 |
| G13 | 6.9 | ± | 1.4 | 6.7 | ± | 1.5 | 496.6 | ± | 40.2 |
| G14 | 5.9 | ± | 2.1 | 8.7 | ± | 1.4 | 517.1 | ± | 42.4 |
| G15 | 6.5 | ± | 2.2 | 6.6 | ± | 1.9 | 472.0 | ± | 39.2 |
| G16 | 6.3 | ± | 1.2 | 4.4 | ± | 1.6 | 455.6 | ± | 38.3 |
| G17 | 6.1 | ± | 1.3 | 5.6 | ± | 1.5 | 490.9 | ± | 38.8 |
| G18 | 5.7 | ± | 0.6 | 6.3 | ± | 0.9 | 450.2 | ± | 31.4 |
| G19 | 6.2 | ± | 1.5 | 7.9 | ± | 0.8 | 521.7 | ± | 41.7 |
| G20 | 5.9 | ± | 1.3 | 5.5 | ± | 1.2 | 396.9 | ± | 27.0 |
| G21 | 4.3 | ± | 1.2 | 6.4 | ± | 1.1 | 476.4 | ± | 37.2 |
| G22 | 6.8 | ± | 0.8 | 7.8 | ± | 1.2 | 530.1 | ± | 41.4 |
| G23 | 5.5 | ± | 0.6 | 7.5 | ± | 1.3 | 511.4 | ± | 41.4 |
| G24 | 4.4 | ± | 0.9 | 8.1 | ± | 1.4 | 540.1 | ± | 44.3 |
| G25 | 6.9 | ± | 1.1 | 8.4 | ± | 3.2 | 478.1 | ± | 39.7 |
| G26 | 5.8 | ± | 1.2 | 8.5 | ± | 2.3 | 504.4 | ± | 42.4 |
| G27 | 6.1 | ± | 0.7 | 7.6 | ± | 1.6 | 490.3 | ± | 41.7 |
| G28 | 6.6 | ± | 0.5 | 7.9 | ± | 1.4 | 398.8 | ± | 33.9 |
| G29 | 4.2 | ± | 1.3 | 8.1 | ± | 2.3 | 252.2 | ± | 21.7 |
| G30 | 5.7 | ± | 1.4 | 8.4 | ± | 0.9 | 334.4 | ± | 23.4 |
| G31 | 4.3 | ± | 1.1 | 7.9 | ± | 0.8 | 296.0 | ± | 21.5 |
| G32 | 5.7 | ± | 1.5 | 6.9 | ± | 1.4 | 319.0 | ± | 22.3 |
| G33 | 5.5 | ± | 1.3 | 7.7 | ± | 1.3 | 339.0 | ± | 23.4 |
| G34 | 7.1 | ± | 0.6 | 7.3 | ± | 0.9 | 358.0 | ± | 30.8 |
| G35 | 4.9 | ± | 0.9 | 8.5 | ± | 1.6 | 302.9 | ± | 21.2 |
| G36 | 4.4 | ± | 0.9 | 6.8 | ± | 1.3 | 271.1 | ± | 20.1 |
| G37 | 5.9 | ± | 1.0 | 7.7 | ± | 1.6 | 311.1 | ± | 25.5 |
| G38 | 5.6 | ± | 1.2 | 7.8 | ± | 0.9 | 372.4 | ± | 30.9 |
| G39 | 5.3 | ± | 1.3 | 8.6 | ± | 1.5 | 275.9 | ± | 23.2 |
| G40 | 4.1 | ± | 0.8 | 9.5 | ± | 0.9 | 258.5 | ± | 22.0 |
| G41 | 6.7 | ± | 0.8 | 9.7 | ± | 1.6 | 246.3 | ± | 18.2 |
| G42 | 5.1 | ± | 1.8 | 10.7 | ± | 1.2 | 338.8 | ± | 26.1 |
| G43 | 4.7 | ± | 1.3 | 4.6 | ± | 1.3 | 472.6 | ± | 33.1 |
| G44 | 4.4 | ± | 0.9 | 5.3 | ± | 1.5 | 463.2 | ± | 33.4 |
| G45 | 3.5 | ± | 0.6 | 4.3 | ± | 1.6 | 507.1 | ± | 37.5 |
| G46 | 5.9 | ± | 1.5 | 6.2 | ± | 1.5 | 331.2 | ± | 25.2 |
| G47 | 6.8 | ± | 1.7 | 5.6 | ± | 1.0 | 425.0 | ± | 34.0 |
| G48 | 6.1 | ± | 1.3 | 6.5 | ± | 1.4 | 475.8 | ± | 31.9 |
| G49 | 3.1 | ± | 1.0 | 4.2 | ± | 1.3 | 500.8 | ± | 34.6 |
| G50 | 4.1 | ± | 1.4 | 6.6 | ± | 1.5 | 477.6 | ± | 37.3 |
| G51 | 7.6 | ± | 1.0 | 3.2 | ± | 0.7 | 396.0 | ± | 29.7 |

**Table 2. Statistical data on radionuclide concentrations in groundnut samples.**

| | Activity concentration (Bq kg$^{-1}$) | | |
|---|---|---|---|
| | $^{226}$Ra | $^{232}$Th | $^{40}$K |
| Average | 5.4 | 6.9 | 427.1 |
| Median | 5.4 | 6.9 | 427.1 |
| Standard error | 0.2 | 0.2 | 12.4 |
| Standard deviation | 1.1 | 1.6 | 88.8 |
| Min. | 2.9 | 3.2 | 246.3 |
| Max. | 7.6 | 10.7 | 541.8 |
| Skewness | −0.2 | −0.1 | −0.6 |
| Kurtosis | −0.6 | −0.4 | −0.9 |
| Number of samples | 51 | 51 | 51 |

Tables 1 and 2, respectively. In addition, frequency histograms of the radionuclide activity concentrations are shown in Figure 2. The values for skewness and kurtosis of data distribution were in the range of −0.1 and −0.9, respectively. These values indicated normality of data distribution. The activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in groundnut samples varied from 2.9 to 7.6 Bq kg$^{-1}$, with an average of 5.4 Bq kg$^{-1}$; 3.2–10.7 Bq kg$^{-1}$, with an average of 6.9 Bq kg$^{-1}$ and 246.3–541.8 Bq kg$^{-1}$, with an average of 427.1 Bq kg$^{-1}$, respectively. The highest $^{226}$Ra activity concentration was measured in the groundnut sample from Düziçi Village (Osmaniye), whereas the lowest was measured in the sample from Kürkçüler Village (Adana). The highest $^{232}$Th activity concentration was measured in the groundnut sample from Burhanlı Village (Ceyhan-Adana), whereas the lowest was measured in the sample from Düziçi Village (Osmaniye). The highest $^{40}$K activity concentration was measured in the groundnut sample from Karataş Village (Adana), whereas the lowest was measured in the sample from Çakaldere Village (Ceyhan-Adana).

The average $^{226}$Ra and $^{232}$Th activity concentrations in the samples were approximately six times lower than the total weighted average values in the earth's crust of 32 Bq kg$^{-1}$ and 45 Bq kg$^{-1}$, respectively United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008). The average $^{40}$K activity concentration in groundnut samples was slightly higher than the total weighted average value within the earth's crust of 420 Bq kg$^{-1}$(UNSCEAR, 2008). According to the Turkish Atomic Energy Authority (TAEK, 2013) report, the average activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in surface-soil samples collected from Adana were 26, 35 and 448 Bq kg$^{-1}$, respectively, and from Osmaniye, these were 13, 15 and 259 Bq kg$^{-1}$, respectively. The average activity concentrations of $^{226}$Ra and $^{232}$Th in groundnut samples were approximately five times lower than those measured in the Adana soil, whereas they were

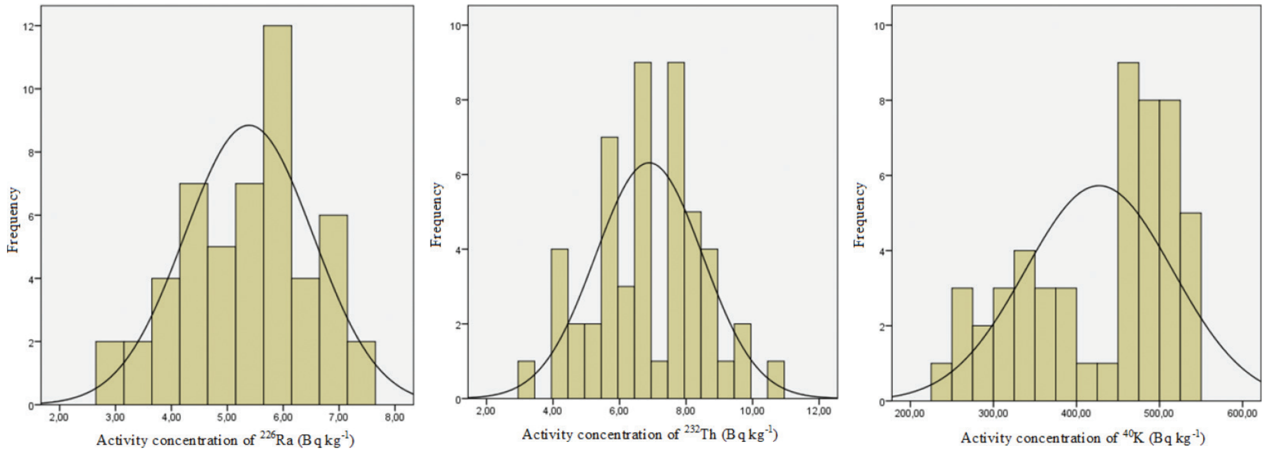


**Figure 2. Histogram of activity concentrations of radionuclides of radium ($^{226}$Ra), thorium ($^{232}$Th) and potassium ($^{40}$K) in groundnut samples.**

**Table 3. Comparison of the average potassium ($^{40}$K) radionuclide content in groundnut samples with that in food samples grown in Turkey.**

| Food | Activity concentration of $^{40}$K (Bq kg$^{-1}$) | References |
|---|---|---|
| Lentil | 274 | TAEK, 2009 |
| Chickpea | 382 | TAEK, 2009 |
| Wheat | 274 | TAEK, 2009 |
| Haricot bean | 541 | TAEK, 2009 |
| Corn | 404 | TAEK, 2009 |
| Hazelnut (Trabzon) | 83 | Çevik *et al*., 2009 |
| Hazelnut (Giresun) | 136 | Çevik *et al*., 2009 |
| Hazelnut (Ordu) | 137 | Çevik *et al*., 2009 |
| Groundnut | 427 | This study |
| Bean (Rize, Turkey) | 737 | Görür *et al*., 2012 |
| Pepper (Rize, Turkey) | 421 | Görür *et al*., 2012 |
| Tomato (Rize, Turkey) | 373 | Görür *et al*., 2012 |
| Tomato (Elazığ, Turkey) | 11 | Canbazoğlu and Doğru, 2013 |
| Chard (Rize, Turkey) | 123 | Görür *et al*., 2012 |

approximately two times lower than those measured in the Osmaniye soil. The average $^{40}$K activity concentration in groundnut samples was slightly lower than that measured in the Adana soil and approximately twice that measured in the Osmaniye soil.

A comparison of the average $^{40}$K content measured in groundnut samples with that in some food samples grown in Turkey is provided in Table 3. It is seen from this comparison that, except for the bean sample, the average $^{40}$K activity concentration in groundnut samples is higher than that measured in other food samples.

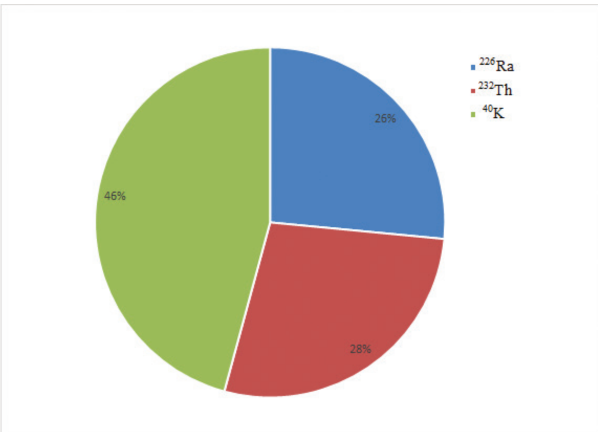


**Figure 3. Relative contributions to total annual effective dose from the radionuclides of radium ($^{226}$Ra), thorium ($^{232}$Th) and potassium ($^{40}$K) in groundnut samples.**

The values of $D_{Eff}$ estimated for groundnut samples varied from 6.5 to 10.1 μSv y$^{-1}$, with an average value of 8.4 μSv y$^{-1}$. This was significantly lower than the global average annual effective dose of 300 μSv y$^{-1}$ for internal exposure by ingesting food or water containing the radionuclides (UNSCEAR, 2000). The ratio of contribution of $^{226}$Ra, $^{232}$Th and $^{40}$K to total annual effective dose was 2.2, 2.3 and 3.8 μSv y$^{-1}$, respectively (Figure 3). As indicated in Figure 3, $^{40}$K provides a significant contribution to total annual effective dose.

## 4. Conclusion

The activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in groundnut samples were determined using a gamma-ray spectrometer with HPGe detector, and the radiological hazards were assessed using these activity concentrations.

The results indicate that consumption of groundnut samples examined in this study does not pose any radiological health hazards.

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## Conflict of interest

The authors declare no conflicts of interest with respect to research, authorship and/or publication of this article.

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