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Radioactivity content of dried nuts consumed in Kütahya, Turkey

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► ***Short Report***

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ABSTRACT

Background: Nuts are nutrient-rich foods and are recommended to be promoted to the public for their immense health benefits. The radioactivity content of 8 different types of nuts consumed in Kütahya, Turkey, was determined in 2024. ***Materials and Methods:*** Fourteen nut samples collected from local markets and supermarkets in Kütahya province were pulverized and dried, then waited in a 1 L Marinelli container for 30 days to attain equilibrium between Ra-226 and Th-232, their daughter products, finally sample content is determined using Canberra 3x3 NaI (Tl) detector. In addition, the samples' Annual Effective Ingestion Dose values were estimated. ***Results:*** K-40, Ra-226 and Th-232 concentrations of the samples were measured between 173.8 ± 2.7 and 305.0 ± 3.6 Bq kg^{-1}, <MDA (2.6) and 3.1 ± 0.7 Bq kg^{-1}, < MDA (2.6) and 3.3 ± 0.7 Bq kg^{-1}, respectively. ***Conclusions:*** The annual effective ingestion dose resulting from nut consumption was calculated assuming that an adult consumes 20 g of dried nuts daily and found between 9.1 and 19.0 µSv y^{-1}, with a mean of 13.9 µSv y^{-1}. A comparison of radioactivity levels and ingestion dose results with the limits presented in the UNSCEAR report shows that they were below the safety limits.

INTRODUCTION

Uranium and thorium series radionuclides with potassium, are the primary radioactive materials naturally occurring in the Earth's crust. These are absorbed by the plants from the soil to plants, and are often found to be accumulated in the plant bodies. Consequently, the ingestion of such foods can result in internal exposure to ionizing radiation depending on the concentration of radionuclides [(1)]. Thus, monitoring the radioactivity content of foods, like other natural or artificial substances, becomes important.

Nuts are nutrient-dense, widely consumed across Turkey, and are actively promoted to the public for their health benefits [(2)]. According to the 2023 Nuts Sector Report, Turkey's domestic nut consumption accounted for 700 thousand tons of nuts sold, and 170 thousand tons were imported. The sector also exports 370 thousand tons of nuts [(3)]. Despite the high production and consumption of nuts in Turkey, the studies on the radioactivity levels of nuts are scarce; if present, they are limited to hazelnuts and peanuts [(4-7)]. Furthermore, Brazil nuts also contain elevated levels of radionuclide concentration [(8-12)]. The studies conducted so far also include radioactivity concentrations of certain types of nuts for various countries [(9, 12-17)].

In this study, the potent concentration of the radionuclides of K-40 (potassium), Ra-226 (radium), and Th-232 (thorium) in a total of 14 samples belonging to 8 different nuts consumed in Kütahya Province, Turkey, were examined with a NaI (Tl) gamma spectroscopy system. The results were compared with previous reports in the literature, as well as the international safety limits set by health organizations. Given the limited research on the radioactivity levels of nuts in Turkey, this study aims to contribute to expand on the literature.

MATERIALS AND METHODS

Sample collection and preparation

A total of 14 samples, consisting of 8 different types of nuts; almond, hazelnut, roasted chickpea, Antep pistachio, walnut, peanut, Siirt pistachio, and cashew, were collected from local markets and supermarkets in Kütahya Province, Turkey, between February and July 2024.

A total of 2.5 kg of each dried nut sampled, excluding Antep and Siirt pistachios, were procured in sealed packages containing only kernels, with each pack weighing between 100 and 200 grams based on the brand. Multiple packages were purchased per sample to ensure uniformity across production dates and brands of the packs. Antep pistachios and Siirt pistachios were purchased in shell (3.5 kg each); the shells were processed during sampling, and only their kernels were used as samples. All the nut samples were sourced from Turkey.

Samples were labeled and dried in the oven (brand: Labart, origin: China) for 8 h at 100 °C after the pulverization process (brand: Lavion grain mill, origin: China). Due to the high oil content, they were

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stored in the laboratory until their mass remained constant. Samples were transferred to the 1 L Marinelli beakers. The net weight of each sample is weighted (brand: Kern, Origin: Germany). Samples are stored in an airtight condition for a minimum of 30 days to attain equilibrium between Ra-226, Th-232, and their daughter products. Each sample was labeled with net mass, sample name, and the sealing date [18, 19].

Radioactivity measurements

The activity concentrations of Ra-226, Th-232, and K-40 content of the nuts were determined with a Canberra 3x3 NaI (Tl) detector system with Genie 2000 software (brand: Mirion Technologies, origin: USA) [18, 19]. Background radiation was minimized by the surrounding detector via 1 cm-thick copper and 5 cm of lead. Energy and efficiency calibration were conducted using a reference soil sample with a known concentration [18]. Sample preparation and radioactivity measurements were performed in Kütahya Dumlupınar University.

The live time of the detector was set to 20,000 s for both sample and background measurements. Background radiation was measured daily by using a Marinelli beaker filled with 1 L ultra-pure water [18, 19]. The activities of K-40, Ra-226, and Th-232 were determined using energies of 1460, 1764, and 2614 keV, respectively. Genie 2000 and Fitzpeaks (brand: JF Computing Service, origin: UK) were used in gamma spectroscopy analysis. Minimum Detectable Activity (MDA) was determined for K-40, Ra-226, and Th-232 as 7.0, 2.6, and 2.6 Bq kg^{-1}, respectively.

Annual effective ingestion dose

The Annual Effective Ingestion Dose, *D*, resulting from nut consumption is the sum of dose contributions from the nuclides K-40 (D_K), Ra-226 (D_{Ra}), and Th-232 (D_{Th}) found in the nuts can be calculated with equation 1 [4]:

$$D = A_i \times I \times DCF_i \quad (1)$$

Where; A_i represents the activity of related nuclides, and *I* represent the intake of food [4]. It was assumed that the intake of nuts is approximately 7.3 kg per year (a handful of nuts per day). DCF_i represents the dose conversion factors related to ingestion. ICRP (International Commission on Radiological Protection) recommends for individuals over 17 years old in the units of µSv Bq^{-1} as 0.0062 for K-40, 0.28 for Ra-226, and 0.23 for Th-232 [20].

Statistical analysis

Statistical analysis was accomplished using Microsoft Excel (Office 365) and R version 4.4.1 (Lucent Technologies, USA) for the values above the MDA, since the levels below the MDA do not present a certain number or zero. The Shapiro-Wilk test was performed for radioactivity results and dose values to understand the statistical distribution. Sample uncertainties are calculated using counting statistics and presented as result ± uncertainty.

RESULTS

The radionuclides, K-40, Ra-226, and Th-232, content of 14 nuts measured in this study are presented in table 1. The Shapiro-Wilk test was applied to the results, and the p-value was found to be >0.05, which shows normal distribution. Samples activities vary between 173.8±2.7 and 305.0±3.0 Bq kg^{-1} for K-40, <MDA and 3.1±0.7 Bq kg^{-1} for Ra-226, <MDA and 3.3 ± 0.7 Bq kg^{-1} for Th-232. Samples mean activity values are 242.9±3.0 Bq kg^{-1} ($p=0.70$, $\alpha=0.05$) for K-40, 3.1 ± 0.8 Bq kg^{-1} ($p=0.51$, $\alpha = 0.05$) for Ra-226, and 3.0±0.8 Bq kg^{-1} for Th-232 ($p=0.93$, $\alpha=0.05$). The highest K-40, Ra-226, and Th-232 concentrations were determined in samples 4, 8, and 9, while sample 8 shows the lowest K-40 concentration. 10 samples Ra-226, 11 samples Th-232 levels are <MDA.

Estimated Annual Effective Ingestion Dose values are presented in table 2. The Shapiro-Wilk test was applied to the ingestion dose results and found to be normally distributed for $\alpha=0.05$. Annual Effective Ingestion Dose (D) values vary between 9.1 and 19.0 µSv y^{-1} with a mean value of 13.9 µSv y^{-1} ($p=0.76$, $\alpha=0.05$).

Table 1. Radioactivity concentrations of the dried nuts samples consumed in Kütahya Province.

	Sample Name	K-40 (Bq kg^{-1})	Ra-226 (Bq kg^{-1})	Th-232 (Bq kg^{-1})
1	Almond 1	246.5 ± 2.9	3.1 ± 0.7	<MDA
2	Almond 2	221.1 ± 3.1	<MDA	<MDA
3	Roasted chickpea 1	276.6 ± 3.5	<MDA	<MDA
4	Roasted chickpea 2	305.0 ± 3.6	<MDA	<MDA
5	Hazelnut 1	252.1 ± 3.4	3.0 ± 0.9	<MDA
6	Hazelnut 2	268.2 ± 3.1	<MDA	<MDA
7	Walnut 1	183.5 ± 3.2	3.1 ± 0.9	2.7 ± 0.9
8	Walnut 2	173.8 ± 2.7	3.1 ± 0.7	<MDA
9	Antep Pistachio	254.2 ± 3.0	<MDA	3.3 ± 0.7
10	Siirt pistachio	301.1 ± 3.0	<MDA	<MDA
11	Peanut 1	246.9 ± 3.0	<MDA	<MDA
12	Peanut 2	252.7 ± 2.9	<MDA	<MDA
13	Cashew 1	218.5 ± 2.9	<MDA	3.0 ± 0.7
14	Cashew 2	200.5 ± 2.6	<MDA	<MDA
	Mean	242.9 ± 3.0	3.1 ± 0.8	3.0 ± 0.8

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Table 2. Ingestion dose contribution of nuts.

	Sample name	D_K (μSv/y^{-1})	D_{Ra} (μSv y^{-1})	D_{Th} (μSv y^{-1})	D (μSv y^{-1})
1	Almond 1	11.2	6.35		17.5
2	Almond 2	10.0			10.0
3	Chickpea 1	12.5			12.5
4	Chickpea 2	13.8			13.8
5	Hazelnut 1	11.4	6.0		17.4
6	Hazelnut 2	12.1			12.1
7	Walnut 1	8.3	6.3	4.4	19.0
8	Walnut 2	7.9	6.4		14.3
9	Antep Pistachio	11.5		5.5	17.0
10	Siirt pistachio	13.6			13.6
11	Peanut 1	11.2			11.2
12	Peanut 2	11.4			11.4
13	Cashew 1	9.9		5.0	14.9
14	Cashew 2	9.1			9.1
	Mean	11.0	6.3	5.0	13.9

Empty Lines: Not calculated.

DISCUSSION

Nuts can be classified alongside root vegetables, fruits, and leafy vegetables to compare our results with the reference activity concentrations in the UNSCEAR (United Nations Scientific Committee on the Effect of Atomic Radiation) 2000 report. According to this report, the activity values for root vegetables and fruits are 30 and 0.5 mBq kg^{-1} for Ra-226 and Th-232, respectively, while they are 50 and 15 mBq kg^{-1} for leafy vegetables, respectively [1]. Ra-226 and Th-232 concentrations of this study, except for <MDA, are higher than the reference values presented by UNSCEAR. Specific references to compare K-40 activity remain unavailable. Since radionuclides are transferred to nuts through the soil uptake by plants, the radioactivity of the nuts sampled in this study was determined to be below the world average soil radioactivity level.

Table 3 presents the activity comparison of nuts sampled in this study with those reported previously [4-7, 9, 12-17]. Radioactivity concentrations of the nuts measured in this study fall within the limit found in the literature. The peak values reported in the studies presented in the literature for Ra-226 and Th-232 concentrations in hazelnuts in Turkey [4], pistachios in Turkey [7] and Nigeria [14], and almonds in Saudi Arabia [9] are significantly higher than the results found in this study. The K-40 contents of studies conducted in Turkey [7], Saudi Arabia, and Nigeria [14] for peanuts, Saudi Arabia [9] and Iraq [13] for walnuts and cashews, Saudi Arabia [9] for hazelnuts, almonds, and chickpeas are higher. Nut types such as Brazil nuts, uncommon in Turkey's consumption, are excluded from this table. Additionally, no published work was available on the Antep and Siirt pistachio.

The calculated mean annual ingestion dose for nut consumption in this study can be considered lower than the ingestion dose estimated by UNSCEAR as 290 μSv y^{-1} [1]. The contribution of uranium and thorium series radionuclides to the average ingestion dose was estimated by weighting the consumption amounts of different food types as 120 μSv y^{-1}, Ra-226, and Th-232 contributions to this dose are reported as only 6.3 and 0.38 μSv y^{-1}, respectively [1]. The estimated ingestion dose in this study due to Ra-226 and Th-232 activity is higher than reported in the UNSCEAR report.

Table 3. Radioactivity comparison of dried nuts sampled in this study with the literature.

Nuts Type	Study region	K-40 (Bq kg^{-1})	Ra-226 (Bq kg^{-1})	Th-232 (Bq kg^{-1})
Hazelnut	**This study**	252.1 - 268.2	<MDA - 3.0	<MDA
	Turkey [4]	<MDA - 312	<MDA - 29	<MDA - 43
	Turkish nuts in the UK [5]	227-242	<MDA	<MDA
	Saudi Arabia [9]	411.3		
	Iraq [13]	325.62	1.39	1.01
Peanut	**This study**	246.9 - 252.7	<MDA	<MDA
	Turkey [6]	193.3 - 273.9	21.7 - 67.2	6.9 - 24.4
	Turkey [7]	246.3 - 541.8	2.9 - 7.6	4.4 - 10.7
	Saudi Arabia [9]	400.2 - 522.6		
	Brazil [12]	205		
	Iraq [13]	329.4 - 376.5	6.5 - 8.6	0.3 - 5.0
	Nigeria [14]	18.8 - 551.2	4.81 - 35.7	2.2 - 22.4
	Yemen [17]	262.78-351.30	1.44-4.88	1.29-1.90
Almond	**This study**	221.1 - 246.5	<MDA - 3.1	<MDA
	Saudi Arabia [9]	396. 5 - 444.7	63.0	50.5
	Iraq [13]	256.5	4.9	2.4
	Namibia [15]	122.2	<MDA	<MDA
Walnut	**This study**	173.8 - 183.5	3.1	<MDA-2.7
	Saudi Arabia [9]	296.32		
	Brazil [12]	136		
	Iraq [13]	262.9 - 356.7	4.2 - 8.7	1.3 - 2.3
	Nigeria [14]	96	ND*	2.8(Ra-228)
Chickpeas	**This study**	276.6 - 305	<MDA	<MDA
	Saudi Arabia [9]	552.2 - 581.9		
Cashew	**This study**	200.5 - 218.5	<MDA	<MDA-3.0
	Saudi Arabia [9]	429.8		
	Brazil [12]	191		
	Iraq [13]	289.8	9.98	1.4
	Nigeria [14]	111	6.5	2.9

Empty lines: No data or MDA level is given. ND*: Not detected.

CONCLUSION

The current study was on radionuclide levels in nuts sampled in the Kütahya province of Turkey. It was revealed that although activity contents may appear low when compared to typical soil radioactivity levels, the foods could significantly contribute to high doses in the relevant group, depending on consumption, and therefore, the importance of monitoring their activity contents was shown.

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