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Radiological hazard of coffee to humans: a comparative study of Arabian and Turkish coffees

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Thirty-nine Arabian and Turkish coffee powder samples purchased from various markets in Saudi Arabia were analyzed by High Pure Germanium (HPGe) gamma spectrometry to determine the activity concentrations of the natural and artificial radionuclides ^{238}U, ^{226}Ra, ^{232}Th, ^{137}Cs, and ^{40}K. All samples, (except for two samples of Turkish coffee) were found to contain a high mean content of ^{40}K, ranging from 839.83 to 1197.11 Bq/kg and from 161.312 to 2411.215 Bq/kg for Arabian and Turkish coffee powders, respectively. The concentrations of ^{226}Ra and ^{232}Th were found to be 2.57 to 10.63 Bq/kg and nondetectable to 8.01 Bq/kg for Arabian coffee and nondetectable to 10.09 Bq/kg and nondetectable to 9.75 Bq/kg for Turkish coffee, respectively. Based on these values, we estimated the potential radiological hazards to consumer health from coffee powder. We determined the radium equivalent, annual effective dose rate, and external and internal hazard for each element, and all were found to be below the limit recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation. However, absorbed dose rate values for some samples were higher than the permissible limit. In all samples, the ^{137}Cs concentration was below the detection limit. The average annual committed effective dose values reported in this study were far below the world average value of 0.30 mSv/yr for an individual. In addition, the limit for the threshold consumption rate was calculated. The statistical methods were applied to study the relationship between all the calculated natural radionuclides and their hazard parameters. Results indicated that the use of these types of coffee had no significant radiological health risks. This study may contribute data on coffee powder for formulating regulations related to radiological health care.

Key words: Arabian and Turkish coffees**,** natural radioactivity**,** radiological hazard parameters.

INTRODUCTION

Coffee is one of the most popular and widely consumed beverages in the world, and its consumption is increasing (Roselli et al., 2013). However, variation exists in the annual consumption between countries. In addition, coffee is grown in many countries, where the coffee trade has played a crucial role in their economic development (Roselli et al., 2013). Coffee comes from the plant genus *Coffea*, which has two primary species, *C. arabica* (Arabica) and *C. canephora* (also known as *C. robusta*, or robusta). Some naturally occurring radioisotopes and other elements present in soil are drawn into the roots of plants via ion channels or specific transporters (Sugiyama et al., 2009; Jibiri et al., 2016). Their distribution throughout the plant tissues depends on their chemical characteristics and several parameters of soil and the plants themselves (Awudu, 2012). Several studies have been performed to determine the concentrations of elements in various types of coffee and to estimate whether these concentrations contribute to toxicity (Szymczycha-Madeja et al., 2014; Welna et al., 2014; Jarošová et al., 2014; Zaidi et al., 2005).

Jarošová et al. (2014) determined the toxic elements and mineral nutrients, including Pb, Ni, Mn, Cr, Cd, Zn, Mg, Fe, Cu, and Ca, in five types of coffee by using inductively coupled plasma mass spectrometry (ICP-OES) and atomic absorption spectrometry (AAS). No significant differences were found between the results obtained through the two methods, but a multivariate analysis helped to identify variations among samples collected from different locations. Zaidi et al. (2005) used instrumental neutron activation analysis to measure 20 trace elements (toxic, essential, and nonessential) in samples of coffee beans from four different origins and two instant coffee brands consumed in Pakistan. They next estimated the daily intake of trace elements and compared those levels with tolerance limits. The intake of toxic elements was well below the recommended safety limits, but the cumulative intake of Mn was four times higher than the acceptable amount.

Knowledge of the concentrations and distributions of natural radionuclides, such as ^{40}K, ^{238}U, and ^{232}Th and their decay products, in soils, plants, sediments, and so forth is useful for monitoring environmental radioactive contamination (El-Reefy et al., 2006). Use of chemical fertilizers, especially phosphorus fertilizer, may lead to increased contamination of agricultural crops by enriching the soil with radioactive elements as well as chemical toxins (Alharbi, 2013).

Roselli et al. (2013) determined the background level of gamma emitters, including ^{212}Bi, ^{212}Pb, ^{228}Ac, ^{214}Bi, ^{214}Pb, ^{40}K, and ^{137}Cs, in 18 brands of coffee powder. The mean activity concentration of ^{40}K was found to be 907.4 ± 115.6 Bq/kg. In addition, the mean activity concentration of ^{214}Bi and ^{214}Pb, indicators of ^{226}Ra, given as the mean value of the two radionuclides, resulted in 10.61 ± 4.02 Bq/kg ^{228}Ra. ^{228}Ac indicators showed a mean activity concentration of 13.73 ± 3.20 Bq/kg. ^{212}Pb, a ^{224}Ra indicator, presented a mean activity concentration of 8.28 ± 2.88 Bq/kg. The mean activity concentration of ^{208}Tl, another ^{224}Ra indicator, was 11.03 ± 4.34 Bq/kg. Results indicated that all samples had ^{137}Cs concentrations less than the detection limit (2.0 Bq/kg).

The aim of this study was to compare the concentration of naturally occurring radioactive materials (NORMs) in Arabian and Turkish coffee powder using gamma spectrometry. The imported samples were bought from selected local markets. Additional goals were to determine the radiological hazard associated with drinking coffee made from the various coffee powders and to estimate the average annual committed effective dose via ingestion of the radionuclides in the coffee and the threshold consumption rate.

The study focused on coffee powder to enrich the radiological information in Saudi Arabia in particular and the world in general because information on the concentration of NORMs and their presence in coffee is scarce.

MATERIALS AND METHODS

Thirty-nine coffee powder samples were purchased at different markets in Saudi Arabia. Each powdered was grinded and dissolved as homogenous solution and weighing about 200 to 250 g. The samples were then transferred to polyethylene 650-mL Marinelli type beakers (of known weight) were hermetically sealed with an insulating tape to impede contact with air moisture say labeled, and packed into radon-impermeable plastic containers to prevent radon gas escape as much as possible. Containers of the same size and geometry were used for reference materials to calibrate the system for measuring radioactivity. The samples and reference materials were stored and kept for a period of 1 month to attain secular radioactive equilibrium among ^{226}Ra, ^{232}Th, and their respective short-lived decay products ^{226}Ra and its decay products in the uranium series and ^{228}Ra and its decay products in the thorium series (Kurnaz et al., 2007; Samad et al., 2012). Finally, each Marinelli container was analyzed using a HPGe detector.

The radiometric measurement

Detection of the amount of natural radioactivity for ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K in coffee powder samples was carried out with gamma spectrometry using a high-purity germanium (HPGe) detector (P-type vertical coaxial, Canberra model GC4018). The detector had 25% relative efficiency and a resolution of 1.85 at 1332 keV of ^{60}Co gamma ray. The gamma acquisition and analysis were determined by using a multichannel analyzer (16,000 channels spectral memory) coupled to a computer using Genie-2000 Basic Spectroscopy Software. Quality-assured standard samples in QCY4 solution (obtained from the International Atomic Energy Agency) were used for the calibration and the absolute efficiency of the detector. The mixture of radionuclides in the solution (with corresponding energies) included ^{60}Co (1173 and 1333 keV), ^{88}Yt (898 and 1836 keV), ^{137}Cs (662 keV), ^{85}Sr (514 keV), ^{113}Sn (391.69 keV), ^{203}Hg (279 keV), ^{139}Ce (1656 keV), ^{57}Co (122 keV), ^{109}Cd (88 keV), and ^{241}Am (60 keV). Detailed information concerning calibration of the HPGe detector and the procedures followed can be found in previous study (Tufail et al., 2006; Fawzia, 2010). To measure the environmental gamma background, an empty identical Marinelli beaker was used. All samples and the background were counted for 36,000 s. After measurement, the activity concentrations were calculated by subtraction of the background values. The ^{137}Cs and ^{40}K concentrations were measured by determining their characteristic gamma lines of energies, 661.6 and 1460.8 keV, respectively. The ^{226}Ra activity concentration was determined by averaging the calculated activity

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concentrations of three photopeaks of ^{214}Bi (1764.5, 1120.3, and 609.3 keV) and two of ^{214}Pb (295.1 and 352 keV). The activity of ^{232}Th was inferred from the weighted mean activities of the gamma peaks of ^{208}Tl (583.0 keV), ^{212}Pb (238.6 keV), and ^{228}Ac (911.2 and 338.4 keV). In addition, the activity of ^{238}U was given by the line of gamma of its product decay: ^{234}Th (63.22 and 92.78 keV) (Darko, 2015). The minimum detectable activity concentrations of ^{40}K, ^{238}U, ^{232}Th, ^{226}Ra, and ^{137}Cs using HPGe detector were 2.51, 1.0, 0.80, 0.75, and 0.85 Bq/kg, respectively.

Calculations

Absorbed dose rate and annual effective dose rate equivalent from ingestion of coffee powder

According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2010), the external outdoor absorbed gamma dose rate (D) from natural radionuclides in the samples under study (at 1 m above the ground level) can be calculated from the following equation:

$$D(\text{nGy/h}) = 0.426A_{\text{Ra}} + 0.664A_{\text{Th}} + 0.042A_{\text{K}} \quad (1)$$

Where, A_{Ra}, A_{Th}, and A_{K} are the activity concentrations of radium, thorium, and potassium, respectively. The absorbed dose can be converted to the annual effective dose equivalent by using the conversion factor 0.7 Sv/Gy (UNSCEAR,2000) and the indoor occupancy factor of 0.8, based on people spending an average of 80% of their time indoors and 20% outdoors (Jibiri, 2016).

The total annual effective dose (AE, the external dose rates) from the ^{226}Ra, ^{232}Th, and ^{40}K is obtained by using the following equation (Giri, 2013):

$$AE(\text{mSv/yr}) = D \times 24 \times 365.25 \times 0.8 \times 0.7 \times 10^{-6} \quad (2)$$

The absorbed dose rate (D) and the annual effective dose (AE) for the coffee powder samples are presented in Table 4.

The radium equivalent

The radium equivalent activity for coffee powder is given by the following equation (Matiullah et al., 2004):

$$Ra_{\text{eq}}(\text{Bq/kg}) = A_{\text{Ra}} + 1.43A_{\text{Th}} + 0.077A_{\text{K}} \quad (3)$$

Equation 3 compares the activity concentrations of coffee powder containing different amounts of ^{40}K, ^{232}Th, and ^{226}Ra. The permissible limit of this index is 370 Bq/kg as reported by UNSCEAR (2000).

The internal and external hazard indices

The internal and external exposures to gamma radiation in coffee powder were determined using the Equations 4 and 5, respectively (Fawzia, 2010):

$$H_{\text{in}} = \frac{A_{\text{Ra}}}{185} + \frac{A_{\text{Th}}}{259} + \frac{A_{\text{K}}}{4910} \quad (4)$$

$$H_{\text{ex}} = \frac{A_{\text{Ra}}}{370} + \frac{A_{\text{Th}}}{259} + \frac{A_{\text{K}}}{4910} \quad (5)$$

To safely consume the coffee powder, the upper limit for both the internal index (H_{in}) and the external index (H_{ex}) should be less than unity as reported by ICRP (2007).

Average annual committed effective dose or dose ingested by the consumer

Estimation of the average annual committed effective dose (AACED) due to ingestion of NORMs in coffee can be calculated using the following equation (Njinga et al., 2015; Chandrashekara and Somashekarappa, 2016):

$$E_{\text{ave}} = C_r \times DCF_i \times A_i \quad (6)$$

where, E_{ave} (Sv/yr) is the AACED, A_i is the activity concentration of each radionuclide i , C_r is the consumption rate of radionuclide, and DCF_i is the standard dose conversion factor (2.8×10^{-4}, 2.3×10^{-4}, and 6.2×10^{-6} mSv/Bq for ^{226}Ra, ^{232}Th, and ^{40}K, respectively, for an adult) (UNSCEAR, 2000). The annual threshold consumption rate (kg/yr) for each coffee sample was obtained using the following equation:

$$C_r = \frac{3E_{\text{ave}}}{\sum_i^3 (DCF_i \times A_i)} \quad (7)$$

Where, A_1, A_2, and A_3 are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively DCF_1, DCF_2, and DCF_3 are the dose coefficients for ingestion for the radionuclides (Sv/Bq) and E_{ave} = 0.3 (mSv/yr) is the threshold AACED due of NORMs in the studied samples.

RESULTS AND DISCUSSION

The activity concentrations of ^{40}K, ^{238}U, ^{226}Ra, and ^{232}Th in Arabian and Turkish coffee powders imported for Saudi markets from different countries were estimated, and the results are summarized in Tables 1 and 2, respectively. As shown in Table 1, the activity concentrations of ^{226}Ra and ^{232}Th varied from 2.57 to 10.63 Bq/kg with a mean value 6.19 Bq/kg and from nondetectable (ND) to 8.01 Bq/kg with a mean value 4.31 Bq/kg, respectively. In addition, as shown in Table 2, the activity concentrations of ^{226}Ra and ^{232}Th ranged from ND to 10.09 Bq/kg with a mean of 2.77 Bq/kg and ND to 9.75 Bq/kg with a mean of 3.12 Bq/kg, respectively. All these values are significantly lower than the permissible levels reported by UNSCEAR (2010) (33 and 45 Bq/kg for ^{226}Ra and ^{232}Th, respectively), as shown in Figures 1 and 2. The activity concentrations of ^{40}K in Arabian coffee powder ranged from 839.83 to 1197.11 Bq/kg with a mean value of 1041.24 Bq/kg. Sample CA5 had the highest activity concentration, while sample CA9 had the lowest value. For Turkish coffee powder samples, the activity concentrations of ^{40}K varied from 161.31 to 2411.22 Bq/kg with a mean of 1507.18 Bq/kg. The lowest activity was recorded for sample CT20, while the highest activity was recorded for sample CT24. With the exception of two

Table 1. Activity concentration (Bq/kg) in different types of Arabian coffee powder.

Sample code no.	Activity concentration			
	^{238}U	^{226}Ra	^{232}Th	^{40}K
CA1	45.93 ± 8.23	2.57 ± 0.42	2.66 ± 0.70	1031.93 ± 56.29
CA2	9.35 ± 1.81	7.98 ± 1.63	2.96 ± 0.79	1118.90 ± 65.99
CA3	22.11 ± 4.31	5.28 ± 1.02	2.12 ± 0.51	948.70 ± 50.82
CA4	102.39 ± 21.74	6.70 ± 1.41	4.93 ± 0.99	1086.45 ± 57.52
CA5	135.11 ± 24.61	10.63 ± 2.84	8.01 ± 1.64	1197.11 ± 61.18
CA6	37.62 ± 7.07	7.54 ± 1.34	7.06 ± 1.36	1070.23 ± 47.95
CA7	61.79 ± 8.81	8.52 ± 1.62	6.91 ± 1.12	1090.50 ± 50.00
CA8	12.64 ± 3.511	7.39 ± 1.25	5.65 ± 1.01	1004.16 ± 54.82
CA9	66.33 ± 9.62	7.863 ± 1.46	3.40 ± 1.04	839.83 ± 36.62
CA10	ND	4.97 ± 1.07	ND	956.65 ± 47.28
CA11	ND	3.10 ± 0.71	2.96 ± 0.63	1049.63 ± 36.33
CA12	52.56 ± 9.73	5.75 ± 1.07	3.52 ± 0.77	1079.09 ± 45.22
CA13	61.98 ± 8.81	5.60 ± 1.00	4.89 ± 0.91	1062.87 ± 49.82
CA14	16.73 ± 3.01	5.98 ± 1.10	5.22 ± 1.22	1041.34 ± 39.96
Mean	44.61± 7.95	6.19± 1.28	4.31± 0.91	1041.24± 49.99

Table 2. Activity concentration (Bq/kg) in different types of Turkish coffee powder.

Sample code no.	Activity concentration			
	^{238}U	^{226}Ra	^{232}Th	^{40}K
CT1	50.31 ± 10.54	10.09 ± 2.18	9.75 ± 1.86	1128.64 ± 62.92
CT2	ND	2.45 ± 0.67	3.07 ± 0.63	1138.37 ± 62.95
CT3	26.19 ± 4.67	5.50 ± 1.12	6.19 ± 1.01	1155.67 ± 50.96
CT4	28.27 ± 5.03	3.97 ± 0.64	5.76 ± 1.11	1200.03 ± 70.15
CT5	27.05 ± 5.37	1.295 ± 0.18	ND	2173.70 ± 80.32
CT6	15.36 ± 3.45	3.64 ± 0.70	4.93 ± .96	1232.48 ± 64.80
CT7	17.03 ± 3.17	4.17 ± .96	4.19 ± .97	1492.13 ± 77.96
CT8	8.68 ± 1.79	7.58 ± 1.13	7.62 ± 1.29	1070.22 ± 51.00
CT9	32.72 ± 7.08	3.65 ± 0.79	2.92 ± 0.66	1203.27 ± 63.07
CT10	57.16 ± 9.32	5.49 ± 0.96	4.65 ± 1.00	1842.68 ± 68.55
CT11	33.10 ± 7.14	ND	ND	1913.53 ± 79.06
CT12	10.08 ± 1.78	1.56 ± .26	1.32 ±0 .36	1845.82 ± 80.00
CT13	10.48 ± 2.14	ND	ND	1801.36 ± 80.13
CT14	19.75 ± 4.07	ND	ND	1805.92 ± 80.12
CT15	ND	4.66 ± 0.89	3.95 ± 0.90	1930.17 ± 82.65
CT16	31.83 ± 5.69	2.46 ± 0.71	9.53 ± 1.79	2046.99 ± 82.05
CT17	22.12 ± 5.96	1.74 ± .46	1.67 ± 0.26	1627.38 ± 75.34
CT18	18.81 ± 3.26	ND	3.18 ± 0.71	1338.38 ± 62.51
CT19	24.61 ± 6.38	ND	ND	1806.83 ± 70.60
CT20	ND	ND	ND	161.31 ± 50.71
CT21	ND	ND	ND	211.92 ± 48.80
CT22	ND	ND	ND	1899.82 ± 76.59
CT23	41.81 ± 8.65	ND	ND	1986.54 ± 83.10
CT24	46.66 ± 9.40	6.97 ±0.89	6.67 ± 1.12	2411.22 ± 83.68
CT25	40.99 ± 0.90	3.05 ± 0.66	2.52 ± 0.56	1653.16 ± 64.24
Mean	22.52± 4.00	2.77± 0.52	3.12± 0.49	1523.10± 70.09

Table 3. Radium equivalent, absorbed dose rate, annual effective dose rate, external hazard index, and internal hazard index in different types of Arabian coffee powder.

Sample code No.	Radium equivalent	Absorbed dose rate	Annual effective dose rate	External hazard	Internal hazard
CA1	85.821	45.823	0.225	0.232	0.239
CA2	98.355	52.127	0.256	0.266	0.287
CA3	81.3615	43.280	0.212	0.220	0.234
CA4	97.394	51.373	0.252	0.263	0.281
CA5	114.254	59.665	0.293	0.309	0.337
CA6	100.039	52.374	0.257	0.270	0.291
CA7	102.370	53.584	0.263	0.277	0.300
CA8	92.788	48.699	0.239	0.251	0.271
CA9	77.382	40.703	0.200	0.209	0.230
CA10	79.051	42.366	0.208	0.214	0.227
CA11	88.145	46.986	0.2301	0.238	0.246
CA12	93.874	49.781	0.244	0.254	0.269
CA13	94.434	45.066	0.245	0.255	0.270
CA14	93.628	49.340	0.242	0.254	0.269
Mean	92.778	48.655	0.241	0.251	0.268

Turkish samples CT20 and CT21, all Arabian and Turkish coffee powders had ^{40}K concentrations that were higher than the acceptable value (412 Bq/kg) (UNSCEAR, 2010). Based on Figure 3, the mean activity concentrations of ^{40}K in Arabian and Turkish coffee powders are 1.53 and 2.69 times higher than the recommended limit, respectively. In addition, the ^{40}K concentration was 46.28% higher in the Turkish coffee than in the Arabian coffee. Moreover, the current results from Arabian and Turkish coffee powders showed a mean concentration of ^{40}K that was higher than that obtained by Roselli et al. (2013), although the mean concentration of ^{226}Ra was within the range found in the same study. This finding may be linked to contaminated soils in the farming areas (Fatima et al., 2008; Faanu et al., 2016). Uranium 238 was detectible in all study samples except samples CA10, CA11, CT2, CT15, CT20, CT21, and CT22. The highest ^{238}U concentrations were found in sample CA5 (135.11 Bq/kg) and sample CT10 (57.16 Bq/kg), representing Arabian and Turkish coffee powders, respectively.

Hence, the mean activity concentration of ^{238}U in Arabian coffee was approximately 98.09% higher than the Turkish coffee. The activity concentration of ^{232}U ranged from ND to 66.33 Bq/kg with a mean value of 44.61 Bq/kg for Arabian coffee powder and from ND to 57.16 Bq/kg with a mean value of 22.52 Bq/kg. Figure 4 shows a comparison of ^{238}U in Arabian and Turkish coffee powders, in which the mean activity in Arabian samples is less than the permissible limit, but the mean activity in Turkish samples was 35.18% higher than the acceptable limit. The measurements show that all studied samples had concentrations of the artificially produced radionuclide ^{137}Cs below the detectable limit except in samples CA5 and CT19, which had the values of 3.44 and 1.26 Bq/kg, respectively.

Tables 3 and 4 list the calculated values of the radium equivalent, absorbed dose rate, annual effective dose rate, and gamma hazard indices H_{ex} and H_{in} used in Equations 1 to 5, respectively. The results showed that the radium equivalent lay in the ranges of 77.382 to 114.254 Bq/kg (CA9 and CA5, respectively) for Arabian coffee powder with a mean value 90.595 Bq/kg and from 12.421 to 202.159 Bq/kg for Turkish coffee powder with a mean value of 124.586 Bq/kg. These values are less than the permitted limit of 370 Bq/kg. The estimated values for the absorbed dose rate in Arabian and Turkish coffee powders varied from 40.703 to 59.665 nGy/h (CA9 and CA5, respectively) with a mean value of 48.655 nGy/h and from 6.727 to 107.791 nGy/h (CT20 and CT24, respectively) with a mean value of 66.709 nGy/h. According to UNSCEAR (2010), all results fell below the recommended limit for the average exposure rate (84 nGy/h). External and internal hazards were also determined based on Equations 4 and 5. Tables 5 and 6 show that the external and internal hazard indexed are less than unity for Arabian and Turkish coffee powders. With a unit consumption rate of 1 kg per annum being used, the AACED due to the ingestion of radionuclides ^{232}Th, ^{226}Ra, and ^{40}K from Arabian and Turkish coffee was estimated using Equation 6, and the results are presented in Tables 5 and 6. The AACED varied from 0.00232 to 0.00396 mSv/yr and from 0.00032 to 0.00598 mSv/yr for Arabian and Turkish coffee powders, respectively. The mean values of AACED in the study samples were far below the world AACED of 0.3 mSv/yr for ingestion of natural radionuclides detailed in UNSCEAR (2010).

Table 4. Radium equivalent, absorbed dose rate, annual effective dose rate, external hazard index, and internal hazard index in different types of Turkish coffee powder.

Sample code no.	Radium equivalent	Absorbed dose rate	Annual effective dose rate	H_{ex}	H_{in}
CT1	110.934	57.613	0.283	0.300	0.327
CT2	94.497	50.457	0.248	0.255	0.262
CT3	103.34	54.47	0.267	0.279	0.294
CT4	104.597	55.349	0.272	0.283	0.293
CT5	168.670	91.242	0.448	0.456	0.459
CT6	105.586	56.052	0.275	0.285	0.295
CT7	125.06	66.68	0.327	0.338	0.349
CT8	100.879	52.731	0.2587	0.272	0.293
CT9	100.466	53.621	0.263	0.271	0.281
CT10	153.986	82.167	0.403	0.416	0.431
CT11	147.342	79.794	0.392	0.398	0.398
CT12	145.58	78.489	0.385	0.393	0.397
CT13	138.705	75.117	0.369	0.375	0.375
CT14	139.792	75.618	0.371	0.378	0.378
CT15	158.927	85.025	0.417	0.429	0.442
CT16	173.699	92.249	0.453	0.469	0.476
CT17	129.44	69.68	0.342	0.350	0.354
CT18	107.60	57.730	0.283	0.291	0.291
CT19	141.218	76.259	0.374	0.381	0.384
CT20	12.421	6.727	0.033	0.034	0.034
CT21	16.317	8.837	0.043	0.044	0.044
CT22	146.363	79.255	0.389	0.395	0.395
CT23	153.117	82.904	0.407	0.413	0.414
CT24	202.159	107.791	0.529	0.546	0.565
CT25	133.95	71.87	0.353	0.362	0.370
Mean	124.586	66.709	0.327	0.337	0.344

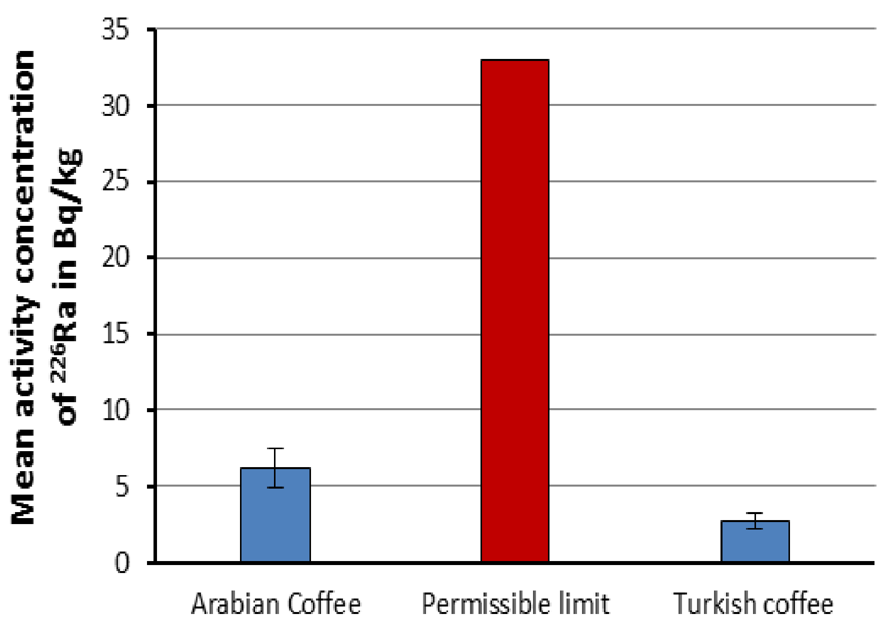

Figure 1. A comparison between the mean activity concentration of ^{226}Ra in Arabian and Turkish coffee with the permissible limit.

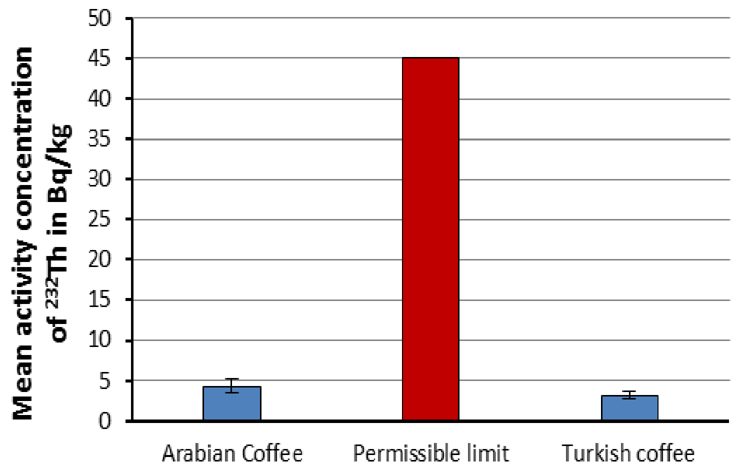

Figure 2. A comparison between the mean activity concentration of ^{232}Th in Arabian and Turkish coffee with the permissible limit.

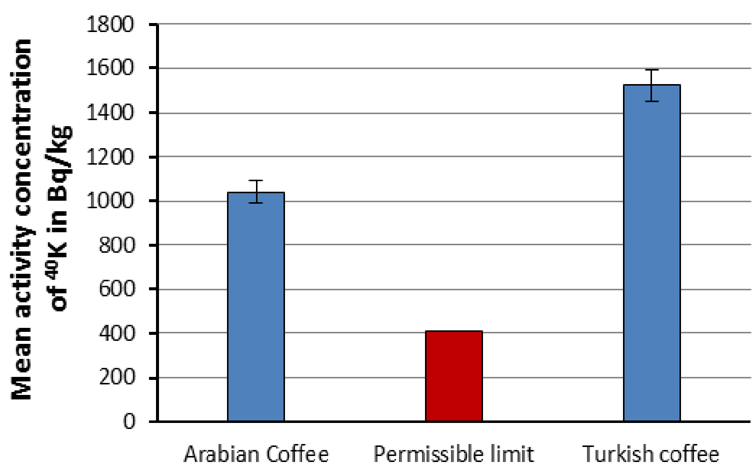

Figure 3. A comparison between the mean activity concentration of ^{40}K in Arabian and Turkish coffee with the permissible limit.

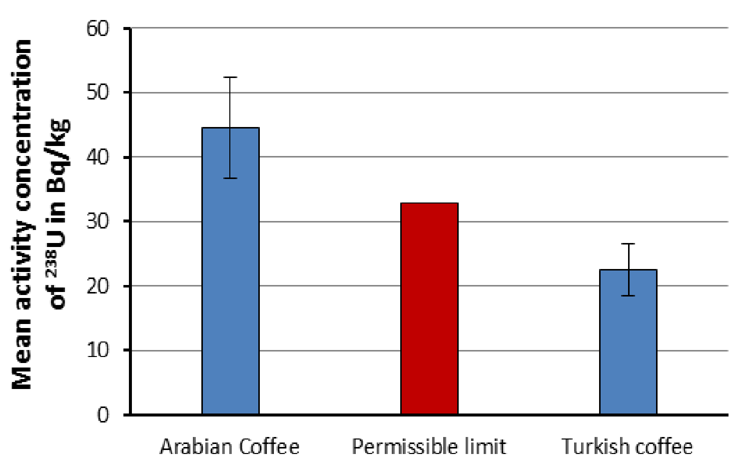

Figure 4. A comparison between the mean activity concentration of ^{238}U in Arabian and Turkish coffee with the permissible limit.

Table 5. AACED due to the ingestion of radionuclides ^{232}Th, ^{226}Ra, and ^{40}K from Arabian coffee and the threshold consumption rate.

Sample code No.	AACED for 1 kg/year (mSv/year)	Threshold consumption rate kg/year
CA1	0.00251± 0.00021	119.522
CA2	0.00313± 0.00035	95.847
CA3	0.00250± 0.00024	120.000
CA4	0.00315± 0.00033	95.238
CA5	0.00396± 0.00052	75.758
CA6	0.00338± 0.00033	88.757
CA7	0.00348± 0.00034	86.207
CA8	0.00310± 0.00031	96.774
CA9	0.00260± 0.00029	115.385
CA10	0.00232± 0.00020	129.310
CA11	0.00261± 0.00019	114.943
CA12	0.00293± 0.00025	102.389
CA13	0.00301± 0.00027	99.668
CA14	0.00291± 0.00028	103.093
Mean	0.00298± 0.00029	100.671

Table 6. AACED due to the ingestion of radionuclides ^{232}Th, ^{226}Ra, and ^{40}K from Turkish coffee and the threshold consumption rate.

Sample code No.	AACED for 1 kg/year (mSv/yr)	Threshold consumption rate kg/year
CT1	0.00394± 0.00037	76.142
CT2	0.00275± 0.00014	109.091
CT3	0.00331± 0.00016	90.635
CT4	0.00324± 0.00017	92.593
CT5	0.00445± 0.00006	67.416
CT6	0.00321± 0.00017	93.458
CT7	0.00370± 0.00033	81.081
CT8	0.00343± 0.00022	87.464
CT9	0.00296± 0.00025	101.351
CT10	0.00454± 0.00031	66.0793
CT11	0.00383± 0.00016	78.329
CT12	0.00395± 0.00022	75.949
CT13	0.00360± 0.00017	83.333
CT14	0.00366± 0.00017	81.967
CT15	0.00459± 0.00032	65.360
CT16	0.00517± 0.00025	58.027
CT17	0.00355± 0.00022	84.507
CT18	0.00308± 0.00018	97.403
CT19	0.00376± 0.00015	79.787
CT20	0.00032± 0.00011	937.500
CT21	0.00043± 0.0001	697.675
CT22	0.00381± 0.00016	78.740
CT23	0.00399± 0.00017	75.188
CT24	0.00598± 0.00034	50.167
CT25	0.00378±0.00024	79.365
Mean	0.00356±0.00021	84.270

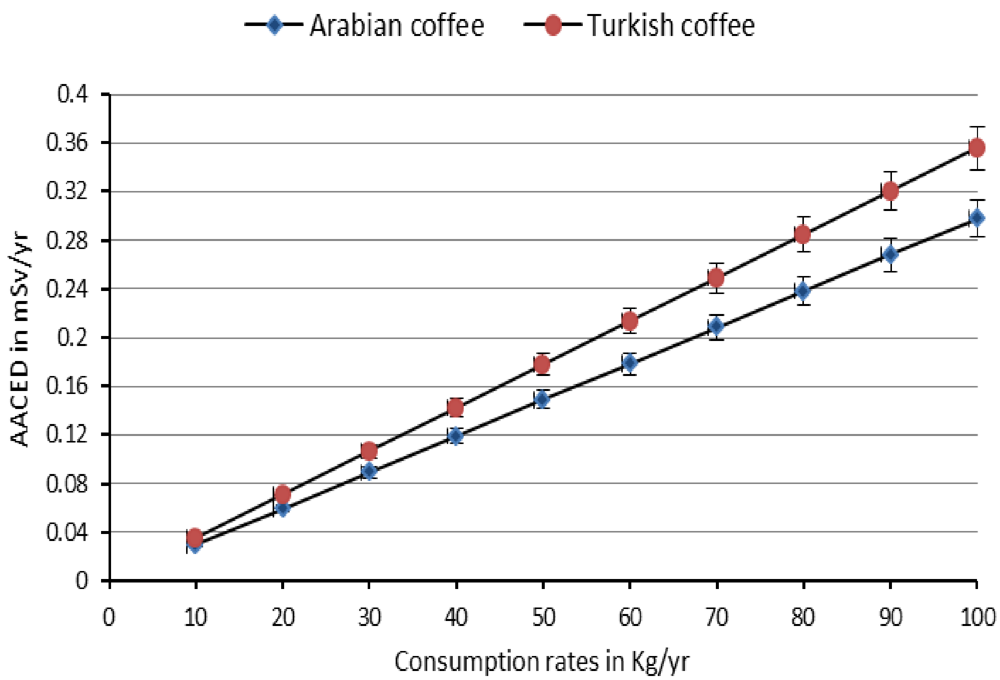

Figure 5. The AAECD as a function of various consumption rates within the range of 0 to 100 kg/year.

The highest AACED value for Arabian coffee powder was associated with sample CA5 because of the high activity concentrations of ^{232}Th, ^{226}Ra, and ^{40}K, while sample CA10 had the lowest AACED value. As shown in Tables 2 and 6, sample CT24 had the highest AACED value for Turkish coffee powder because of the high activity concentration of ^{40}K, while sample CT20 had the lowest value owing to the low activity concentrations of ^{232}Th, ^{226}Ra, and ^{40}K. Figure 5 presents the AAECD as a function of various consumption rates within the range of 0 to 100 kg/year.

The threshold consumption rate (Table 5 and 6) is the amount at which the AACED value exceeds 0.3 mSv for any of the coffee powders. Consequently, Tables 5 and 6 provide baseline data indicating that an individual with a consumption rate below the threshold values would experience an insignificant radiological health risk, but someone with a consumption rate that is slightly higher than the threshold values faces significant radiological health risk.

Statistical analysis

Descriptive statistics

Basic descriptive statistics were used to characterize the central tendency and variation of the data. The distribution of radionuclides measured in Arabian and Turkish coffees and the radiological hazards using SPSS, version16.0 for Windows (Sivakumar et al., 2014). Figures 6 and 7 shows the distribution of radionuclides (^{226}Ra, ^{232}Th, ^{40}K, and ^{238}U) with respect to sample code numbers in the Arabian and Turkish coffee. Tables 7 and 8 summarize the statistical parameters such as minimum, maximum, arithmetic mean, standard deviation, skewness, and kurtosis. The asymmetry of the probability distribution for real values of random variables can be characterized by measuring the degree of skewness. A normal distribution has a skewness of zero. Therefore, positive (or negative) skewness indicates a distribution with an asymmetric tail extending towards values that are more positive (or negative) (Adam and Eltayeb, 2012). The radionuclides in Arabian and Turkish coffees (Tables 7 and 8) have positive skewness values, indicating that the distributions are asymmetric, with the exceptions of ^{40}K, ^{232}Th, and ^{226}Ra in Arabian coffee and ^{40}K in Turkish coffee.

Kurtosisis determined if the distributions for data are peaked or flat relative to a normal distribution. Positive kurtosis indicates a relatively peaked distribution, while negative kurtosis indicates a relatively flat distribution. Higher kurtosis means that more of the variance is explained by infrequent extreme deviations, as opposed to frequent slight deviations (Raghu et al., 2015). According to Tables 7 and 8, the distributions associated with ^{40}K and ^{238}U in Arabian coffee and for ^{40}K and ^{226}Ra in Turkish coffee have positive kurtosis values, indicating peaked distributions, and the others radionuclides have negative kurtosis values, indicating flat distributions.

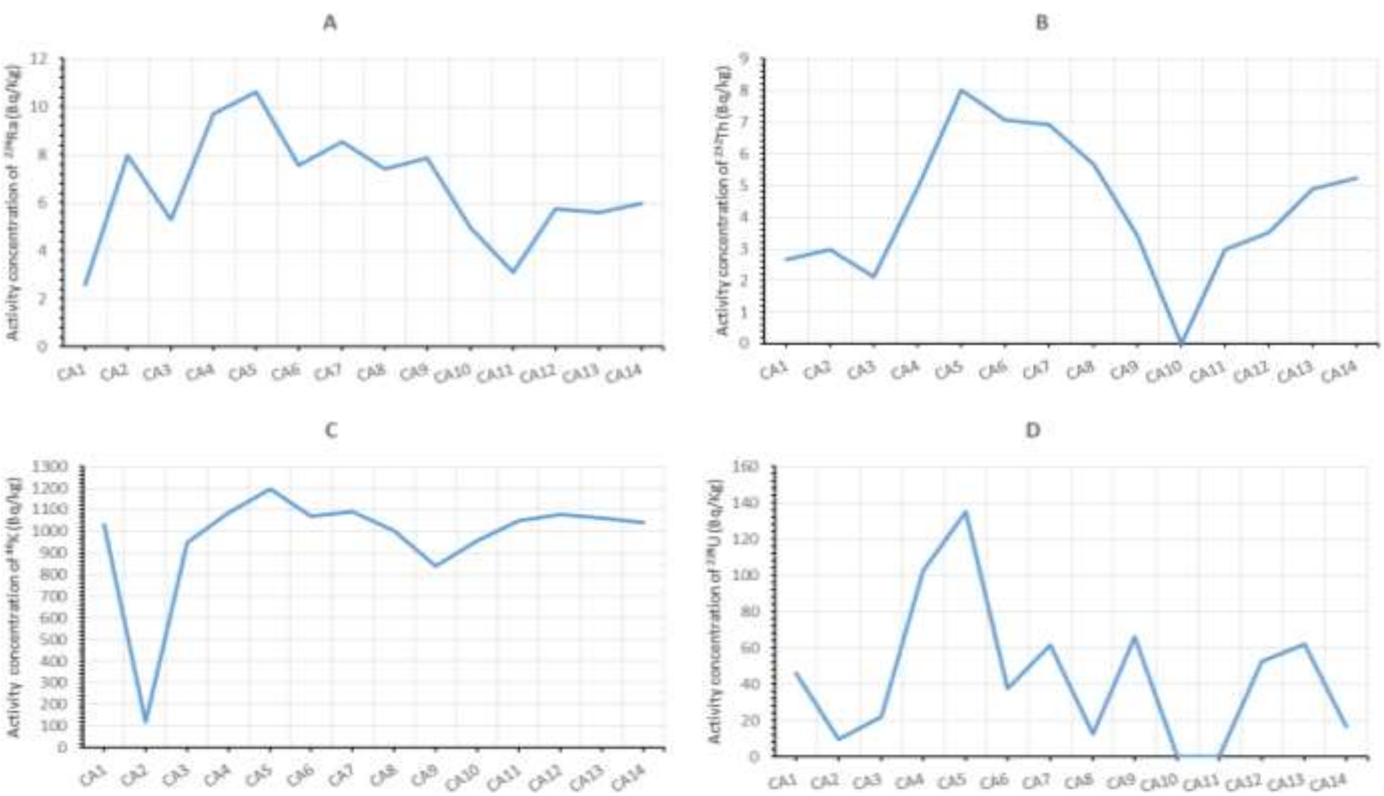

Figure 6. The distributions of ^{226}Ra, ^{232}Th, ^{40}K, and ^{238}U with respect of sample code numbers in Arabian coffee.

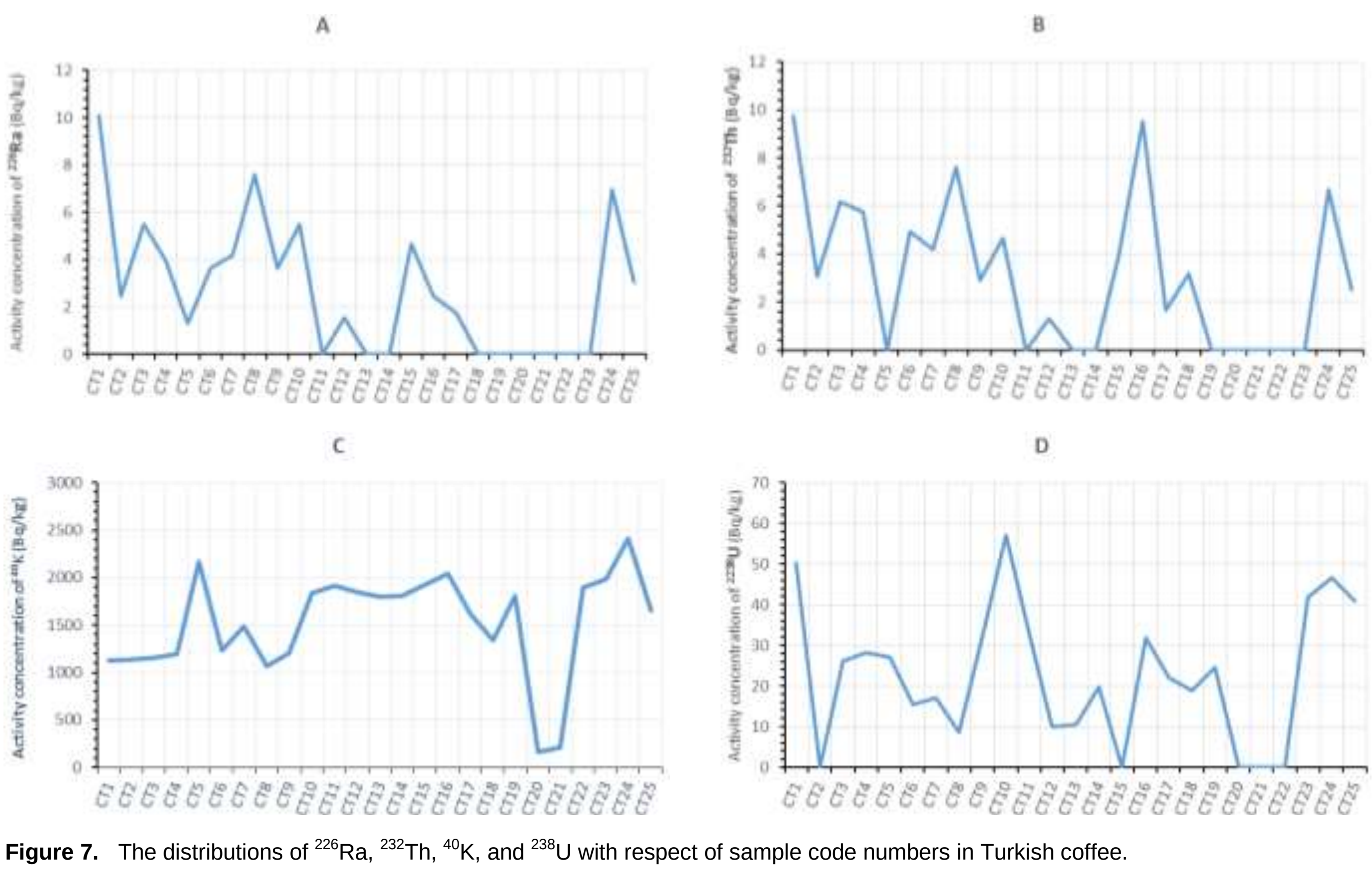

Figure 7. The distributions of ^{226}Ra, ^{232}Th, ^{40}K, and ^{238}U with respect of sample code numbers in Turkish coffee.

Table 7. Descriptive statistics of radionuclides and radiological hazard of Arabian coffee.

Parameter	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
^{40}K	118.9±36.33	1197.11±65.99	969.809±49.986	258.486	-3.112	10.633
^{232}Th	0.0±0.0	8.01±1.64	4.306±0.906	2.193	-0.067	-0.259
^{226}Ra	2.57±0.42	10.63±2.84	6.634±1.281	2.313	-0.113	-0.400
^{238}U	0.0±0.0	135.11±24.61	44.61±7.947	39.458	0.975	0.703
Radium equivalent	77.382	114.254	92.778	9.956	0.299	0.354
Absorbed dose rate	40.703	59.665	48.655	5.083	0.403	0.249
Annual effective dose rate	0.200	0.293	0.240	0.024	0.236	0.423
External hazard	0.209	0.309	0.251	0.027	0.300	0.366
Internal hazard	0.227	0.337	0.268	0.031	0.565	0.338
AACED	0.002±0.00	0.004±0.001	0.003±0.0	0.000	0.603	0.297
Threshold consumption rate	75.758	129.310	103.064	15.035	0.045	-0.584

Table 8. Descriptive statistics of radionuclides and radiological hazard of Turkish coffee.

Parameter	Minimum	Maximum	Mean	Std. deviation	Skewness	Kurtosis
^{40}K	161.31±48.8	2411.22±83.68	1523.1±48.70.09	546.8438	-0.9975	1.113
^{232}Th	0.0±0.0	9.75±1.86	3.12±0.608	3.1298	0.693	-0.5042
^{226}Ra	0.0±0.0	10.09±2.18	2.73±0.528	2.8263	0.9141	0.322
^{238}U	0.0±0.0	57.16±10.54	22.52±4.23	16.7982	0.286	-0.7029
Radium equivalent	12.421	202.159	124.5858	42.5839	-1.1515	2.237
Absorbed dose rate	6.727	107.791	66.7091	22.964	-1.1289	2.0381
Annual effective dose rate	0.033	0.529	0.3274	0.1128	-1.1296	2.0399
External hazard	0.034	0.546	0.3365	0.115	-1.1509	2.2335
Internal hazard	0.034	0.565	0.344	0.1163	-1.1858	2.5913
AACED	0.0001±0.0003	0.006±0.0004	0.0036±0.0002	0.0012	-1.2012	3.3361
Threshold consumption rate	50.167	937.5	139.5443	207.3985	3.4344	11.1314

Frequency distribution

To estimate the probability distribution of continuous variables the histograms are represented in Figure 8A to D) for Arabian coffee and in Figure 9A to D for Turkish coffee. The frequency distributions (according to the normality test for Shapiro-Wilk) for all activity concentrations in Arabian and Turkish coffees were analyzed (Tanaskovi et al., 2012). The graphs in Figure 8 show that the ^{40}K was distributed in non-normal distribution, while the ^{238}U, ^{232}Th, and ^{226}Ra were distributed in a normal (bell-shaped) distribution in Arabian coffee. All radionuclides in Turkish coffee were distributed in non-normal distribution except ^{238}U as shown in Figure 9.

Pearson's correlation analyses

Pearson's correlation analyses were performed to determine the interrelation between the natural radionuclides and the calculated radiological hazard parameters (Liu et al., 2003). The obtained correlation coefficients are presented in Tables 9 and 10. Positive correlations were observed between ^{226}Ra and ^{283}U with ^{232}Th in Arabian coffee, and also between ^{283}U and ^{226}Ra in Turkish coffee, but, it is less severe than it is in Arabic coffee. From the earlier stated observations, ^{226}Ra series and ^{232}Th series are usually found together in nature. Hence, these radionuclides contribute to the emission of gamma radiation in all regions. Positive correlations existed among of the most hazard parameters and ^{232}Th, ^{226}Ra, and ^{238}U in Arabian coffee. In addition, a strong correlation was observed between hazard parameters and ^{40}K and weak correlation between them and ^{238}U in Turkish coffee. Moreover, strong correlations among most of the radiological hazard parameters were noted and each other.

Conclusion

In this study, measurement of radioactivity in Arabian and Turkish coffee powders sold in Saudi Arabia markets was

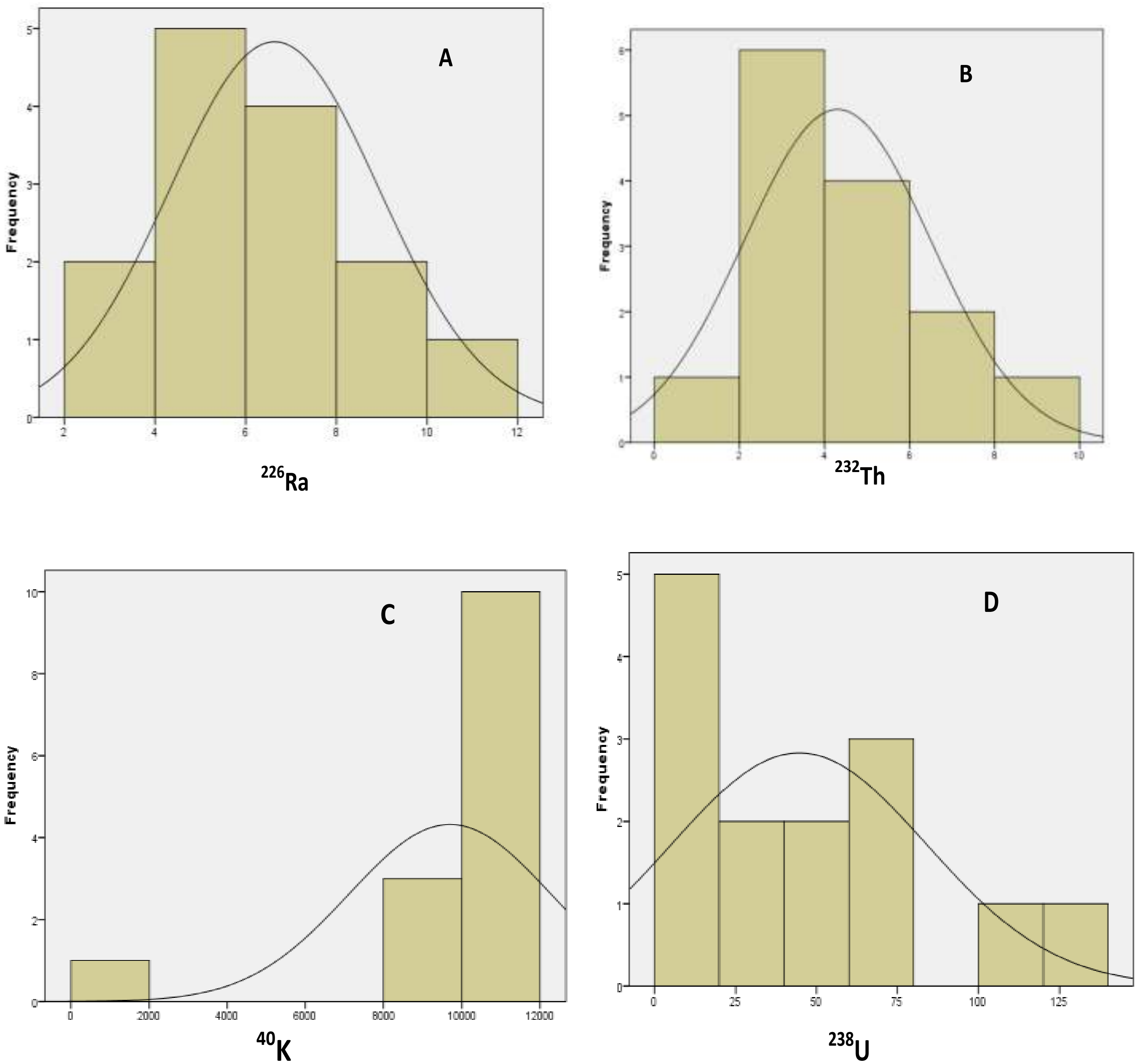

Figure 8. Frequency distributions of activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{238}U in Arabian coffee.

performed. The ^{40}K, ^{232}Th, ^{226}Ra, and ^{238}U concentrations were comparable with those reported elsewhere. The mean ^{40}K activity concentrations in Turkish coffee were greater than those in Arabian coffee, and both were higher than the allowable value. The mean ^{238}U activity concentrations in Arabian coffee were greater than in Turkish coffee, but both were less than the permissible limit. In addition, the mean activities of ^{232}Th and ^{226}Ra in Arabian and Turkish coffee powders were much less than the recommended limit. To assess the radiological risk, the mean values of the radium equivalent, absorbed dose rate, annual effective dose rate, H_{ex}, and H_{in} were estimated, and all were less than the allowable limits reported by UNSCEAR (2010). The results specified for all samples under study are far below the AACED limit (0.3 mSv/year for individual) provided by UNSCEAR (2010). Thus, these results indicate that the radiological risk related to drinking coffee is insignificant. Coffee shop

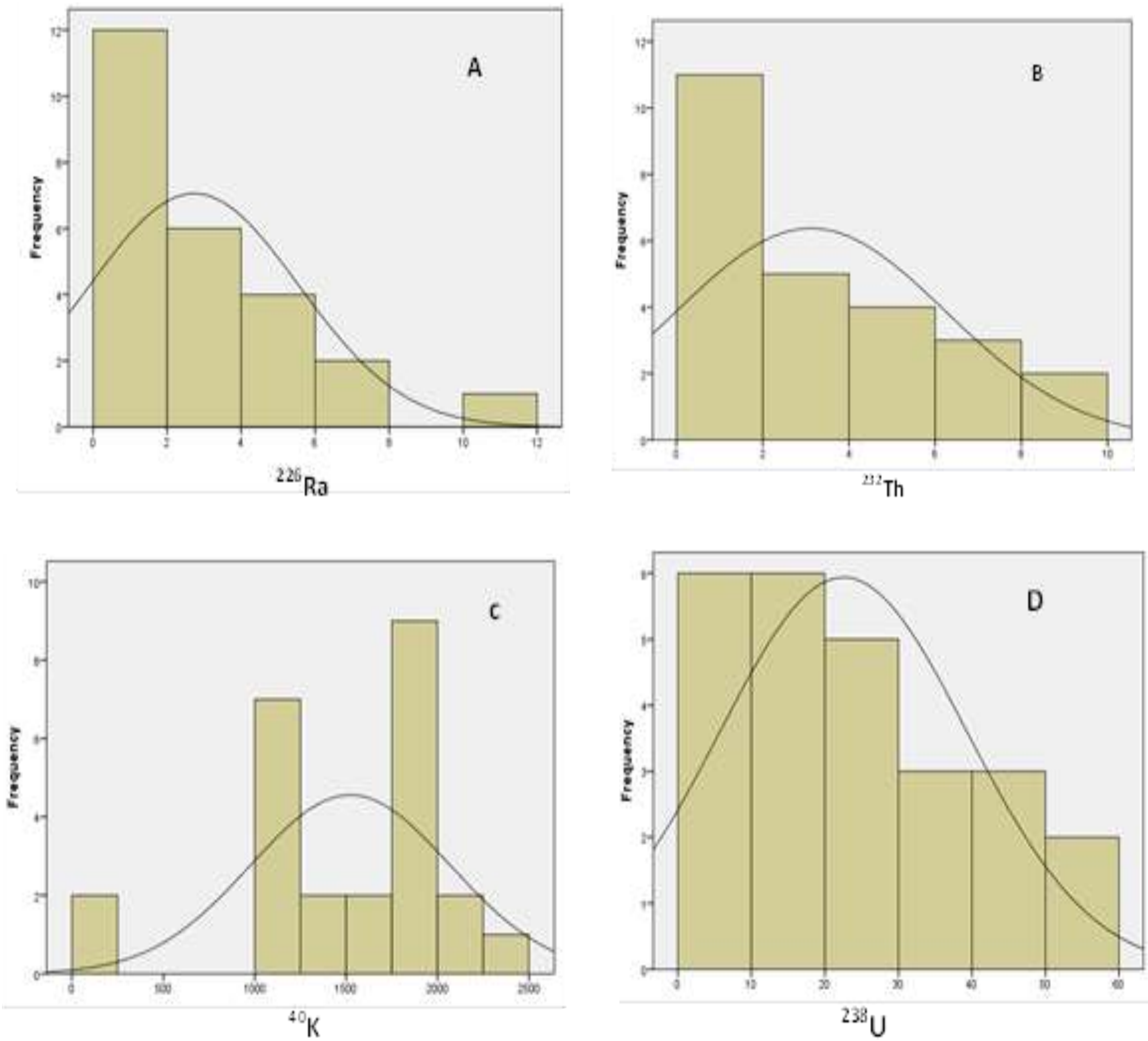

Figure 9. Frequency distributions of activity concentrations of ^{226}Ra, ^{232}Th,^{40}K, And ^{238}U in Turkish coffee.

workers may face a greater health hazard because they experience external exposure to potentially large amounts of coffee powder and may thus accumulate large doses.

The annual effective ingestion dose from coffee should be added to the total global dose from food consumption. The data obtained from this research provides information on the activity concentration of natural radionuclides and increases the knowledge about natural radioactivity. The statistical analysis also confirms that these samples under the study of Arabian and Turkish coffees do not possess significant gamma radiation effects. Coffee quality must be strictly controlled, and the study of radionuclide concentration in this matrix has great significance. In terms of the coffee market, determining the radioactivity values of the commodity is important for customers.

Conflicts of Interests

The authors have not declared any conflict of interests.

Table 9. Pearson correlation coefficients of radionuclides and radiological hazard of Arabian coffee.

Parameter	^{40}K	^{232}Th	^{226}Ra	^{238}U	Radium equivalent	Absorbed dose rate	Annual effective dose rate	External hazard	Internal hazard	AACED
^{40}K	1	0.372	-0.054	0.399	0.135	0.093	0.119	0.134	0.099	0.147
^{232}Th		1	0.656*	0.586*	0.833**	0.769**	0.805**	0.832**	0.853**	0.908**
^{226}Ra			1	0.649*	0.645*	0.637*	0.619*	0.644*	0.735**	0.786**
^{238}U				1	0.563*	0.504	0.550*	0.559*	0.588*	0.631*
Radium equivalent					1	0.967**	0.999**	1.000**	0.990**	0.960**
Absorbed dose rate						1	0.967**	0.968**	0.958**	0.919**
Annual effective dose rate							1	0.999**	0.983**	0.945**
External hazard								1	0.990**	0.959**
Internal hazard									1	0.985**
AACED										1

*Correlation is significant at the 0.05 level (2-tailed).** Correlation is significant at the 0.01 level (2-tailed).

Table 10. The Pearson correlation coefficients of radionuclides and radiological hazard of Turkish coffee.

Parameter	^{40}K	^{232}Th	^{226}Ra	^{238}U	Radium equivalent	Absorbed dose rate	Annual effective dose rate	External hazard	Internal hazard	AACED
^{40}K	1	-0.018	-0.026	0.414*	0.987**	0.991**	0.991**	0.987**	0.975**	0.915**
^{232}Th		1	0.850**	0.367	0.140	0.110	0.110	0.140	0.194	0.375
^{226}Ra			1	0.413*	0.127	0.099	0.099	0.127	0.190	0.356
^{238}U				1	0.475*	0.464*	0.465*	0.476*	0.497*	0.546**
Radium equivalent					1	1.000**	1.000**	1.000**	0.998**	0.968**
Absorbed dose rate						1	1.000**	1.000**	0.996**	0.960**
Annual effective dose rate							1	1.000**	0.996**	0.960**
External hazard								1	0.998**	0.968**
Internal hazard									1	0.982**
AACED										1

*Correlation is significant at the 0.05 level (2-tailed) .** Correlation is significant at the 0.01 level (2-tailed).

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