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Radiological assessment of flour consumed in Kuwait

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Abstract

This study investigated the natural radioactivity in flour consumed in Kuwait. To cover a wide range of samples, wheat, rice and gram (chickpeas) based flour samples were tested. Gamma spectrometry revealed the presence of ^{226}Ra, and ^{40}K in all samples, while ^{228}Ra was detected in 14 out of the 18 samples. The activity concentrations of the three radionuclides were found to be within normal levels, and hence so did the estimated annual effective doses. Moreover, the estimated lifetime cancer risk was found to be well below the acceptable level. Hence, these findings confirm the radiological safety of flour consumed in Kuwait for the three targeted radionuclides. Interestingly, significant statistical differences were found in the averages of the activity concentrations that were sensitive to the ingredient of the flour.

Keywords: Environmental radiation; Gamma spectrometry; ^{40}K; NORM; ^{226}Ra.

1. Introduction

Natural radioactivity is responsible for a large amount of the ionizing radiation exposure to humans. Despite its generally low level, natural radioactivity contributes to almost 50% of the total exposure to the general public, thereby competing with contributions of its artificial counterparts, like medical procedures (Mahesh, 2009; Schauer & Linton, 2009). Naturally occurring radioactive matter (NORM) is generally long-lived and is widely spread in the environment. Examples of NORM are ^{238}U and its decay series, ^{232}Th and its decay series, and the primordial isotope of potassium ^{40}K. These radionuclides are inevitably present in environmental products, including edible crops.

Food ingestion is a primary pathway for radioactivity exposure. Thus, the magnitude of internal exposure is primarily caused by the amount and type of consumed food. This confirmed relationship was globally viewed with scientific interest and a certain extent of public concern, which in turn motivated numerous studies at national and international levels. At the international level, the United Nations, represented by its sub-agencies and committees produced many publications that were made free of charge to researchers and interested individuals. For example, the International Atomic Energy Agency (IAEA) has prepared a reference of instructions and guidelines with regard to experimental procedures for measuring radioactivity in food (Nogueira, 1989). Moreover, the International Commission on Radiological Protection (ICRP) has provided computational approaches to estimate doses from food ingestion (ICRP, 1996). Furthermore, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has collected radioactivity values that were reported by researcher and radiation protection specialists worldwide, before calculating global and regional averages of activity concentrations in food, and corresponding reference values (2000; 2001; Charles, 2001) .

At the national level, the literature includes many studies that reported country / city specific food radioactivity levels. Studies like these help in establishing baseline data that can serve as references for inter-comparison analyses of different regions, as well as timeline comparisons for region-specific analyses, which compare past and present levels, as well as forecast future levels.

In Kuwait, where the current study was based, a list of food items was previously investigated. This food list included milk (Alrefae *et al.,* 2012a)Nageswaran, Al-Failakawi, et al., 2012, breakfast cereal (Alrefae *et al.,* 2012b), rice (Alrefae & Nageswaran, 2013)2013, canned seafood (Alrefae *et al*., 2014)2014, and palm dates (Alrefae, 2015) These food items were previously selected for investigation, owing to their popularity among the general public. Also popular is flour, which is consumed on a daily basis. Being a basic food item, flour is heavily subsidized by the Kuwaiti government, and is hence readily available locally. In fact, Kuwait was the first country in the region to subsidize the gluten-free production line to make this type of flour available for people with digestive disorders. Moreover, rice-based flour and gram (chickpeas) based flour are also available in the local markets for everyone.

The goal of this study was to measure NORM in flour consumed in Kuwait and to estimate annual effective doses to the general public from its consumption. It is believed that the findings of this study will help in establishing a national baseline of the exposure level from the ingestion of food, which in turn could serve as a reference for regional and timeline comparisons.

2. Materials and methods

Flour samples were collected from the local market, where the collection took place between September and December of 2015. For a wide range of representation, the collected samples originated from 6 different countries and covered 3 types of basic ingredients, namely wheat, rice and gram (chickpeas). Following collection, all samples underwent proper lab preparation (Nogueira, 1989), where some samples needed grinding to achieve the required fine, homogeneous structure. Next, each sample was placed inside a cylindrical container before being sealed and shelved for a period of at least 4 weeks. This shelving period was necessary to attain secular equilibrium between long-lived parent radionuclides and their short-lived daughters, which was necessary for adequate gamma spectrometry.

Measurements were performed using a low background, high purity germanium (HPGe) system (Canberra, CT, USA) of model number GC 8021. This counting system, which was mechanically cooled, was connected to an arrangement of electronics that included a preamplifier, a bias supply, a linear amplifier, an analog to digital converter (ADC), and a multi-channel analyzer (MCA). For data acquisition and storage, the system was connected to a desktop computer through a USB port. The personal computer was equipped with Gennie2K® software for data analysis. The detector, which carried a cylindrical crystal of 79.50 mm diameter and a 58.50 mm length, had a shaping time constant of 6.0 μs, which gave an energy resolution of 2.1 keV FWHM at an energy of 1333 keV. To minimize background radiation, the detector was housed inside a 10 cm thick lead shield with 1 mm tin and 16 mm copper linings. Relative to a NaI(Tl) cylindrical detector of size 3 inch diameter and 3 inch length, the HPGe system presented a relative efficiency of 80% for an energy of 1333 keV. This relative efficiency test was performed using a ^{60}Co point source placed at a distance of 25 cm from both detectors. Energy calibration for the counting system was performed using a set of point sources, while efficiency calibration was done using a standard source of the same geometry and density of the investigated samples. To reduce statistical counting errors, each sample underwent a counting time of 86400 seconds (one full day). To determine the background counts, an empty container was counted under the same conditions for the same period. The targeted radionuclides were ^{226}Ra, ^{228}Ra, and ^{40}K, where the analyzed full-energy-peaks were 295, 352, 609, 1120, and 1765 keV (^{226}Ra), 238, 338, 583, and 911 keV (^{228}Ra), and 1461 keV (^{40}K). The activity concentration A (Bq kg^{-1}) for each of the three targeted radionulcides was calculated for each sample using the formula (Nogueira, 1989)

$$A = \frac{N}{\varepsilon P_\gamma \, mt} \tag{1}$$

where N was the net number of counts of the corresponding full-energy-peak, P_γ was the emission probability per disintegration, ε was the detector's efficiency at the specific full-energy-peak, m was the weight of the sample, and t was the counting time in seconds.

The minimum detectable activity (MDA) was calculated using the formula

$$MDA = \frac{2.71 + 4.66\, S_b}{\varepsilon P_\gamma \, mt} \tag{2}$$

where S_b was the standard error in the net background count rate for the full-energy-peak (Currie, 1968). Hence, values above 0.20 Bq kg^{-1}, 0.18 Bq kg^{-1}, and 2.46 Bq kg^{-1} were accepted for the activity concentrations for ^{226}Ra, ^{228}Ra, and ^{40}K respectively.

The uncertainty in the activity concentration (δA) was estimated for each sample by considering three main sources of error. First, the statistical uncertainty in the number of counts (δN) was taken as the square root of the number of counts ($\sqrt{N}$), assuming that the full-energy-peak was Gaussian shaped (Knoll, 2010). Second, the uncertainty in the sample weight (δm) was taken to be 5% of the measured weight following the instructions of the scale's manufacturer. Third, the uncertainty in the detector's efficiency ($\delta\varepsilon$) was taken as 5% of the efficiency at the energies of the observed full-energy-peaks. This error value was chosen based on the detector's performance in quality assurance tests. Hence, the uncertainty in the activity concentration was taken as

$$\delta A = \sqrt{\left(\frac{\partial A}{\partial N}\delta N\right)^2 + \left(\frac{\partial A}{\partial m}\delta m\right)^2 + \left(\frac{\partial A}{\partial \varepsilon}\delta \varepsilon\right)^2} \tag{3}$$

where $\frac{\partial A}{\partial N}$, $\frac{\partial A}{\partial m}$, and $\frac{\partial A}{\partial \varepsilon}$ were the partial derivatives of the activity concentration with respect to the number of counts, the sample weight, and the detector efficiency respectively.

The calculated quantities included the annual intake of radioactivity. This quantity, which was assumed to be due to the accumulation of the targeted radionuclides, was calculated using the formula:

$$D_a = A\, I \tag{4}$$

where D_a was the annual radionuclide intake (Bq yr^{-1}), A

was the activity concentration of the radionuclide (Bq kg^{-1}) and I was the annual consumption of flour (kg yr^{-1}). Owing to the lack of reliable statistics for the consumption of flour in Kuwait, the quantity I was taken to be 37.5 kg yr^{-1} half of the annual consumption of rice (Alrefae & Nageswaran, 2013), which is considered to be the most popular local food.

The annual effective dose (D_{eff}) from the consumption of flour was calculated as well. This quantity was considered to be among the most important due to the proportional relationship between its value and the induced health effects from the intake of radionuclides.

$$D_{eff} = D_a D_{cf} \quad (5)$$

where D_{cf} was the ingestion dose conversion factor (2.8×10^{-7} Sv Bq^{-1} for ^{226}Ra, 6.9×10^{-7} Sv Bq^{-1} for ^{228}Ra, and 6.2×10^{-9} Sv Bq^{-1} for ^{40}K) (ICRP, 1996). The total dose was simply calculated by summing the contributions associated with the individual radionuclides.

$$D_{eff}^{Total} = D_{eff\ Ra\ 226} + D_{eff\ Ra\ 228} + D_{eff\ K\ 40} \quad (6)$$

The lifetime cancer risk (LCR) was calculated to assess the carcinogenic effects that are induced from the consumption of flour, owing to the presence of the targeted radionuclides. This calculation was performed using the formula (https://www.epa.gov/sites/production/files/2015-05/documents/402-r-99-001.pdf)

$$LCR = D_a A_L R_c \quad (7)$$

where A_L was the lifetime span (70 years), and R_c was the mortality risk coefficient taken as 9.56×10^{-9}, 2.74×10^{-8} , and 5.89×10^{-10} for ^{226}Ra , ^{228}Ra, and ^{40}K respectively.

Statistical tests were performed to determine any significant differences among the data. This analysis was done using the functions available in Matlab (Mathworks, USA). In particular, comparisons were implemented by one-way analysis of variance (ANOVA). In cases where the activity in the data presented was below detection limits (BDL), or non-detection (ND), values of zeros were used.

3. Results

Table 1 shows the activity concentrations of the targeted radionuclides, namely ^{226}Ra, ^{228}Ra and ^{40}K, for the investigated flour samples. Besides the country of origin, the Table also shows the basic ingredient for each sample. ^{226}Ra was detected in all samples, with a maximum value of 8.08 ± 0.42 Bq kg^{-1} (a gram flour from India), a minimum value of 0.42 ± 0.02 Bq kg^{-1} (a rice flour from Kuwait) and an all-sample average of (± SD) 3.00 ± 1.84 Bq kg^{-1}. ^{228}Ra was detected above the MDA in 14 samples, and was not detected in 3 samples. The maximum, above MDA, detected value was 2.49 ± 0.19 Bq kg^{-1} (a white flour sample from Kuwait), while the minimum, above MDA, detected value 0.51 ± 0.06 Bq kg^{-1} (a white flour sample from Italy). The all-sample average (± SD) was 1.28 ± 0.67 Bq kg^{-1} , where below MDA and non-detected values were taken as zeros. ^{40}K was detected in all samples with a maximum value of 386.78 ± 18.62 Bq kg^{-1} (a gram flour from India), a minimum value of 18.60 ± 0.93 Bq kg^{-1} (a rice flour from Thailand), and an all-sample average of (± SD) 161.90 ± 142.92 Bq kg^{-1}.

Table 1. Activity concentration of ^{226}Ra, ^{228}Ra, and ^{40}K [Bq kg^{-1}] for the measured samples

Sample	Origin	Ingredient	^{226}Ra			^{228}Ra			^{40}K		
1	India	Brown Flour	1.33	±	0.072	1.13	±	0.10	64.03	±	3.10
2	India	Gram Flour	3.76	±	0.20	ND			372.84	±	17.95
3	India	Gram Flour	8.08	±	0.42	1.35	±	0.13	386.78	±	18.62
4	India	Gram Flour	3.58	±	0.19	BDL			340.49	±	16.39
5	Italy	White Flour	2.59	±	0.14	0.51	±	0.06	44.37	±	2.16
6	Italy	While Flour	3.72	±	0.20	0.75	±	0.08	55.04	±	2.67
7	Kuwait	Rice Flour	0.70	±	0.04	ND			32.13	±	1.57
8	Kuwait	Brown Flour	1.36	±	0.074	0.60	±	0.07	116.61	±	5.63
9	Kuwait	White Flour	2.86	±	0.15	1.10	±	0.10	32.45	±	1.58
10	Kuwait	Brown Flour	0.76	±	0.04	0.63	±	0.07	116.93	±	5.65
11	Kuwait	Brown Flour	2.49	±	0.13	2.10	±	0.17	125.57	±	6.06
12	Kuwait	White Flour	4.15	±	0.22	2.49	±	0.19	108.05	±	5.22
13	Kuwait	Gram Flour	3.63	±	0.19	1.34	±	0.12	324.13	±	15.60
14	Kuwait	Gram Flour	4.74	±	0.25	ND			362.33	±	17.44
15	Kuwait	Rice Flour	0.42	±	0.02	0.79	±	0.08	26.48	±	1.30
16	Malaysia	Brown Flour	2.65	±	0.14	2.23	±	0.17	59.16	±	2.87
17	Thailand	Rice Flour	2.51	±	0.13	0.82	±	0.09	18.60	±	0.93
18	United Kingdom	Gram Flour	4.59	±	0.24	2.05	±	0.18	328.21	±	15.81
	Average ± Std		3.00	±	1.84	1.28	±	0.67	161.90	±	142.92
	Reference[a]		0.08			0.06					

ND Not Detected

BDL Below Detection Limit

a UNSCEAR 2000 for grain products

4. Discussion

The presence of natural radionuclides in flour was expected. Specifically, the detection of ^{40}K in all samples was anticipated due to the natural abundance of potassium. Moreover, the detection of ^{226}Ra in all samples was not surprising, since this radionuclide resembles a link in the decay series of ^{238}U, which is typically present in environmental samples. As for ^{228}Ra, its un-detection in some samples does not necessarily imply its absence. It is well understood that background levels and system MDA could conceal minor full-energy-peaks (Knoll, 2010). In fact, many authors have reported non-detection of ^{228}Ra, or its parent ^{232}Th, in wheat samples specifically (Hosseini *et al.,* 2006a); (Abojassim *et al.,* 2015) and in food samples in general (Ababneh *et al.,* 2009; Hosseini *et al.,* 2006b; Jibiri & Okusanya, 2008).

Analysis of the activity concentrations revealed greater values of ^{226}Ra than those of ^{228}Ra for all samples. This observation was confirmed by the output of the statistical test (ANOVA), which showed a significant difference ($p < 0.001$) in the activity concentrations of ^{226}Ra and ^{228}Ra for the flour samples. Furthermore, a similar variation was seen in the activity concentrations of ^{40}K, which were significantly greater ($p < 0.000001$) than those of the other targeted radionuclides for all flour samples. Such noticeably greater values of ^{40}K were in line with expectations, since similar findings were observed in the literature (UNSCEAR 2000; 2001; Abojassim *et al.,* 2015; Al-Masri *et al.,* 2004; Alrefae, 2015; Alrefae & Nageswaran, 2013; Alrefae *et al.,* 2014; Alrefae *et al.,* 2012a; Alrefae *et al.,* 2012b; Charles, 2001; Desimoni *et al.,* 2009; Görür *et al.,* 2012; Hosseini *et al.,* 2006a; Jibiri & Okusanya, 2008).

Further analysis of the activity concentrations of the targeted radionuclides revealed ingredient-based differences. For example, ^{226}Ra was found to be significantly ($p < 0.01$) higher in the gram-based samples than in the wheat and rice based samples. Similarly, ^{40}K was found to be ($p < 0.0001$) higher in the gram-based samples than in the wheat and rice based samples. This significant elevation of ^{40}K activity concentration was also found in wheat-based samples ($p < 0.05$) compared to gram and rice based samples. These variations are likely due to the selective, elemental uptake of plants, which differs from one plant species to another. The activity concentration values were compared with their counterparts that were reported in the literature. In light of the above discussion which statistically differentiates between flour types of different ingredients, the comparison was made accordingly. Table 2 shows the activity concentrations for the measured samples of wheat base, compared to their counterparts in the literature. While the literature data of ^{228}Ra were not available, the reported values of ^{226}Ra and ^{40}K concentrations agreed with the findings of our study. This agreement is evident in the range of 1 – 4 Bq kg^{-1} for ^{226}Ra (rounded to whole numbers) which covered the concentrations of the same radionuclide reported by others. Furthermore, the agreement is seen in the range of 32 – 126 Bq kg^{-1} for ^{40}K (rounded to whole numbers) which overlapped with the range of values found the literature for the concentration (42 – 265 Bq kg^{-1}) for the same radionuclide. It is noteworthy that such agreement reinforces the validity of our findings.

Table 2. Activity concentrations of ^{226}Ra, ^{228}Ra, and ^{40}K [Bq kg^{-1}] for the measured samples of wheat base, compared to their counterparts in the literature.

Origin	^{226}Ra	^{228}Ra	^{40}K	Reference
France	1		146	Hosseini *et al*. (2006b)
India	1	1	64	Present study
Iraq			100	Abojassim *et al*. (2015)
Italy	3 - 4	1	44 - 55	Present study
Khazakhstan	1		99	Hosseini *et al*.(2006b)
Kuwait	1 - 4	1 - 3	32 - 126	Present study
Lebanon			146	Abojassim *et al*. (2015)
Malaysia	3	2	59	Present study
Saudi Arabia			265	Abojassim *et al*. (2015)
Turkey	6		42 -192	Abojassim *et al*. (2015) , Gorur *et al*. (2012)

Comparison with literature data is also shown is Table 3, which presents the activity concentrations for the measured samples of rice base, compared to rice measurements reported by others (Alrefae & Nageswaran, 2013; Venturini & Sordi, 1999; Yu & Mao, 1994). While the literature data of ^{226}Ra and ^{228}Ra were not available, the reported values of ^{40}K concentrations agreed with the findings of our study. This agreement is evident in the range of 17 – 32 Bq kg^{-1} for ^{40}K (rounded to whole numbers) which fell within the reported the range of values 15 – 110 Bq kg^{-1} , which was reported by other investigators for the same radionuclide.

Table 3. Activity concentrations of ^{226}Ra, ^{228}Ra, and ^{40}K [Bq kg^{-1}] for the measured samples of rice base, compared to their counterparts in the literature.

Origin	^{226}Ra	^{228}Ra	^{40}K	Reference
Brazil			15	Venturi & Surdi 1999
Egypt			36	Alrefae *et al*. (2013)
France			51	Alrefae *et al*. (2013)
Germany			87 - 101	Alrefae *et al*. (2013)
Hong Kong			15	Yu & Mao 1999
India			36 - 81	Alrefae *et al*. (2013)
Iraq			38	Hosseini 2006b
Pakistan			7 - 50	Alrefae rice
Thailand			22 - 23	Hosseini 2006b
Kuwait	0 - 1		27 - 32	Present study
Thailand	3	2	17	Present study

An estimate of the annual intake of the targeted radionuclides from the consumption of flour is shown in Table 4. On average, the annual intake of each of the radionuclides for all samples was found to be 112.37, 47.93, and 6071.26 Bq yr^{-1} for ^{226}Ra, ^{228}Ra, and ^{40}K respectively, where ND and BDL values were taken as zeros for average calculations. Statistical analysis revealed the significant high amount ($p < 0.000001$) of ^{40}K intake relative to the other targeted radionuclides. Evidently, the intakes of ^{226}Ra (1.8%) and ^{228}Ra (0.8%), were determined negligible compared to their ^{40}K counterpart (97.4%). This observation can be explained by the significantly greater activity concentration of ^{40}K, which was noted above, compared to the other targeted radionuclides. In turn, these significant high values associated with ^{40}K are most likely due to the natural abundance of this radionuclide in the environment.

Table 4. Radionuclide annual intake [Bq yr^{-1}] from the consumption of flour.

Sample	Annual intake [Bq yr^{-1}] ^{226}Ra	^{228}Ra	^{40}K
1	49.84	42.52	2401.08
2	141.02	-	13981.5
3	303.13	50.77	14504.18
4	134.35	-	12768.35
5	97	19.17	1664.03
6	139.67	27.96	2064
7	26.33	-	1204.97
8	51.04	22.62	4373
9	107.24	41.11	1216.7
10	28.52	23.78	4384.98
11	93.53	78.86	4708.98
12	155.65	93.25	4051.9
13	136.15	50.34	12154.8
14	177.88	-	13587.44
15	15.7	29.61	993.11
16	99.35	83.6	2218.35
17	93.99	30.57	697.48
18	172.22	76.82	12307.88
Avg	112.37	47.93	6071.26
Reference[a]	22	15	

a UNSCEAR 2000

The annual effective dose of the targeted radionuclides was estimated, and is shown in Table 5. The average annual effective dose for all samples was found to be 31.46, 33.07, 37.65 μSv yr^{-1} for ^{226}Ra, ^{228}Ra, and ^{40}K respectively, with an average for the total of 93.93 μSv yr^{-1} . The average worldwide effective dose from the ingestion of ^{238}U and ^{232}Th series is reported to be 120 μSv yr^{-1} (UNSCEAR 2000; 2001; Charles, 2001). Since ^{226}Ra and ^{228}Ra are radionuclides in the ^{238}U and ^{232}Th series respectively, the sum of the average dose contributions of ^{226}Ra and ^{228}Ra (64.53 μSv yr^{-1}), was compared to the average worldwide value, and was found to be roughly half of it.

Similarly, the annual effective dose of ^{40}K was found to be less than 25% of the reported worldwide average of 170 μSv yr^{-1} for the ingestion of this radionuclide. These dose estimations and comparisons indicate the radiological safety of consumption of flour in Kuwait for the presence of the targeted radionuclides.

Table 5. Annual effective dose [μSv yr^{-1}]from the consumption of flour.

Sample	^{226}Ra	^{228}Ra	^{40}K	Total
1	13.95	29.34	14.89	58.18
2	39.49	-	86.69	-
3	84.88	35.03	89.93	209.83
4	37.62	-	79.16	-
5	27.16	13.23	10.32	50.71
6	39.11	19.29	12.80	71.20
7	7.37	-	7.47	-
8	14.29	15.61	27.11	57.01
9	30.03	28.37	7.54	65.94
10	7.99	16.41	27.19	51.58
11	26.19	54.41	29.20	109.79
12	43.58	64.34	25.12	133.04
13	38.12	34.73	75.36	148.21
14	49.81	-	84.24	-
15	4.40	20.43	6.16	30.99
16	27.82	57.68	13.75	99.25
17	26.32	21.09	4.32	51.73
18	48.22	53.01	76.31	177.54
Average	31.46	33.07	37.64	93.93
World Average (from all food items)	6.30	11.00	170.00	290.00

The lifetime cancer risk (LCR) for the radiological intake of the targeted radionuclides is shown in Figures 1,2, and 3 for ^{226}Ra, ^{228}Ra, and ^{40}K respectively. As seen from the figures, the values were found to vary from 5.25 $\times10^{-6}$ to 1.01×10^{-4} with an average of 3.76×10^{-5} for ^{226}Ra, from 1.84 $\times10^{-5}$ to 8.94×10^{-5} with an average of 4.60×10^{-5} for ^{228}Ra (excluding BDL and UN values), and from 1.44×10^{-5} to 2.99×10^{-4} with an average of 1.25×10^{-5} for ^{40}K. All LCR values were found to be at least an order of magnitude less than the acceptable value of 10^{-3} cancer radiological risk.

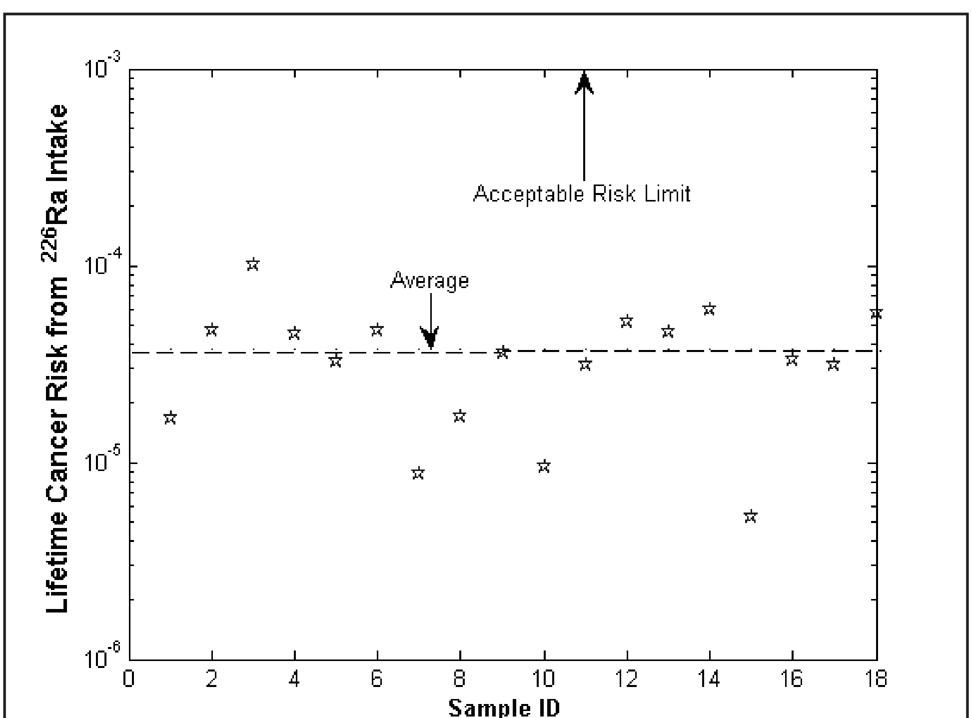

Fig. 1. Lifetime cancer risk from the consumption of flour due to the presence of ^{226}Ra

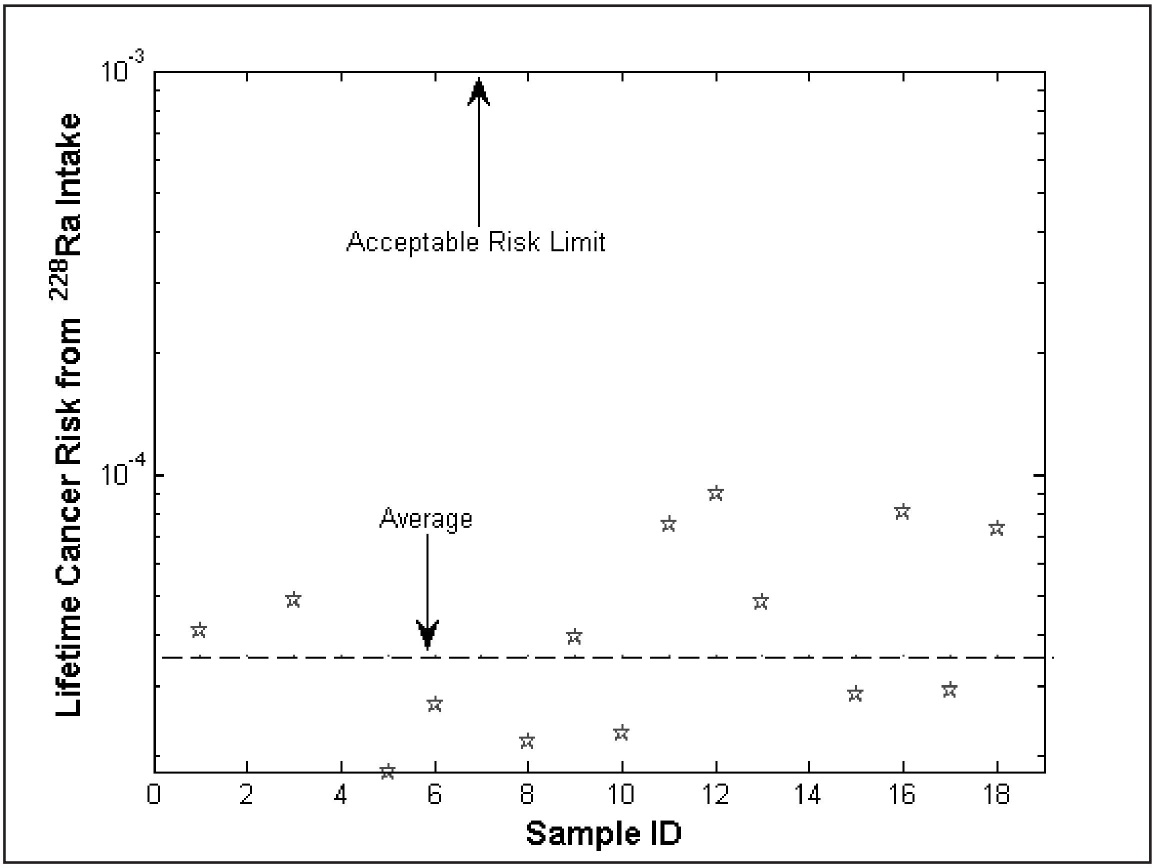

Fig. 2. Lifetime cancer risk from the consumption of flour due to the presence of ^{228}Ra

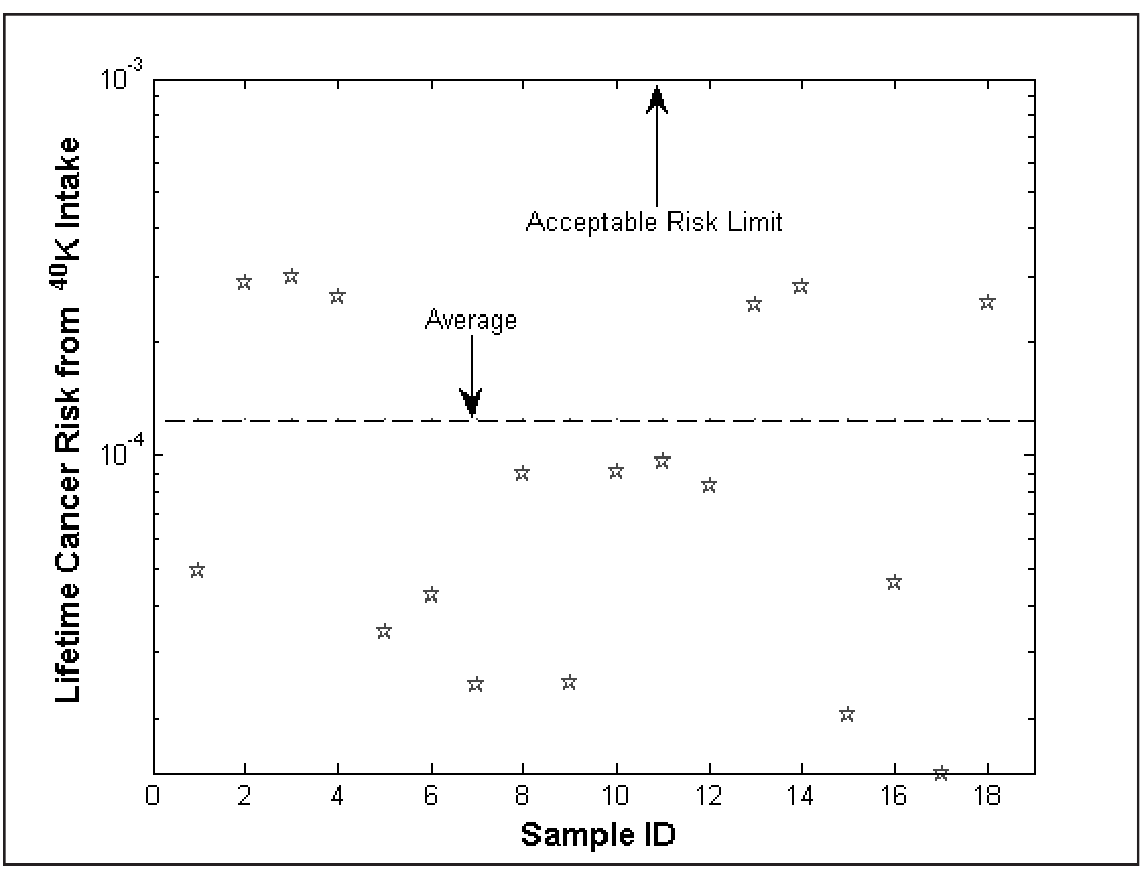

Fig. 3. Lifetime cancer risk from the consumption of flour due to the presence of ^{40}K

5. Conclusion

This study investigated the natural radioactivity of flour consumed in Kuwait. In particular, the study targeted three radionuclides, namely ^{226}Ra, ^{228}Ra, and ^{40}K respectively. While ^{226}Ra and ^{40}K were detected in all samples, ^{228}Ra was detected in 14 out of the 18 investigated samples. Nonetheless, the radioactivity concentrations of the targeted radionuclides were found to be within normal levels. Moreover, these concentration values were used to estimate annual effective doses from the ingestion of the targeted radionuclides. The doses were found to be within the acceptable levels. Furthermore, the lifetime cancer risk from the ingestion of the targeted radionuclides was calculated, and was found to be well below the hazardous level. These findings confirm the radiological safety of the consumption of flour in Kuwait for the targeted radionuclides.

The findings of this study will help in establishing a national baseline of radioactivity exposure to the general public in Kuwait. Such baseline could serve as a valuable tool in resembling a reference to compare various exposure levels in different times, and to assess the radiological wellbeing of people.

References

UNSCEAR .(2000). The United Nations Scientific Committee on the Effects of Atomic Radiation. Health Phys 79, 314.

UNSCEAR.(2001). United Nations Scientific Committee on the Effects of Atomic Radiation. Health Phys 80, 291.

Ababneh, Z.Q., Alyassin, A.M., Aljarrah, K.M.A. & Ababneh, A.M. (2009). Measurement of natural and artificial radioactivity in powdered milk consumed in Jordan and estimates of the corresponding annual effective dose. Radiation Protection Dosimetry, 1–6.

Abojassim, A.A., Al-Alasadi, L.A., Shitake, A.R., Al-Tememie, F.A. & Husain, A.A. (2015). Assessment of Annual Effective Dose for Natural Radioactivity of Gamma Emitters in Biscuit Samples in Iraq. Jornal of Food Protection **78**:1766-1769.

Al-Masri, M.S., Mukallati, H., Al-Hamwi, A., Khalili, H., Hassan, M. et al., (2004). Natural radionuclides in Syrian diet and their daily intake. Journal of Radioanalytical and Nuclear Chemistry, **260**:405-412.

Alrefae, T. (2015). Long-lived gamma emitting radionuclides in palm dates and estimates of annual effective doses. Health Physics, **108**:547-550.

Alrefae, T. & Nageswaran, T. (2013). Radioactivity of long lived gamma emitters in rice consumed in Kuwait. Journal of the Association of Arab Universities for Basic and Applied Sciences, **13**:24.

Alrefae, T., Nageswaran, T. & Al-Shemali, T.(2014). Radioactivity of long lived gamma emitters in canned seafood consumed in Kuwait. Journal of the Association of Arab Universities for Basic and Applied Sciences, 15.

Alrefae, T., Nageswaran, T.N., Al-Failakawi, A. & Al-Shemali, T. (2012a). Radioactivity of long lived gamma emitters in milk powder consumed in Kuwait and estimates of annual effective doses. Kuwait Journal of Science & Engineering, **39**:143-158.

Alrefae, T., Nageswaran, T.N. &Al-Shemali, T. (2012b). Radioactivity of long lived gamma emitters in breakfast cereal consumed in Kuwait and estimates of annual effective doses. Iranian Journal of Radiation Research, **10**:117-122.

Charles, M. (2001). UNSCEAR report 2000: sources and effects of ionizing radiation. United Nations Scientific Comittee on the Effects of Atomic Radiation. Jornal of Radiological Protection, **21**:83-86.

Currie, L.A. (1968). Limits for qualitative detection and quantitative determination- Application to radiochemistry. Analytical chemistry, **40**: 8.

Desimoni, J., Sives, F., Errico, L., Mastrantonio, G. & Taylor, M.A. (2009). Activity levels of gamma-emitters in Argentinean cow milk. Journal of Food Composition and Analysis, **22**:250-253.

Görür, F.K., Keser, R., Akçay, N., Dizman, S., As, N., et al. (2012). Radioactivity and heavy metal concentrations in food samples from Rize, Turkey. Journal of the Science of Food and Agriculture, **92**:307-312.

Hosseini, T., Fathivand, A.A., Abbasisiar, F., Karimi, M. & Barati, H. (2006a). Assessment of annual effective dose from U-238 and Ra-226 due to consumption of foodstuffs by inhabitants of Tehran city, Iran. Radiation Protection Dosimetry, **121**:330-332.

Hosseini, T., Fathivand, A.A., Barati, H. & Karimi, M. (2006b). Assessment of radionuclides in imported foodstuffs in Iran. Iranian Journal of Radiation Research, 4.

ICRP. (1996). Age-dependent doses to members of the public from intake of radionuclides, ICRP publication.

Jibiri, N.N. & Okusanya, A.A. (2008). Radionuclide contents in food products from domestic and imported sources in Nigeria. Journal of Radiological Protection, **28**:405-413.

Knoll, G.F. (2010). Radiation detection and measurement, 4th ed. John Wiley, Hoboken, New Jersey.

Mahesh, M. (2009). NCRP Report Number 160: its significance to medical imaging. Journal of American College of Radiology, **16**:890-892.

Nogueira, D.P. (1989). Measurement of radionuclides in food and the environment - A guidebook. Revista De Saude Publica, **23**:441-441.

Schauer, D.A. & Linton, O.W. (2009). NCRP Report No. 160, Ionizing radiation exposure of the population of the United States, medical exposure--are we doing less with more, and is there a role for health physicists? Health Phys, **97**:1-5.

Venturini, L. & Sordi, G.A. (1999). Radioactivity in and committed effective dose from some Brazilian foodstuffs. Health Phys, **76**:311-313.

Yu, K.N. & Mao, S.Y. (1994). Application of high-resolution gamma-ray spectrometry in measuring radioactivities in drinks in Hong-kong. Applied Radiation and Isotopes, **45**:1031-1034.

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التقييم الإشعاعي للطحين المستهلك في دولة الكويت

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الملخص

تم قياس مستوى الإشعاع الطبيعي في الطحين المستهلك في دولة الكويت. وشملت الدراسة أنواع الطحين المختلفة (طحين القمح، طحين الأرز، وطحين الحمص). خضعت جميع العينات إلى مطياف جاما الذي رصد النظائر المشعة للراديوم 226 والبوتاسيوم 40 في جميع العينات، بينما تم رصد الراديوم 228 في 14 عينة من مجموع العينات البالغ 18. وقد جاءت مستويات هذه النظائر المرصودة ضمن النطاق المقبول، ولذا تحققت السلامة الإشعاعية لعينات الطحين المدروسة.