Evaluation of radionuclides contamination in wheat flour and bread using gamma-ray spectrometry

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Abstract: Because of the increasing of cancer incidence rates, this study was carried out to evaluate the activity concentration of radionuclides in the most common food consumed in Saudi Arabia (wheat flour and bread) and to estimate their radiological impact in long-term. For this purpose, the activity concentrations of ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs in wheat flour and bread samples were measured using gamma-ray spectrometry. The result showed that the mean values of the activity concentrations in brown bread were higher than those in wheat flour and white bread. A decreasing trend of the mean values of their specific activities has been observed in the order: brown bread > white bread > wheat flour. The highest concentrations of ²³²Th were found in brown bread that contained more bran and other grains. However, these values were lower than the acceptable limit. Furthermore, the radium equivalent activity (Ra_{eq}), absorbed dose rate in air (D), annual effective dose rate (E) and the internal hazard indices (H_{in}) were calculated. The radiation hazard indexes for all samples were lower than the acceptable values. The data were compared with those given in the literature.

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1. Introduction

Natural radioactivity is widespread throughout the earth's environment and it exists in various geological formations in soil, rocks, plants, water and air (Yang et al., 2005, Al-Hamidawi, 2015, Alsaffar et al., 2015, Ahmad et al., 2015) The radionuclides concentrations in soil and plants are higher in cultivated lands due to the effect of phosphate fertilizers which contain high concentration of radionuclides (Amaral et al,. 2005, Ahmed and El-Arabi, 2005, Fawzia, 2007, Lambert et al., 2007, Alshahri and Alqahtani, 2015). Radionuclides transfer through the environment by various pathways, for example, through the atmosphere, aquatic systems and soil sub-compartments; each of these pathways contribute to human exposure. A large fraction of radiation exposure occurs as a result of ingestion of foodstuffs produced in the natural environment due to the emission of gamma rays and the inhalation of radon and its daughters which can pose serious health hazards (Hosseini et al., 2006, Asaduzzaman et al., 2014, Kant et al., 2015).

The most important terrestrial sources of natural radiation are the long-lived ⁴⁰K and the ²³⁸U and ²³²Th decay series. These radionuclides are mainly responsible for internal exposure, through ingestion of food and water and through inhalation of air particulates (**Amaral** *et al.*, **2005**). The ²³⁸U series decays via a chain containing eight alpha decays and six beta decays to ²⁰⁶Pb. This chain includes radon gas, which is produced from the decay series of ²³⁸U by the alpha decay of ²²⁶Ra. Radon is an inert,

colorless, odorless and tasteless gas with a half- life of 3.825 d. Radon is a cause of lung cancer when inhaled (Akbari et al., 2013, Alshahri and Alqahtani, 2015). Thorium accumulates in human lungs, liver and skeleton tissues, uranium accumulates in lungs and kidneys and potassium accumulates in muscles. Depositions of large quantities of these radionuclides in particular organs produce radiation damage and biochemical and morphological changes (Akhter et al., 2007, Adeniji et al., 2013). Moreover, cesium-137, which can pass to humans through the food chain, is one of the most important radionuclides among man-made radionuclides due to the fact that it has similar chemical properties of potassium, has a long physical half-life (30.2 years) and emits beta particles and gamma rays (Kilic et al., 2009). A radioactive isotope of cesium, ¹³⁷Cs, is found in the fallout from the detonation of nuclear weapons and the waste from nuclear power plants. ¹³⁷Cs is one of the most common radioisotopes used in industry. It is used in various measuring devices, such as moisturedensity gauges (Abd El Wahab and Morsy, 2006). Contamination with cesium-137 can cause serious illness or death, depending upon the dose, and has been associated with the development of cancer long after exposure (Strandberg, 2004, Abd El Wahab and Morsy, 2006, Lavi et al., 2006).

Cancer is a leading cause of disease worldwide. An estimated 14.1 million new cancer cases occurred in 2012. Lung, female breast, colorectal and stomach cancers accounted for more than 40% of all cases diagnosed worldwide (**WHO**, 2014). In Saudi Arabia, incidence rates of cancer are steadily increasing. There are more than 12,000 new cancer cases per year in the Kingdom of Saudi Arabia (KSA), with an incidence rate of 52.3 per 100,000 and the overall age-standardized incidence is 82.1 per 100,000 populations. Most of these cases present with advanced stages of the disease (**Ministry of Health**, **2012**).

Wheat flour is an essential commodity to human existence through the centuries and is currently the most widely consumed staple food and cultivated in different regions of the world. Most breads are made with wheat flour; some breads contain other grains or more bran. The intake of radionuclides, due to breads consumption, is the largest contributor of radiation doses received by the human body. Therefore, it is important to establish databases of the concentration of long-lived radionuclides in wheat and its products which are the most popular food, to ensure that the radiation levels are within the specified safety limits. These databases can be useful as baseline values to estimate the radiation hazard indices from wheat flour and bread among various brand names in Saudi Arabia markets.

2. Material and Methods

2.1 Sample preparation

Thirty samples of the most available types of flour and wheat breads among various brand names were collected from the local markets in Saudi Arabia. To remove moisture, the bread samples were dried in an electric oven at 100° C for 24 hours. After drying, the bread samples were crushed into a fine powder to pass through a 2 mm mesh sieve. For radiation measurements, each sample was packed into 152 ml standard size beakers and tightly sealed and stored for 28 days to reach equilibrium. Two reference materials were packed into the same standard size beakers for efficiency calibration.

2.2 Experimental setup

A Hyper pure germanium detector (HPGe), coaxial type, P-type with a relative efficiency of 20% was used. The detector was shielded with a low-level background lead shield. The HPGe was calibrated for efficiency using the reference material RGU-1 from IAEA. The certified activity of uranium is 400 ppm which refers to 4960 Bq kg⁻¹. The energy transitions of the ²²⁶Ra daughters (²¹⁴Pb and ²¹⁴Bi) were used to develop the efficiency calibration curve. A fourthdegree polynomial fitting was performed to achieve the best R² value (≈ 0.97).

After subtracting the background, the radionuclides were measured at the gamma lines as given in Table (1). 226 Ra was measured using its progenies 214 Pb with energies of 295.2 keV (19.3%) and 351.93 keV (37.6%), and 214 Bi with energies of

609.31 keV (46.1%), 1120.29 keV (15.1%) and 1764.49 keV (15.4%). Radium was determined based on the above mentioned energy transitions after achieving secular equilibrium for 28 days after sample packing. For ²³²Th, the specific activity concentration was determined using the gamma lines of 338.40 keV (12.4%) and 911.07 keV (25.8%) for ²²⁸Ac and the gamma lines of 583.14 keV (84.5%) for ²⁰⁸Tl. In the case of ⁴⁰K and ¹³⁷Cs, the specific activity concentrations were estimated directly by their gamma lines of 1460.75 keV (10.7%) and 661.7 keV (85.12%), respectively.

The software used for analysis and reduction of the gamma-ray spectra was **Quantum Gold**, Version 4.04.00.

The Minimum detectable activity (MDA) for each radionuclide (Ra, Th and K) in the background was calculated separately based on the sample's weight using the detection limit according to the formula (**Currie, 1986**):

$$MDA (counts) = \frac{2.7 + 4.65 \sqrt{BG}}{s \, l_y t} \tag{1}$$

where BG is the background count below the peak of interest, ε is the absolute efficiency, I_{γ} is the gamma line intensity and t is the counting time in second. The MDAs for ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs were 8.6, 5.6, 52 and 0.22 Bg kg⁻¹, respectively.

To assess the radiological hazard, it is useful to calculate an index called the radium equivalent activity, Ra_{eq} , which can be calculated from the following relation (Boukhenfouf and Boucenna, 2011, Alshahri and Alqahtani, 2015):

 $\begin{aligned} & \operatorname{Ra}_{eq} \left(\operatorname{Bq} kg^{-1}\right) = \operatorname{A}_{Ra} + 1.43\operatorname{A}_{Th} + 0.077\operatorname{A}_{K} \end{aligned} (2) \\ & \text{where } \operatorname{A}_{Ra}, \operatorname{A}_{Th} \text{ and } \operatorname{A}_{K} \text{ are the specific activities} \\ & \operatorname{of}^{226}\operatorname{Ra}, \overset{232}{}^{232}\operatorname{Th} \text{ and } \overset{40}{}^{40}\operatorname{K}, \text{ respectively, expressed in Bq} \\ & \operatorname{kg}^{-1}. \end{aligned}$

The absorbed dose rate in air 1 m above the ground surface for the radionuclides (232 Th, 226 Ra, and 40 K) was computed on the basis of guidelines provided by Ahmed and El-Arabi, **2015**. The conversion factors used to compute the absorbed dose rates (D) in air per unit activity concentration in 1 Bq kg⁻¹ sand correspond to 0.606 nGy h⁻¹ for 232 Th, 0.429 nGy h⁻¹ for 226 Ra, and 0.0417 nGy h⁻¹ for 40 K. Therefore, D could be obtained from the following relation:

D (nGy h^{-1}) = 0.429 A_{Ra} + 0.606 A_{Th} + 0.0417 $A_{K}(3)$

where A_{Ra} , A_{Th} and A_{K} are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K (Bq kg⁻¹), respectively.

The annual effective dose rate $E (mSv y^{-1})$ received by the population is calculated using the following equation (UNSCEAR, 2000):

E (mSv y⁻¹) = D (nGy h⁻¹) × 8760 (h y⁻¹) × 0.2 × 0.7 (Sv Gy⁻¹) × 10⁻⁶ (4) where D (nGy h^{-1}) is the absorbed dose rate in air, 8760 h is the time for one year, 0.7 (Sv Gy⁻¹) is the conversion factor, which converts the absorbed dose rate in air to human effective dose and 0.2 is the outdoor occupancy factor (UNSCEAR, 2000).

Another radiation hazard index is called Internal Hazard Index (H_{in}) (Nasim *et al.*, 2012, Ahmad *et al.*,

2015). This index value must be less than unity and is defined as follow:

$$H_{in} = \frac{A_{Ra}}{105} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}$$
(5)
where A_{Ra}, A_{Th} and A_K are the activity
concentrations of ²²⁶Ra ²³²Th and ⁴⁰K (Bg kg⁻¹)

Table 1. Gamma rays and their related isotopes used to calculate the activity concentrations of the nuclides in the first column (Mansour *et al.*, 2012,. Boukhenfouf and Boucenna, 2011)

respectively.

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Nuclide	Half life (yr)	Gamma ray energy (keV)	Isotope	Intensity (%)
²²⁶ Ra	1650	295.2	²¹⁴ Pb	19.3
		351.93	²¹⁴ Pb	37.6
		609.31	²¹⁴ Bi	46.1
		1120.29	²¹⁴ Bi	15.1
		1764.49	²¹⁴ Bi	15.4
²³² Th	1.405×10^{10}	338.40	²²⁸ Ac	12.4
		911.07	²²⁸ Ac	29.0
		583	²⁰⁸ Tl	84.5
40 K	1.277×10^{9}	1460.83		10.7
¹³⁷ Cs	30.1	661.7		85.12

3. Results and discussion

3.1. Radionuclides in wheat flour and bread

The specific activities of ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs in all wheat flour and bread samples were measured. The results are given in Table (2). The specific activities of 226 Ra ranged from 11.5 ± 3.7 to 34.6 ± 4.1 Bq kg⁻¹ with a mean value of 22.7 ± 3.2 Bq kg⁻¹ for wheat flour samples, from 14.9 ± 3.5 to $31.3 \pm$ 3.7 Bq kg⁻¹ with a mean value of 23.3 ± 3.1 Bq kg⁻¹ for white bread samples and from 8.67 ± 1.0 to 37.3 ± 4.4 Bq kg⁻¹ with a mean value of 23.8 \pm 2.7 Bq kg⁻¹ for brown bread samples. The specific activities of ²³²Th ranged from 8.56 \pm 1.7 to 28.3 \pm 3.3 Bq kg⁻¹ with a mean value of 16.6 ± 2.5 Bq kg⁻¹, from MDA value to 26 ± 3.1 Bq kg⁻¹ with a mean value of 16.4 ± 2.3 Bq kg⁻¹ and from 6.9 ± 0.8 to 43.1 ± 5.1 Bq kg⁻¹ with a mean value of 19.9 \pm 2.3 Bq kg⁻¹ for wheat flour, white bread and brown bread, respectively. The highest activity concentration of radium was $37.3 \pm$ 4.4 Bq kg⁻¹ in brown bread for sample B2 and the highest activity concentration of thorium was 43.1 \pm 5.1 Bq kg⁻¹ in brown bread for sample B7 which were within the range of the acceptable values (UNSCEAR, 2000). From Table (2), the activity concentrations of radium and thorium in all samples were within or lower than the range of the acceptable values (UNSCEAR, 2000) The data show that the mean values of radium and thorium in brown bread were higher than the mean values in wheat flour and

white bread whereas the radioisotopes of ⁴⁰K and ¹³⁷Cs were present in low concentrations in all samples.

Comparison of radium, thorium and potassium activities in all samples are given in Figures (1), (2) and (3). These figures compare between UNSCEAR values and the values of this study.

The variations of activity concentrations in all samples may be due to the different amount of radionuclides found in the soil which can be absorbed by wheat plants (Amaral *et al.*, 2005, El- Taher and Makhluf, 2010). The radionuclides in soil can be transferred from soil to plants via the root system and no differentiation was observed between the absorption of chemically analogous isotopes via the root system (Vandenhove *et al.*, 2009, Asaduzzaman *et al.*, 2014).

3.2. Activity concentration of ²³²Th in white and brown bread

The activity concentration of thorium in most of the brown bread samples were higher than the values in white bread samples which may due to the contents of the brown bread as shown in Figure (4). Brown bread is made from whole grain wheat which contains bran. Bran is an integral part of whole grains and represent the hard outer layer of cereal grains. Bran is particularly rich in dietary fiber and contains significant quantities of minerals (Nike *et al.*, 2005). This result can be observed in samples B4 and B7, which contain more bran and other grains (e.g., linseed and millet).

3.3. Radiation hazard indexes

The radium equivalent activity (Ra_{eq}), total absorbed dose rate in air 1 m above the ground (D), annual effective dose (E) and internal hazard index (H_{in}) were calculated for all samples under investigation. The calculated values are presented in Table (3). The radium equivalent activity varied from 49.2 ± 6.8 to 89.5 ± 9.8 Bq kg⁻¹ with a mean value of 66.1 ± 6.7 Bq kg⁻¹ for wheat flour samples, from 51.3 ± 5.5 to 85.3 ± 9.2 Bq kg⁻¹ with a mean value of 65.2 ± 8.1 Bq kg⁻¹ for white bread samples and from $59.3 \pm$ 6.2 to 103 ± 11 Bq kg⁻¹ with a mean value of 77.7 \pm 7.7 Bq kg⁻¹ for brown bread. The radium equivalent activities for all samples were lower than the acceptable value of 370 Bq kg⁻¹ (UNSCEAR 2000) as shown in Figures (1), (2) and (3). Figure (5) shows a good correlation between Ra_{eq} and ²³²Th in wheat flour, white bread and brown bread samples. The values of correlation coefficient are R² = 0.702, R² = 0.725 and R² = 0.770 for wheat flour, white bread and brown bread samples, respectively.

Table 2. Activity concentration in Bq kg⁻¹ of ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs for wheat flour and bread samples.

Type of sample	Sample code	²²⁶ Ra	²³² Th	⁴⁰ K	¹³⁷ Cs
	F1	17.8 ± 2.1	12.7 ±1.5	200 ± 15	< MDA
	F2	12.7 ± 1.5	14.6 ± 2.9	203 ± 15	3.13 ± 0.5
	F3	23.4 ± 2.8	14.4 ± 2.8	312 ± 16	< MDA
	F4	11.5 ± 3.7	14.8 ± 1.7	279 ± 21	< MDA
Wheat flour	F5	29.2 ± 3.4	17.4 ± 2.0	379 ± 19	< MDA
wheat nour	F6	34.6 ± 4.1	8.56 ± 1.7	200 ± 16	< MDA
	F7	21.4 ± 2.5	13.3 ± 1.5	256 ± 17	2.73 ± 0.5
	F8	30.7 ± 3.6	28.3 ± 3.3	238 ± 19	2.33 ± 0.4
	F9	23.8 ± 4.7	19.2 ± 5.1	267 ± 21	2.73 ± 0.5
	F10	21.5 ± 2.5	22.4 ± 2.6	242 ± 19	< MDA
Mean		22.7 ± 3.2	16.6 ± 2.5	258 ± 18	2.73 ± 0.5
	W1	17.4 ± 2.1	18.9 ± 2.2	203 ± 26	< MDA
	W2	24.6 ± 2.9	13.2 ± 1.5	232 ± 18	0.97 ± 0.2
	W3	24.7 ± 2.9	18.9 ± 2.2	203 ± 26	0.24 ± 0.05
	W4	23.5 ±2.8	22.8 ± 4.6	217 ± 23	2.26 ± 0.6
White bread	W5	14.9 ± 3.5	21.3 ± 2.5	251 ± 21	2.74 ± 0.8
white bread	W6	20.0 ± 3.6	10.6 ± 3.2	242 ± 24	0.49 ± 0.1
	W7	25.5 ± 3.2	19.6 ± 2.2	266 ± 21	2.11 ± 0.6
	W8	31.3 ± 3.7	< MDA	260 ± 23	6.15 ± 1.8
	W9	25.3 ± 3.0	26.0 ± 3.1	297 ± 23	< MDA
	W10	25.7 ± 3.1	12.5 ± 1.5	231 ± 23	0.57 ± 0.1
Mean		23.3 ± 3.1	16.4 ± 2.3	240 ± 22	1.93 ± 0.5
	B1	32.8 ± 3.9	13.2 ± 1.5	349 ± 24	1.42 ± 0.4
	B2	37.3 ± 4.4	13.8 ± 1.6	347 ± 26	1.86 ± 0.5
	B3	30.3 ± 3.6	6.9 ± 0.8	248 ± 19	< MDA
	B4	33.1 ± 3.9	24.8 ± 2.9	359 ± 28	2.91±0.6
Duorum huood	B5	18.3 ± 1.6	17.7 ± 2.1	342 ± 27	0.49 ± 0.1
Brown bread	B6	17.5 ± 1.5	16.1 ± 2.1	432 ± 20	< MDA
	B7	22.6 ± 2.7	43.1 ± 5.1	241 ± 19	3.39 ± 0.6
	B8	16.8 ± 2.0	23.3 ± 2.7	310 ± 17	< MDA
	B9	8.67 ± 1.0	18.7 ± 2.2	359 ± 28	< MDA
	B10	20.9 ± 2.5	21.7 ± 2.3	302 ± 16	< MDA
Mean		23.8 ± 2.7	19.9 ± 2.3	328 ± 22	2.01 ± 0.2



Figure 1. Comparison of 226 Ra, 232 Th, 40 K and Ra_{eq} activities in Wheat flour samples with the allowed values by UNSCER, 2000.



Figure 2. Comparison of 226 Ra, 232 Th, 40 K and Ra_{eq} activities in white bread samples with the allowed values by UNSCER, 2000.



Figure 3. Comparison of ²²⁶Ra, ²³²Th, ⁴⁰K and Ra_{eq} activities in brown bread samples with the allowed values by UNSCER, 2000.

Type of sample	Sample code	Ra	D	Е	H _{in}
Type of sample	Sample code	Ka _{eq}	$(nGy h^{-1})$	$(mSv y^{-1})$	
	F1	51.4 ± 5.4	16.1	0.02	0.19
	F2	49.2 ± 6.8	22.8	0.03	0.17
	F3	68 ± 8.0	31.8	0.04	0.25
	F4	53.8 ± 8.5	25.5	0.03	0.18
Wheat flour	F5	83.3 ± 7.7	23.1	0.03	0.30
wheat hour	F6	62.2 ± 7.7	28.4	0.03	0.26
	F7	60.1 ± 5.9	27.9	0.03	0.22
	F8	89.5 ± 9.8	40.3	0.05	0.33
	F9	71.8 ± 13	33.1	0.04	0.27
	F10	71.7 ± 7.6	32.9	0.04	0.25
Mean		66.1 ± 6.7	30.6	0.04	0.24
	W1	60.1 ± 7.2	27.4	0.03	0.21
	W2	61.3 ± 6.4	28.3	0.03	0.23
	W3	67.4 ± 8.0	30.6	0.04	0.25
	W4	72.8 ± 11	33.0	0.04	0.26
White breed	W5	64.7 ± 8.8	29.8	0.04	0.21
white bread	W6	53.8 ± 10	25.2	0.03	0.20
	W7	74 ± 7.9	33.9	0.04	0.27
	W8	51.3 ± 5.5	24.3	0.03	0.22
	W9	85.3 ± 9.2	39.1	0.05	0.30
	W10	61.4 ± 7.0	28.3	0.03	0.24
Mean		65.2 ± 8.1	30.0	0.04	0.23
	B1	78.5 ± 7.9	36.7	0.05	0.30
	B2	83.8 ± 8.7	38.9	0.05	0.33
	B3	59.3 ± 6.2	27.6	0.03	0.24
	B4	96.2 ± 10	44.3	0.05	0.35
Duaran haaad	B5	69.9 ± 6.7	32.9	0.04	0.24
Brown bread	B6	73.7 ± 6.0	35.4	0.04	0.25
	B7	103 ± 11	45.9	0.06	0.34
	B8	74 ± 7.2	34.3	0.04	0.25
	B9	63 ± 6.3	30.1	0.04	0.19
	B10	75.2 ± 7.0	34.8	0.04	0.26
Mean		77.7 ± 7.7	36.0	0.04	0.28

Table 3. Radium equivalent activity (Bq kg⁻¹), absorbed gamma radiation dose rate in air (nGy h⁻¹), annual effective dose (mSv y^{-1}) and internal radiation hazard index (H_{in}) for sand samples and sediment.

The gamma adsorbed dose rate (D) in air and annual effective dose (E) for all samples ranged between 16.1-44.3 nGy h^{-1} and between 0.02-0.06, respectively. These results were within the estimated average global terrestrial radiation of 55 nGy h^{-1} and the acceptable value of annual effective dose (1 mSv y⁻¹) for the public (UNSCEAR 2000).

The internal hazard index ranged between 0.17 and 0.32 with a mean value of 0.24 for wheat flour,

between 0.20 and 0.30 with a mean value of 0.23 for white bread and between 0.19 and 0.35 with a mean value of 0.28 for brown bread. From Figure (6), the data show a good correlation between radium equivalent activities and the internal hazard indices in all samples. However, the values of H_{in} in all samples are lower than unity.



Figure 4. Activity concentrations of ²³²Th in white and brown bread.



Figure 5. Relationship between Ra_{eq} and ²³²Th in wheat flour, white bread and brown bread.



Figure 6. Relationship between Ra_{eq} and H_{in}.

3.4. Comparison of Activity Concentrations with Similar Studies

The activity concentrations of ²²⁶Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs for the present study were compared with the similar investigations of available studies (Hoshi *et al.*, 1994, Santos *et al.*, 2002, Jeambrun *et al.*, 2012, Kimura *et al.*, 2012, Alharbi and El-Taher, 2013, Abid Abojassim *et al.*, 2014). The obtained values for ²²⁶Ra, ²³²Th and ⁴⁰K concentrations were higher than the reported values from other studies whereas the activity concentrations of ¹³⁷Cs were within the range of values of the reported data in the literature. The variations in the activity concentrations

of radionuclides in wheat flour and bread for this study and other studies may be due to the local geology of the different countries and the effect of phosphate fertilizers on cultivated land. Moreover, the food Additives may contribute to increase the concentration of radionuclides in bread.

Conclusion

The activity concentrations of ²²²Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs in wheat flour and bread were evaluated using gamma-ray spectrometry. These data show that the mean values of ²²²Ra, ²³²Th, ⁴⁰K and ¹³⁷Cs were lower than the allowed limits for all samples. Thorium

concentrations in most of the brown bread samples were higher than the values in white bread samples. This result can be observed clearly in sample B7 which contain more bran and other grains. The radium equivalent activities and the internal hazard indices were calculated to assess the radiological hazards from the consumption of wheat flour and bread. All of calculated values were lower than the the recommended level. Thus, the accumulation of radionuclides in wheat flour and bread samples under investigation do not pose any health risks. However, the obtained data emphasize the need for more studies on radionuclides in other foodstuffs to establish a baseline for radiation exposure and its impact on human health.

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