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Evaluation of lifetime cancer risk arising from natural radioactivity in foods frequently consumed by people in Eastern of Turkey

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Abstract

In this study, the distribution of natural radionuclides in various foods that people in Turkey frequently consume in their daily lives and the radiation hazards that may arise for humans due to the consumption of these foods were evaluated. The results of ^{226}Ra, ^{232}Th and ^{40}K concentrations in the analyzed food samples were ranged from 2.2 ± 0.6 to 36.2 ± 6.9 Bq kg^{-1}, from 2.98 ± 1.38 to 49.56 ± 5.41 Bq kg^{-1}, and from 83.55 ± 78 to 304.89 ± 45.7 Bq kg^{-1}, respectively. The absorbed dose rate, annual effective dose rate, lifetime cancer risk and annual effective ingestion dose were estimated and which were also compared with the internationally approved values. It was found that none of the results exceeds the recommended limit value.

Keywords Natural radioactivity · Gamma ray spectrometry · Various foods · Ingestion dose · Cancer

Introduction

The naturally occurring radioactive substances that are found in soil, building materials, air, water and food of the earth are greatest contributory to the average dose taken by the world's populace [1]. The sources of internal radiation exposures in foodstuffs arise mainly by gamma radiation from radionuclides in the uranium (^{238}U) and thorium (^{232}Th) series and from potassium (^{40}K) [2]. Activity concentration of these radionuclides in building materials derived from rock, soil and water varies place to place and depend on geological and geographical conditions [3]. Radioactive elements found in the atmosphere, water and soil pass to plants, animals and humans. Plants take in radioactive materials from the soil in two basic ways, namely direct and indirect storage [4]. The radionuclide transfer from soil to the plant by the plant roots is affected by the properties of the soil such as PH, clay mineral and organic matter contents. In addition, applications such as plowing, liming, fertilizing and irrigation to cultivate the soil significantly affect the uptake and distribution profile of radionuclides through the roots in plants [5, 6].

In the literature, there are several studies have been performed to measure natural radioactivity in various foodstuff. For example, Azeez et al. [7] determined the activity concentrations of naturally occurring radioactive nuclides in plants such as wheat, barley, rice, tomato, cucumber, pepper, courgette, watermelon, potato and radish. Furthermore, the activity concentrations in the corresponding soil taken from the greenhouses and agricultural areas where these agricultural products were grown-up in Erbil, Iraq were determined [7]. The activity levels of ^{226}Ra, ^{232}Th and ^{40}K in powdered milk samples commercialized in Saudi Arabia were determined using the gamma-ray spectrometry. They also estimated annual effective dose as well as the radiological risk on the infantile well-being due to the consumption of milk [8]. Alrefae et al. [9] measured the activity concentrations of naturally occurring ^{226}Ra, ^{232}Th and ^{40}K radionuclides in varied kinds of meat (raw and processed lamb and beef) sold in Kuwaiti market places and evaluated the possible radiological effects of these meats consumption on human health [9]. Al-Hamarneh et al. [10] determined the radioactivity levels of the radium and uranium isotopes in soil samples and on different types of crop plants which are grown on these lands taken from the cultivated fields in Tabuk city of north western Saudi Arabia. Hence they

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calculated the transfer factors of radionuclides soil to crop plant species [10]. The activity concentrations of primitive radionuclides (^{226}Ra, ^{232}Th and ^{40}K) and anthropogenic radionuclide (^{137}Cs) in both soil and date palm pits, as well as a principal parameter, soil-to-plant transfer factor (TF), were calculated by Abu Shayeb et al. [11]. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in the basic foodstuffs (wheat, millet, potatoes, lentils and cauliflower) that constitute the master element of the diurnal dietary of the Pakistanian population and in the soil where the crops are grown, and the transfer factors of these radionuclides from the soil to the food were investigated [12].

Naturally occurring long-lived radionuclides present in the soil in various proportions are transported to plant, animals and humans in various ways. These radionuclides accumulate through the roots at the edible parts of plant and when these edible parts are taken into the human and animals body by digestion contribute to the total internal radiation dose received by alive [10].

In order to investigate food safety and suitability for humans, it would be good to investigate the natural radioactivity concentrations in the foods we consume every day and to use these doses to estimate the total annual effective intake dose and cancer risk for consumers. For this purpose, various researches have been carried out in diversified territories to define the amount of dose that people are exposed to depending on the consumption of different foods [6, 13–15].

Civilized communities do not get all their food from the immediate environment. Rather, they generally consume food produced throughout the country. Animal husbandry is very common in Kars province and its surroundings, so milk production is also quite high in this region. Various cheeses and animal meats produced in this region are consumed with admiration all over the country. Therefore, these work objectives to state the activity concentrations of natural radionuclides in assorted essential nutrients, e.g., cereals, cheese, bakery, meat and rock salt consumed by the local people and people living in different parts of our country and dose assessments. The results obtained in this work were tabulated and checked with the outcomes of similar works in the current literature.

Materials and methods

Study area and sample preparation

Kars is located in the northern parts of Eastern Anatolia Region of Turkey between 42° 10′ and 44° 49′ East longitudes and 39° 22′ and 41° 37 Northern latitudes. It has Armenia on the eastern border, Erzurum on the western border, Ardahan on the northern border, and Ağrı and Iğdir on the southern border. The region has an average altitude of 1768 m above sea level, covers approximately 1.2 percent of the land in Turkey with a surface area of 10,127 km^2 and has a total population of 288,878. The study area is given in Fig. 1.

For this study, a total of 90 food samples were collected from local markets, local farmers, butchers and bakeries, 5 from each sample. The groups of food samples studied are cereals, meat, cheese, baked goods and rock salt,

Fig. 1 Sampling location of samples in the city of Kars and its districts, Turkey

which constitute the main component of the daily diet of the local population. The collected samples were crushed using a grinder and sieved through a 1 mm mesh sieve to homogenize. All samples were kept in the laboratory for one week and then dried for 12 h at 110 °C in a temperature-controlled oven to remove moisture [16]. Then each sample was weighted and transferred into airtight cylindrical plastic container (5 cm diameter and 5.5 cm height). Each sample was then detained for approximately 40 days in tightly closed plastic containers before counting to achieve equilibrium among the radium and thorium with their respective progeny [17].

Radioactivity measurements

The natural radioactivity concentrations of each food sample within the food groups were calculated using a NaI (T1) scintillation detector based on a gamma spectrometer system. The detector is protected by a 5 cm thick lead layer in order to minimize the contribution of radiation and ambient radiation originating from the structure it is in. Each sample was acquired for approximately 86,000 s to obtain good statistics in the evaluation of γ ray peaks. Background measurements were made at the same conditions to obtain net counts for the sample. Gamma spectra obtained from the measurements were analyzed using an MCA (Multi Channel Analyzer) system and a PC (Personal Computer) based on Maestro software. Energy calibration and relative efficiency calibration of the used gamma spectrometer in this study were previously described by Bilgici Cengiz [18]. The activity concentrations of ^{40}K was evaluated directly by its own 1460.8 keV gamma peak. ^{226}Ra activity concentrations was determined using the 1764.5 keV gamma peak of ^{214}Bi and similarly, 2614.5 keV gamma peak of ^{208}Tl were used to indicate the activity concentrations of ^{232}Th [19]. Taking into account background spectra the activity concentrations of measured samples were calculated using Eq. (1) [20].

$$A = \frac{N}{\varepsilon_\gamma P(E)_\gamma T_m M} \tag{1}$$

where A is the activity of the interested radionuclides in Bq kg^{-1}, N is the net count (background subtracted) under the photopeak, ε_γ is photopeak efficiency of detector, $P(E)_\gamma$ is the γ-ray emission probability at energy E, T_m is the counting time in second and M is the mass of the sample in kg. Minimum detectable activity (MDA) (in Bq kg^{-1}) for each radionuclide at the 95% degree of confidence was also determined by using Eq. (2) [21, 22].

$$\mathrm{MDA} = \frac{1,64\,\sigma N_\mathrm{B}}{\varepsilon_\gamma P(E)_\gamma T_m M} \tag{2}$$

where σN_B is the standard deviation of background counts for particular gamma energy. The MDA was estimated to be 0.5 ± 0.2, 1.5 ± 0.2 and 5.3 ± 0.6 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively.

Dose estimation

People living in the study area are exposed to radiation doses throughout their lives due to the natural radioactivity of the various foods they consume. In order to evaluate the radiological risks caused by gamma radiation due to the presence of natural radioactive concentrations in foods, the absorbed dose rate, annual effective doses, lifetime cancer risk and annual effective ingestion dose to humans were calculated.

Absorbed dose rate (ADR)

The absorbed dose rate generally used to express the effects of terrestrial gamma radiation on human health was estimated according to following Eq. (3) [2];

$$\mathrm{ADR}\left(nGy\,h^{-1}\right) = a A_\mathrm{Ra} + b A_\mathrm{Th} + c A_\mathrm{K} \tag{3}$$

where a, b and c a e the dose conversion coefficients for ^{226}Ra, ^{232}Th and ^{40}K (nGy h^{-1} Bq^{-1} kg) respectively; A_Ra, A_Th and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}), respectively. The values of a, b and c are taken to be 0.462, 0.604 and 0.0417 respectively [23].

Annual effective dose (AED)

The annual effective dose in units of μSvy^{-1}, which represents the health risk for the whole body due to ingestion of foods, were determined from Eq. (4) [24];

$$\mathrm{AED}\left(\mu\mathrm{Sv\,y}^{-1}\right) = \mathrm{ADR}\left(\mathrm{nGy\,h}^{-1}\right) \times F_\mathrm{occup}\left(\mathrm{h\,y}^{-1}\right) \times F_\mathrm{con}\left(\mathrm{Sv\,nGy}^{-1}\right) \tag{4}$$

where ADR is the absorbed dose rates in unit of μSv y^{-1}, F_occup is the occupancy factor (8760 h y^{-1}) and F_con is the conversion factor from absorbed doses to effective dose (0.7 × 10^{-6} Sv nGy^{-1}) [2].

Ingestion dose to man (AEID)

The annual effective ingestion dose to man due to consumption of food that contain various amount of ^{226}Ra, ^{232}Th and ^{40}K radionuclides can be calculated with the following Eq. (5). [24]:

$$\mathrm{AEID}\left(\mu\mathrm{Sv\,y}^{-1}\right) = C \times AI \times F_\mathrm{DC} \tag{5}$$

where C is the concentration of each radionuclide in unit of Bq kg^{-1}, AI is the annual intake of each food in unit of kg y^{-1} and F_{DC} is the standard dose conversion factor, which is equal to 0.28 μSv Bq^{-1} for ^{226}Ra, 0.23 μSv Bq^{-1} for ^{232}Th and 0.0062 μSv Bq^{-1} for ^{40}K [23].

Lifetime cancer risk (LTCR)

In this study, the lifetime probability of developing cancer risk arising from foods taken with the daily diet was examined. There is no single cause of cancer development. Genetics, general health status, diet, personal habits and environmental factors are associated with cancer development. Cancer development risk is also related to the geography in which people live. For lifetime risk assessment were estimated by applying the annual ingestion effective dose due to the presence of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in the foods, from the age of first exposure until the actual life expectancy was 78 years for Turkish population [25]. LTCR is calculated by using Eq. (6) [26];

$$\mathrm{LTCR} = \mathrm{AEID} \times L_{\mathrm{span}} \times F_{\mathrm{RC}} \tag{6}$$

here the AEID is annual effective ingestion dose to man due to consumption of food, L_{span} is mean life span (average 78 years), F_{RC} is risk conversion factor and F_{RC} coefficient is used to convert internal dose to excess cancer risk. The exposure-to-dose conversion factors for ingestion used in Eq. (7) are 5.02×10^{-3}, 7.38×10^{-1} and 3.58×10^{-1} μSv^{-1} for ^{40}K, ^{232}Th and ^{226}Ra, respectively [2, 23, 27].

Results and discussion

In order to make radiological hazard assessments, the activity concentrations of natural radioactive nuclides in foods collected from agricultural areas, local markets and local farmers in Kars province were measured by a gamma ray spectrometer equipped with a NaI(Tl) detector. A total of ninety foods were examined in six food groups, including unprocessed grains, processed grains, animal products, dairy products, bakery products and rock salt samples.

In investigated food samples, the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were found to be range from 2.2 ± 0.6 to 36.2 ± 6.9 Bq kg^{-1}, from 2.98 ± 1.38 to 49.56 ± 5.41 Bq kg^{-1}, and from 83.55 ± 78.0 to 304.89 ± 45.7 Bq kg^{-1}, respectively. The measured mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the food samples are shown in Table 1.

Radioactivity in cereal samples

Cereals and also bakery products produced from cereals are the main foodstuffs in the traditional diet of the Turkish people. Locally grown wheat, barley and oats in the study area were therefore considered for radionuclide determination. The ^{226}Ra was detected in all analysed cereal samples and

Table 1 Average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in different food groups in Kars, Turkey

Food group	Food name	Activity concentration in food samples (Bq kg^{-1}, dry weight)		
		^{226}Ra	^{232}Th	^{40}K
Unprocessed cereals	Wheat	16.84 ± 4.93	29.93 ± 1.85	293.60 ± 42.1
	Oats	34.33 ± 6.75	20.08 ± 2.54	201.71 ± 57.3
	Barley	15.79 ± 3.70	19.62 ± 2.35	235.20 ± 45.7
Processed cereals	Wheat Flour	10.80 ± 2.37	11.00 ± 2.23	274.10 ± 25.5
	Bulgur	13.17 ± 3.03	17.68 ± 2.70	277.36 ± 28.2
	Boiled and dried wheat	15.54 ± 3.85	14.64 ± 2.68	181.49 ± 19.8
Animal products	Beef	2.93 ± 0.83	4.24 ± 2.03	206.79 ± 22.5
	Goose meat	2.35 ± 0.91	3.45 ± 2.10	182.08 ± 15.4
	Turkey meat	2.91 ± 0.96	3.37 ± 1.09	199.29 ± 18.3
Dairy products	Cheddar cheese	11.66 ± 2.00	18.12 ± 2.54	168.65 ± 17.6
	White chechil cheese	10.78 ± 2.25	14.92 ± 3.04	129.14 ± 12.5
	Moldy chechil cheese	6.09 ± 2.33	7.53 ± 2.20	87.84 ± 11.9
	Curd cheese	8.99 ± 1.98	16.29 ± 2.83	130.70 ± 14.8
Bakery products	Macaroni	13.18 ± 3.85	18.45 ± 4.24	105.67 ± 29.8
	White bread	15.71 ± 4.02	21.78 ± 3.92	196.33 ± 32.7
	Whole wheat bread	19.62 ± 4.58	23.93 ± 3.75	136.59 ± 28.5
	Turkish bagel	16.74 ± 5.20	18.15 ± 2.89	143.78 ± 27.9
Salt	Rock Salt	9.38 ± 4.20	48.68 ± 5.30	116.93 ± 22.7

the activity level ranged from 10.8 ± 2.37 Bq kg^{-1} (wheat flour) to 34.33 ± 6.75 Bq kg^{-1} (oats) with an average value of 17.75 ± 4.11 Bq kg^{-1}. The activity concentration of ^{232}Th varies between 11.0 ± 2.2 Bq kg^{-1} (wheat Flour) and 29.93 ± 1.85 Bq kg^{-1} (wheat). The activity concentration of ^{40}K varies between 181.49 ± 19.8 Bq kg^{-1} (boiled and dried wheat) and 293.6 ± 42.1 Bq kg^{-1} (wheat). In Table 2, the radionuclide concentration values of cereals products in some countries are given.

As can be seen in Table 2, the average values of natural radioactivity concentration levels in all the cereal plants and wheat flour samples we examined were found to be higher than the average concentration values of other countries except Malaysia and USA [28–36]. The average values of ^{226}Ra radioactivity concentration levels in wheat and barley samples in Malaysia were 4 times higher than the average values of ^{226}Ra radioactivity concentration levels of the same cereal products in this study. In addition, it is seen that the average values of the ^{40}K radioactivity concentration levels reported for the oat and barley samples are 5 times higher than the average concentration values found in this study for the above-mentioned cereal products [28].

According to the values given in the literature, it is clearly seen from Table 2 that the average natural radioactivity concentration values in wheat, barley and oat grains in Saudi Arabia, Brazil, Sudan and Pakistan are higher than the average concentration values we found for these cereal products USA [29–32].

While the average ^{226}Ra activity concentration of the wheat flour samples examined in this study was approximately 9 times lower than the average ^{226}Ra activity concentration values of the wheat flour samples in the USA, the average ^{232}Th activity concentration of the wheat flour samples was found to be approximately 4 times higher than the reported values [36]. In addition, when the results of natural radiation concentration determination studies performed on wheat flour samples in Sudan, Iraq and Iraq (Basrah) are compared with the results we have obtained, it is seen that they are compatible with the reported results [31, 34, 35].

Radioactivity in animal products samples

The mean activity levels of ^{226}Ra, ^{232}Th, and ^{40}K were monitored in animal meat foods ranged from 2.35 ± 0.91–2.93 ± 0.83 Bq kg^{-1}, 3.37 ± 1.09–4.24 ± 2.03 Bq kg^{-1} and 182.08 ± 15.4–206.79 ± 22.5 Bq kg^{-1}, are given in Table 1, respectively. While lowest concentrations of ^{226}Ra and ^{40}K were recorded in goose meat, the lowest concentration of ^{232}Th activity value was recorded in turkey meat samples. In beef, the highest concentrations of these radionuclides were observed.

In a study conducted in Saudi Arabia, the average ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations in beef were measured in the range of 4.53 ± 0.20–6.37 ± 0.28 Bq kg^{-1}, 3.47 ± 0.22–6.49 ± 0.40 Bq kg^{-1} and 104.86 ± 9.02–145.27 ± 12.50 Bq kg^{-1}, respectively [29]. Again in the same study, average ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations

Table 2 Comparison of the radionuclide concentration results in the grain products examined in this study with the radionuclide concentration values in the same grain products in different countries (Bq kg^{-1})

Country	Type of samples	Specific activity (Bq kg^{-1})			References
		^{226}Ra	^{232}Th	^{40}K	
Turkey	Wheat	16.84 ± 4.93	29.93 ± 1.85	293.60 ± 42.10	This study
	Oats	34.33 ± 6.75	20.08 ± 2.54	201.71 ± 57.30	
	Barley	15.79 ± 3.70	19.62 ± 2.35	235.20 ± 45.70	
	Wheat flour	10.80 ± 2.37	11.00 ± 2.23	274.10 ± 25.50	
Malesia	Wheat	64.87	49.57	517.05	[28]
	Oats	70.52	48.44	995.90	
	Barley	56.97	34.71	986.02	
Saudi Arabia	Wheat	3.91 ± 0.19	3.20 ± 0.19	139.26 ± 11.97	[29]
	Barley	10.63 ± 0.64	6.33 ± 0.38	178.31 ± 15.33	
Brazil	Wheat	–	–	96	[30]
	Oat	0.75	–	119	
Sudan	Wheat	3.48 ± 1.33	2.79 ± 1.14	95.79 ± 6.85	[31]
Pakistan	Wheat	1.4 ± 0.30	1.3 ± 0.20	122.8 ± 23.10	[32]
Kingdom of Saudi Arabia	Barley	–	–	19.70 ± 0.08	[33]
Sudan	Wheat flour	2.83 ± 0.95	3.19 ± 2.03	118.70 ± 7.12	[31]
Iraq	Wheat flour	6.60 ± 3.71	1.95 ± 1.33	133.10 ± 67.04	[34]
Iraq (Basrah)	Wheat flour	0.19 ± 0.0	0.52 ± 0.00	47.19 ± 0.0	[35]
USA	Wheat flour	89.2 ± 0.70	2.67 ± 0.33	–	[36]

in chicken meat were found in the range of 3.30 ± 0.17–3.56 ± 0.22 Bq kg^{-1}, 2.48 ± 0.16–3.98 ± 0.25 Bq kg^{-1} and 114.86 ± 9.86–166.47 ± 14.32 Bq kg^{-1}, respectively. The mean ^{40}K activity concentration measured in beef and chicken meat in Saudi Arabia appears to be slightly lower than the mean ^{40}K activity concentration in beef and poultry meat from this study. As seen in Table 3, the average ^{226}Ra, ^{232}Th and ^{40}K activity concentrations observed in beef and chicken meats in studies conducted in various countries of the world (Egypt, Brazil, Hong Kong, USA and Iran) were lower than our calculated the average activity concentrations [30, 36–39]. The average ^{40}K activity concentration reported in chicken meat in Turkey are higher than the average ^{40}K activity concentration value obtained in this study [40].

Radioactivity in dairy products samples

The range of ^{226}Ra, ^{232}Th and ^{40}K mean activity in dairy products were found to be 6.09 ± 2.33–11.66 ± 2.00 Bq kg^{-1}, 7.53 ± 2.20–18.12 ± 2.54 Bq kg^{-1} and 87.84 ± 11.9–168.65 ± 17.6 Bq kg^{-1}, respectively. It can also be observed from Table 1 that ^{226}Ra, ^{232}Th and ^{40}K activity levels are the highest in cheddar cheese, whereas ^{226}Ra, ^{232}Th and ^{40}K activity levels of moldy chechil cheese are the lowest. The activity of the radionuclides was found to be higher than the values reported for the studies in several regions by different researchers.

In Table 4, the results of the studies conducted to determine the average ^{226}Ra, ^{232}Th and ^{40}K radioactivity concentrations in cheese in Egypt, Western Europe, Cuba and Iran are lower than the average concentration results we found for cheese [37, 39, 41, 43]. In addition, our results show compatibility with the results of the study conducted in Turkey [42].

Table 3 Comparison of radionuclide concentration results in beef and poultry samples from different countries with radionuclide concentration results in beef and poultry samples examined in this study (Bq kg^{-1})

Country	Type of samples	Specific activity (Bq kg^{-1})			References
		^{226}Ra	^{232}Th	^{40}K	
Turkey	Beef	2.93 ± 0.83	4.24 ± 2.03	206.79 ± 22.50	This study
	Poultry	2.63 ± 0.90	3.41 ± 1.59	190.86 ± 16.80	
Egypt	Beef	–	–	98	[37]
	Chicken	–	–	93	
Brazil	Beef	–	–	80	[30]
	Chicken	–	–	53.5	
Saudi Arabia	Beef	4.53 ± 0.20 – 6.37 ± 0.28	3.47 ± 0.22 – 6.49 ± 0.40	104.86 ± 9.02 – 145.27 ± 12.50	[29]
	Chicken	3.30 ± 0.17 – 3.56 ± 0.22	2.48 ± 0.16 – 3.98 ± 0.25	114.86 ± 9.86 – 166.47 ± 14.32	
Hong Kong	Beef	6.0×10^{-3}	–	91	[38]
	Chicken	6.0×10^{-3}	–	76	
USA	Beef	2.0×10^{-3}	2.0×10^{-3}	–	[36]
	Chicken	1.9×10^{-2}	2.7×10^{-1}	–	
Iran	Beef	5.0×10^{-3}	–	–	[39]
	Chicken	4.6×10^{-2}			
Turkey	Chicken	–	–	309 ± 41	[40]

Table 4 Comparison of average natural radionuclide concentration values in cheese samples examined with average natural radionuclide concentration values in cheese samples in different countries (Bq kg^{-1})

Country	Specific Activity (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Turkey	9.38 ± 2.14	14.21 ± 2.65	129.08 ± 14.20	This study
Egypt	–	–	58	[37]
Western Europe	–	–	15–21	[41]
Turkey	4.6 ± 0.5 – 19.9 ± 1.9	–	36.1 ± 3.5–87.1 ± 8.9	[42]
Cuba	7.2×10^{-3}	7×10^{-4}	123 ± 21	[43]
Iran	5.2×10^{-2}	–	–	[39]

Radioactivity in bakery products samples

Bread, which is the most important wheat product, is of great importance in Turkish society's nutrition due to its high share in total food consumption. Bread is an important food in terms of carbohydrates, minerals, fibres and vitamins. Bread varieties are the products produced in accordance with the bread making technique, including cereal products and bread improvers, as well as the components included in the definition of bread. The mean activity ranges of ^{226}Ra, ^{232}Th and ^{40}K in bakery products samples varied from 13.18 ± 3.85–19.62 ± 4.58 Bq kg^{-1}, 18.15 ± 2.89–23.93 ± 3.75 Bq kg^{-1} and 105.67 ± 29.8–196.33 ± 32.7 Bq kg^{-1}, respectively. The highest concentrations of ^{226}Ra and ^{232}Th were found in whole wheat bread, while the highest ^{40}K value was found in white bread.

The average ^{226}Ra, ^{232}Th and ^{40}K radioactivity concentration values found in the pasta, bread and noodle samples from Iraq (Basrah), Hong Kong, Brazil and the Kingdom of Saudi Arabia are considerably lower than the average ^{226}Ra, ^{232}Th and ^{40}K radioactivity concentrations in the pasta and various breads examined in this study [30, 33, 35, 38]. However, as seen in Table 5, the average ^{226}Ra radioactivity concentration value found as a result of the examination of macaroni in the USA is 5 times higher than the average ^{226}Ra radioactivity concentration value we found for macaroni [36].

Radioactivity in salt samples

Salt is found in natural life as solid rock salt or molten salt water. Solid salts are found in underground salt mines as rock salt. Salt substance today it is used extensively, directly or indirectly, in agriculture, animal husbandry, medicine, traffic and industry, especially in foodstuffs. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in analysed rock salt samples (Table 1) were ranged from 6.32 ± 2.31 to 12.42 ± 4.15 Bq kg^{-1}, 14.65 ± 3.3 to 86.42 ± 5.3 Bq kg^{-1} and 89.5 ± 9.6 to 152.00 ± 24.1 Bq kg^{-1} and the average activity values of these radionuclides were 9.38 ± 4.20, 48.68 ± 5.30 and 116.93 ± 22.7 Bq kg^{-1}, respectively.

As a result of the examination of the radioactivity concentrations in the rock salt samples, it was determined that the average ^{232}Th concentration values were higher than the average ^{232}Th concentration values found in similar studies conducted in some countries given in Table 6 [44–48].

The obtained average ^{226}Ra activity concentration values for rock salt in this study are quite consistent with the ^{226}Ra activity concentration values found in Romania and Iraq [46, 47]. The average ^{40}K activity concentration values for rock

Table 5 Comparison of the results of this study with the average natural radionuclide concentration results in bakery products in different countries

Country	Products Name	Specific activity (Bq kg^{-1})			References
		^{226}Ra	^{232}Th	^{40}K	
Turkey	Macaroni	13.18 ± 3.85	18.45 ± 4.24	105.67 ± 29.80	This study
	Bread	17.66 ± 4.31	22.86 ± 3.83	166.46 ± 30.60	
Iraq	Macaroni	6.08 ± 0.89	21.67 ± 1.31	663.09 ± 12.79	[34]
Iraq (Basrah)	Macaroni	0.72 ± 0.39	0.97 ± 0.99	209.17 ± 71.12	[35]
Kingdom of Saudi Arabia	Macaroni	–	–	7.30 ± 0.07	[33]
Egypt	Macaroni	–	–	36	[37]
USA	Macaroni	70.5 ± 0.8	1.03 ± 0.18	–	[36]
Brazil	Macaroni	–	–	31.9	[30]
	Bread	–	–	39.4	
Hong Kong	Bread	3×10^{-4}	–	38	[38]
	Noodle	9×10^{-3}	–	47	

Table 6 Concentration of radionuclides in salt samples in different countries (Bq.kg^{-1})

Country	Specific activity (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Turkey	9.38 ± 4.20	48.68 ± 5.30	116.93 ± 22.70	This study
Egypt	0.46 ± 0.0–32.6 ± 1.6	0.2 ± 0.0–10.5 ± 0.5	0.42 ± 0.0–158.6 ± 7.9	[44]
Jordan	2 ± 1	9 ± 5	82 ± 57	[45]
Romania	13.29 ± 3.83	28.56 ± 2.31	–	[46]
Iraq	15.90	6.74	1624	[47]
India	BDL–13.30	27.88–45.27	135.54–381.28	[48]

salt samples in Iraq and India are higher than the average ^{40}K activity concentration values we obtained from the rock samples we examined [47, 48].

The absorbed dose rate (ADR), annual effective dose (AED) in analyzed food samples were calculated using Eq. (3) and (4) respectively. As shown in Table 7, the lowest values of both ADR and AED were calculated as 20.50 nGy h^{-1} and 12.57 μSv y^{-1} in moldy chechil cheese, respectively, while the highest ADR and AED values were calculated as 69.54 nGy h^{-1} and 42.77 μSv y^{-1} in wheat, respectively. The obtained mean ADR and AED values in the present study are 23.76 nGy h^{-1} and 14.57 μSv y^{-1}, respectively which are lower than the world average of 57 nGy h^{-1} and 70 μSv y^{-1} respectively and therefore does not pose a serious health risk for people [2].

Table 8 shows that the total ingestion dose (AEID) due to each radionuclide activity ranges from 18.37 (turkey meat) to 195.84 μSv y^{-1} (wheat flour), with an average value of 65.62 μSv y^{-1}. The total annual effective dose due to consumption of these food samples was calculated as 984.32 μSv y^{-1}, which is higher than the world mean value (290 μSv y^{-1}) reported by UNSCEAR (2000) however this

Table 7 Absorbed dose rate (ADR), annual effective dose (AED), lifetime cancer risk (LTCR) of food products consumed of Kars, Turkey

Food group	Food name	ADR (nGy h^{-1})	AED (μSv y^{-1})
Unprocessed cereals	Wheat	69.74	42.77
	Oats	58.10	35.62
	Barley	54.32	33.31
Processed cereals	Wheat Flour	52.68	32.31
	Bulgur	58.27	35.73
	Boiled and dried wheat	43.16	26.46
Animal products	Beef	34.91	21.41
	Goose meat	30.46	18.68
	Turkey meat	33.25	20.39
Dairy products	Cheddar cheese	41.53	25.47
	White chechil cheese	33.28	20.41
	Moldy chechil cheese	20.50	12.57
	Curd cheese	33.51	20.55
Bakery products	Macaroni	32.98	20.23
	White bread	49.74	30.50
	Whole wheat bread	43.87	26.90
	Turkish bagel	40.16	24.62
Salt	Rock Salt	51.06	31.31

Table 8 Annual consumption rate of different food products per capita in Kars and its surroundings, annual effective doses due to consumption of these food samples and lifetime cancer risk (LTCR)

Food group	Food name	Annual consumption (kg y^{-1})	Annual effective dose (μSv y^{-1})				LTCR × 10^{-4}
			^{226}Ra	^{232}Th	^{40}K	Total	
Cereals	Wheat Flour	27.0	81.65	68.31	45.88	195.84	5.45
	Bulgur	4.0	14.75	16.27	6.38	37.89	1.18
Meat	Beef	14.0	11.49	13.65	17.95	43.09	0.97
	Goose meat	15.2	10.00	12.06	17.16	39.22	0.88
	Turkey meat	6.5	5.30	5.04	8.03	18.37	0.40
Cheese	Cheddar	10.5	34.22	43.68	10.96	88.85	3.12
	White chechil	11.0	33.20	37.75	8.81	79.76	2.79
	Moldy chechil	7.8	13.30	13.51	4.25	31.06	1.03
	Curd	5.0	12.59	18.73	4.05	35.37	1.28
Bakery products	Macaroni	6.7	24.73	28.43	4.39	57.55	2.09
	White bread	15.6	68.62	78.15	18.99	165.76	5.60
	Whole wheat bread	9.0	49.44	49.54	7.62	106.60	3.80
	Turkish bagel	2.0	9.37	8.35	1.78	19.51	0.65
Salt	Salt	4.5	11.82	50.38	3.26	65.46	2.79

dose is lower than the limit value (1.0 mSv) recommended by the ICRP [2, 23]. Therefore, consumption of the studied food samples in Kars is radiologically safe in the presence of the investigated radionuclides.

The dose from different food groups decreases in the order cereals > bakery products > salt > dairy products > meat. Of the total effective dose rate, 33% is provided by cereals, 24% by bakery products, 18% by salt, 16% by dairy products and 9% by meat. Since the average consumption rate of cereal products (especially wheat flour) for the local people are higher than the food in the other groups, the effective ingestion absorption dose are found to be higher due to activity of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in cereal products (Fig. 2).

Table 8 shows the calculated values of the LTCR risk to people's health due to each food consumption in the current study. The estimated values of which are equal to 0.40×10^{-4} and 5.60×10^{-4} for turkey meat and white bread, respectively with an average of 2.11×10^{-4}. These values are within the recommended lifetime radiological excess risk of 1×10^{-6} to 1×10^{-4} [49].

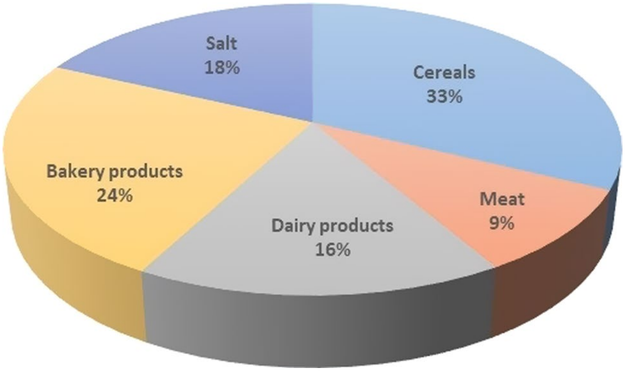

Fig. 2 Average ingestion effective dose values for consumers in investigated food samples

Table 9 shows the reported average effective dose values due to consumption in different food groups for some countries, and the dose values obtained in this study are generally in agreement with the dose values reported in other countries [29, 32–34, 50–58].

Conclusion

In this study, activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides were determined in 90 food samples of 6 kinds produced and frequently consumed in Kars Region of Turkey using NaI(Tl) detector.

Since the total consumption rate of flour and bakery products for the local people is much higher than the consumption of other foods, the ingestion effective dose of all natural radionuclides in the samples of flour and white bread are much higher than the other consumed foods. In addition, since the specific activity values of ^{226}Ra and ^{232}Th radionuclides were higher than the specific activity values of ^{40}K radionuclides in all foods (except meat), it was found that the contribution of ^{226}Ra and ^{232}Th activities to the consumed effective dose was higher. The total annual ingestion effective dose from dietary intake of natural radionuclides are predicted equal to 984.32 μSv y^{-1} in all foods for local consumers. Committed effective dosages obtained from this study are lower than the 1 mSv y^{-1}, the limit recommended

Table 9 Average effective dose values due to consumption in the different groups of foods in Kars region and its comparison with some countries values given in literature

Country	Average effective dose values (μSv y^{-1})								References
	Cereals	Flour	Macaroni	Meats	Dairy Products	Vegetables	Fruits	Salt	
Turkey	37.89	81.65	24.73	33.56	60.57			33.50	This study
Turkey (Elazıg)						20			[50]
Turkey (Rize)							63		[51]
Saudi Arabia	348.83			150.60		369.02			[29]
Iraq		321.3							[34]
Pakistan	216.9								[32]
Sudan	1160			1.0			87		[52]
India	70								[53]
Nigeria				41.24					[54]
Kingdom of Saudi Arabia		3.75	2.33		5.63			0.018	[33]
Japan	17			2.9	4.4				[55]
India (Tamil Nadu)				1.21	12.12				[56]
Pakistan								20.0	[57]
Turkey								4.70	[58]

for the public. The mean calculated cancer risk due to the intake of the studied radionuclides found in food samples was estimated at 2.11×10^{-4}, within the range of acceptable risk values recommended by USEPA. Therefore, there is no radiological risk in the cereals, animal, dairy and bakery products and rock salt samples examined in the Kars region, and the results of this study show that radionuclide intake due to mentioned foods consumption has no harmful effects on public health.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest regarding the publication of this paper.

Consent for publication We confrm that this work is original and has not been published elsewhere, or it is not currently under consideration for publication elsewhere.

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