Kütahya Dumlupınar University
Institute of Graduate Studies

Journal of Scientific
Reports-A
E-ISSN: 2687-6167
Number 47, June 2021

RESEARCH ARTICLE

DETERMINATION of the NATURAL RADIOACTIVITY DISTRIBUTION and CONSUMPTION EFFECTIVE DOSE RATE of CEREAL CROPS in ARDAHAN PROVINCE, TURKEY

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Received Date:19.06.2021 *Accepted Date:14.12.2021*

ABSTRACT

A total of 141 samples; wheat flour samples (66 samples) and cereal product samples (75 samples) such as barley, wheat, vetch, rye and oat collected from local residences, small markets and regional farmers in different districts of Ardahan City were analyzed using a gamma spectrometer with NaI (Tl) scintillation detector. It was observed that the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in wheat flour samples used in the nourishment of living creatures varied between 9.22 ±1.71 - 38.32±5.74 Bq kg^{-1}, 10.53 ± 2.82 - 32.70±2.85 Bq kg^{-1} and 204.31±32.14- 429.54±45.8 Bq kg^{-1}, respectively. Activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K for cereal crops detected are compatible with similar studies conducted in the world. The estimated total annual effective dose, based on intake of ^{226}Ra, ^{232}Th and ^{40}K in cereal crops, ranged from 27.56 ± 5.43 (barley) µSvy^{-1} and 207.32 ± 44.8 (wheat flour) µSvy^{-1}. These values show that the consumption dose rate resulting from the ingestion of cereal crops by the people of the study region is low and no harmful health effects are expected for living things.

Keywords: *Natural radioactivity, NaI(Tl) detector, Cereal crops, Wheat flour, Consumption dose.*

1. INTRODUCTION

People are constantly and inevitably exposed to naturally sourced ionizing radiation throughout their lives. Cosmo genic nuclides were formed by high-energy cosmic rays coming into the atmosphere and radioactive nuclides found in the various degrees in the earth's crust are the two main sources of ionizing radiation. Therefore; determining the levels of radioactivity created by natural and artificial radionuclides in the environment is of great importance in determining the effects of both terrestrial and artificial ionizing radiation that people are exposed to [1, 2]. Natural radiation sources constitute approximately 80% of the total radiation dose exposed to the world population. The annual average effective dose that the world population is exposed to it from natural radiation sources has been reported by UNSCEAR (United Nations Scientific Committee on the Effect of Atomic Radiation) is 2.4 mSvy^{-1} per person [3].

Many investigations have been performed entire of the globe to work out the activity concentrations of natural radionuclides in environmental specimens and to calculate the radiation dose exposed from them. Gamma spectrometric analysis of Pakistan's soil samples and food products (such as wheat, potatoes) used by local people in their daily diets was performed using a high-pure germanium (HPGe) detector. Average activity concentrations in soil samples were measured as 56.2 Bqkg^{-1}, 58.5 Bq kg^{-1}, 851.9 Bqkg^{-1} and 13.39 Bqkg^{-1} for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, respectively. In addition, the transfer factors of these radioactive nuclides from soil to food products were also studied in this study. Transfer factors of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs radioactive nuclides to food products were found as 0.17, 0.07, 0.16 and 0.23, respectively [4]. Activity concentrations of natural radionuclides in wheat samples collected from agricultural lands in India were determined using gamma spectrometer with HPGe detector. Mean activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K were calculated as 0.7, 1.1 and 102.9 Bqkg^{-1}, respectively [5]. Ballesteros et al. in 2015 carried out evaluations on typical foods from all over Spain in Environmental Radioactivity Laboratory (LRA), within the trackt of various monitoring programmes supported by the Generalitat Valenciana, in Spain. They analysed a total of 2200 samples of fruits, grains, vegetables, fish, milk, eggs and meat from markets and small producers. They analysed all samples with gamma ray spectrometry and detected ^{40}K in all samples [6].

The ^{226}Ra, ^{232}Th and ^{40}K activity concentrations and distributions of barley, wheat, vetch, rye and oat cereal crops obtained from local farmers in Ardahan province and its surrounding districts were determined. As a result of the recently changing nutrition habits in our country, as in the world, cereal crops are used as an ingredient in various healthy foods in human nutrition. Therefore, determining the natural radioactivity levels of cereal crops consumed by human beings is great importance for human health. In addition, cereal crops grown in the region are widely used in sheep growing, cattle breeding and poultry farming. It will be beneficial to examine the foods such as meat, milk, cheese and eggs obtained from these animals in the terms of environmental health as they are consumed by local people and people living in different regions of our country for nutritional purposes.

2. MATERIALS AND METHODS

2.1. Sample collection

In this work, a total of 75 barleys, wheat, vetch, rye and oat samples grown in different districts of Ardahan province and widely used in animal husbandry were taken from local farmers in the study area, each at least 3 kg.

Figure 1. Stations where wheat flour and feed crops are obtained.

The wheat grown in the study area is transformed into flour and is mostly used by the local people for making bread, pasta and bakery products. Total of 66 wheat flour samples were obtained from 15 different stations in the study area, each at least 2 kg. The stations where wheat flour samples and cereal crops were collected are shown in Figure 1.

2.2. Gamma-ray spectrometry analysis

All collected samples were brought to the laboratory in labeled plastic bags. Samples were thoroughly purified from impurities in them. The samples pulverized with the mixer were sieved and oven dried at 105 °C for 24 hours [7]. Subsequently, the samples were placed in a 100 ml volume, 65x55 mm in size, transparent pathological sample containers with tared screw caps and weighed with precision scales and recorded in kilograms [8]. Samples were stored in sample containers for forty days to ensure stabilize between ^{226}Ra, ^{232}Th and their short-lived degradation [7, 8]. Gamma spectrometric analyzes of ^{226}Ra, ^{232}Th and ^{40}K radionuclides were performed using 3"x3" NaI (Tl) scintillation detector with 20% relative efficiency and ScintivisionTM-32 (A35-B32) computer program. Energy and relative efficiency calibration of the gamma spectrometer were defined using IAEA-375 (standard calibration material) [9]. The minimum detectable activity (MDA) was approximately 5.50, 2.88 and 60.1 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively.

For the calculation of the activity concentrations, the areas under each photo peak were chosen, taking into account the corresponding photo peaks at various energies. While calculating the net peak area, in order to calculate the external contributions, the natural background was 86400 seconds to determine the activity of the background and samples. The gamma peak of 1460 keV was analyzed to calculate the ^{40}K activity concentration. ^{226}Ra concentration was determined by measuring 609, 1120 and 1764 keV gamma rays from ^{214}Bi, while gamma rays at 583 and 2614 keV from ^{208}Tl were used to determine the activity concentration of ^{232}Th [10].

3. RESULTS AND DISCUSSION

3.1. Radioactivity in wheat flour and cereal crops

When the flour samples in the study area were examined, the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were found to be 12.00 ± 2.40 Bq kg^{-1}, 12.41 ± 2.50 Bqkg^{-1} and 314.62 ± 21.6 Bqkg^{-1}, respectively. The minimum value of ^{226}Ra activity concentration was found to be 9.22 ± 1.71 Bqkg^{-1} and the maximum value of 16.12 ± 2.61 Bqkg^{-1} in the examined wheat flour samples, while the lowest value of ^{232}Th activity concentration was found to be 7.23 ± 1.91 Bqkg^{-1} and the highest value was found to be 19.50 ± 2.50 Bqkg^{-1}. In wheat flour samples consumed daily by humans, ^{40}K activity concentration was measured as the lowest 185.72 ± 26.20 Bqkg^{-1} and the highest 446.11 ± 25.20 Bqkg^{-1}.

The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in studied cereal crops were obtained as 16.97 ± 3.90 Bqkg^{-1}, 20.66 ± 2.55 Bqkg^{-1}, 245.42 ± 46.81 Bqkg^{-1} for barley samples; 18.05 ± 4.93 Bqkg^{-1}, 30.97 ±1.88 Bqkg^{-1}, 303.64 ± 42.73 Bqkg^{-1} in wheat samples; 18.95 ± 2.47 Bqkg^{-1}, 18.14 ± 2.05 Bqkg^{-1}, 360.52 ± 36.42 Bqkg^{-1} in vetch samples; 16.85 ± 2.97 Bqkg^{-1}, 14.64 ± 2.61 Bqkg^{-1}, 411.91 ± 45.63 Bqkg^{-1} in rye samples and finally 24.37 ± 5.04 Bqkg^{-1}, 21.48±2.34 Bqkg^{-1}, 212.21 ± 57.64 Bqkg^{-1} in oat samples, respectively.

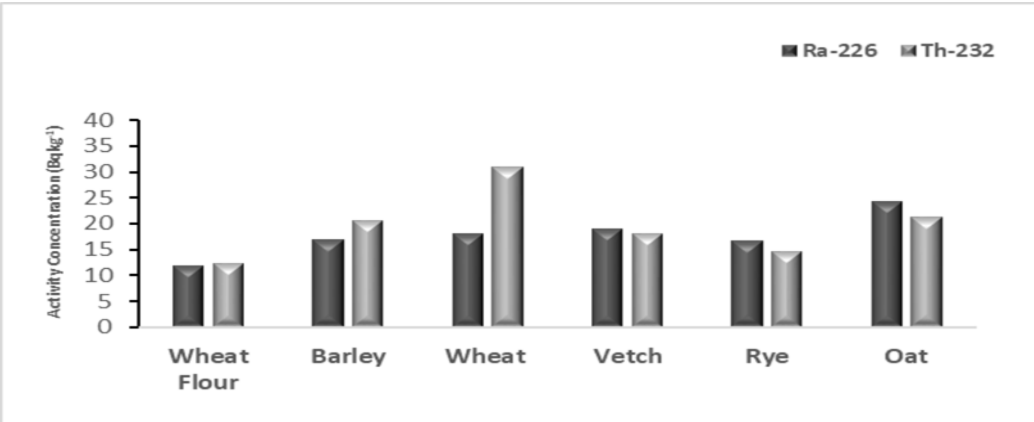

Figure 2. The average activity concentrations of ^{226}Ra and ^{232}Th in wheat flour and cereal crops.

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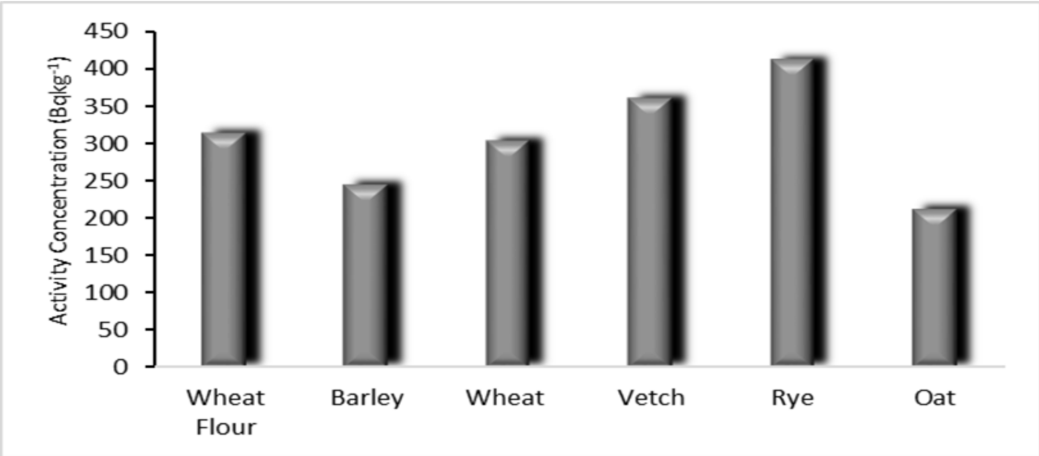

Figure 3. Distribution of ^{40}K in wheat flour and cereal crops taken from the study area.

As can be seen in Figures 2 and 3, the lowest ^{226}Ra and ^{232}Th activity concentrations were evaluated in the wheat flour specimens and the lowest ^{40}K activity concentrations were measured in the oat samples. The highest ^{226}Ra, ^{232}Th and ^{40}K activity concentrations were measured in oat, wheat and rye samples, respectively.

In Table 1, the comparison of the average values of natural radioactivity levels of wheat flour and cereal crops collected from the study area with the values reported in some studies in the literature were given. In this study, the average activity concentrations of ^{232}Th and ^{40}K for wheat flour, barley, wheat, vetch, rye and oats were lower than the average activity concentrations reported for pasture crops in Digor district of Kars province, but average activity concentrations of ^{226}Ra for wheat vetch and oat were higher than reported values [11].

In the study that carried out in the Gediz Basin, the ^{226}Ra and ^{40}K activity concentrations for corn samples were presented 25.82 ± 2.3 Bqkg^{-1} and 491.62 ± 52.61 Bqkg^{-1}, respectively [12]. For the cabbage samples examined in the Western Anatolia region, the activity concentrations of ^{232}Th and ^{40}K were reported as 45.5 ± 5.2 Bqkg^{-1} and 766.0 ± 40 Bqkg^{-1}, respectively [13]. It is seen that our obtained mean activity concentrations values for all examined cereal samples were below their reported activity concentrations values.

In this work the average activity concentrations of ^{232}Th for wheat flour and cereal crops were found to be higher than the activity concentration of ^{232}Th in market tea in Turkey [14]. The ^{40}K activity concentrations in the examined wheat flour were found to be higher than the ^{40}K average activity concentrations in wheat flour in West Anatolia and Iraq [13, 15].

When compared the results of this study with the studies conducted in different regions of the world, it was observed that the ^{226}Ra, ^{232}Th and ^{40}K obtained activity concentrations for wheat samples were higher than the activity concentrations in the wheat samples reported for Pakistan, India, Spain, Iraq and Egypt [4-6, 16,17]. The ^{40}K activity concentration was measured for the barley samples was found to be consistent with the ^{40}K activity concentration of the barley samples reported for Iraq [16].

Table 1. Comparison of the average valuations of natural radioactivity levels of plant samples with the with the valuations informed in the published works.

			Activity concentrations (Bqkg^{-1})		
References	**Region Worked**	**Name of Samples**	**^{226}Ra**	**^{232}Th**	**^{40}K**
This work	Ardahan	Wheat flour	12.0 0 ± 2.40	12.41 ± 2.50	314.62 ± 21.60
This work	Ardahan	Barley	16.97 ± 3.90	20.66 ± 2.55	245.42 ± 46.81
This work	Ardahan	Wheat	18.05 ± 4.93	30.97 ± 1.88	303.64 ± 42.73
This work	Ardahan	Vetch	18.95 ± 2.47	18.14 ± 2.05	360.52 ± 36.42
This work	Ardahan	Rye	16.85 ± 2.97	14.64 ± 2.61	411.91 ± 45.63
This work	Ardahan	Oat	24.37 ± 5.04	21.48 ± 2.34	212.21 ± 57.64
[11]	Digor	Pasture plant	17.9 ± 10.4	75.9 ± 19.5	630.6 ± 12.3
[12]	Gediz	Corn	25.82 ± 2.34		491.62 ± 52.61
[13]	West Anatolia	Cabbage		45.5±5.2	766.0 ± 40
		Wheat flour	6.1 ± 5.8		128 ± 45
[15]	Iraq	Wheat flour		1.94 ± 1.33	133.09 ± 67.04
[14]	Turkey	Market Tea		5.9 ± 1.7	766.0 ± 40
[5]	India	Wheat	0.7 ± 0.1	1.1 ± 0.02	102.9 ± 9.8
[6]	Spain	Barley			78.0–222.4
		Wheat			67.0–122.6
[4]	Pakistan	Wheat	3.7	8.4	130.7
[16]	Iraq	Barley	1.92 ± 0.36	1.94 ± 0.34	242.22 ± 10.76
		Wheat	1.46	1.38	180.54 ± 8.52
[17]	Egypt	Wheat	1.00- 1.55	1.05- 1.20	103.0- 120.3

3.2. Consumption dose to human being

The annual effective dose that indicates the importance of the stochastic health impacts for the whole body. The annual effective dose due to radionuclide intake through food ingestion can be calculated if the amount of activity concentration of certain radionuclides deposited depending on the food stuff and the annual average consumption rate are known.

The annual committed effective dose ACD_{eff} (μSv y^{-1}) of radionuclides to human beings owing to the consumption of cereal crops are reckoned with the equation 1 [18];

$$ACD_{eff} = A_C \times I_C \times F_{DC} \quad (1)$$

where A_C is the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in cereal crops (Bq kg^{-1}); F_{DC} is the dose conversion factor for ^{226}Ra, ^{232}Th and ^{40}K radionuclides (Sv Bq^{-1}) and I_C is the annual consumption rate of the cereal crops (kg y^{-1}). The amount of cereal crops consumption rates was obtained from published report of Turkish Statistical Institute (TUİK) in 2020 [19]. The values dose

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conversion factors due to the ingestion of ^{226}Ra, ^{232}Th, and ^{40}K from cereal products for adults are 2.8x10^{-7} Sv Bq^{-1}, 2.3x10^{-7} Sv Bq^{-1} and 6.210^{-9} Sv Bq^{-1}, respectively [20]. Annual consumption rates of wheat flour and cereal products per person (kg y^{-1}) in Ardahan region of Turkey and the effective dose values calculated owing to ingestion of these foodstuffs are shown in Table 2.

The annual effective dose in µSv y^{-1} due to the consumption of cereal crops by adults were calculated using equation 1. The mean values and ranges of annual effective doses owing to intake of ^{226}Ra, ^{232}Th, and ^{40}K from consuming cereal crops were determined as 31.95± 8.88 (10.05–102.45) µSv y^{-1}, 29.91 ± 3.45 (8.23–89.93) µSv y^{-1}and 15.02 ± 6.66 (2.50–55.61) µSv y^{-1}, respectively. According to the existence of natural radionuclides in the collected wheat flour samples, the average of ingestion effective dose was calculated as 207.32 µSv y^{-1}. These calculated values are less than 321.3 µSvy^{-1}, which is the average annual effective dose value found as a result of studies carried out with wheat flour in Iraq and is also very compatible with the average annual effective dose value (213.1 µSv y^{-1}) in Pakistan [15, 21].

Cereal products are mostly used in the feed industry. However, as a result of changing dietary habits, cereal plants are used as an ingredient in various healthy foods. The annual effective dose, has a minimum value in barley grain due to least consuming by adults in Turkey. Depending on the consumption of wheat and barley, the annual effective consumption dose rate calculated as 20.60 µSv y^{-1}in this study, lower than the average annual effective consumption dose rate (67.73 µSv y^{-1}) for the same cereal products in Iraq [22]. From those results, it can be concluded that the annual consumed effective dose for ^{40}K, ^{232}Th and ^{226}Ra in examined cereal crop samples is lower than the allowable limits of 1 mSv y^{-1} by the International Radiological Protection Commission [23].

Table 2. Annual per capita consumption rate of some cereal products in Ardahan and its surroundings and annual effective doses depending on the consumption of these products.

Cereal Crops Name	Annual Consumption (kg y^{-1})	Annual Effective Dose (µSv y^{-1})			
		^{226}Ra	^{232}Th	^{40}K	Total
Wheat Flour	25.4	85.34	72.44	49.54	207.32
Barley	2.5	11.88	11.87	3.80	27.56
Wheat	5.8	29.31	41.31	10.92	81.54
Rye	2,7	12.74	9.09	6.90	28.73
Oat	3.0	20.47	14.82	3.95	39.24

4. CONCLUSION

In this study, the natural radioactivity levels of a number of 141 wheat flour and cereal crops samples which are collected from Ardahan province and its surrounding districts were determined using NaI (Tl) scintillation detector. The lowest ^{226}Ra and ^{232}Th activity concentrations were measured in the rye samples and the lowest ^{40}K activity concentrations in oat samples in crops. The highest ^{226}Ra, ^{232}Th and ^{40}K activity concentrations were measured in oat, wheat and rye samples, respectively. These different natural radioactive activity values obtained in the samples which examined can be explained by the physicochemical properties of the soil in whic cereal crops are grown, the transfer factors of radioactive nuclides from the soil to cereal crops and the metabolic features of these plants. In addition, the amount of organic fertilizers and chemical fertilizers used to increase soil fertility and plant production by affecting the stable element content of the soil are among the reasons for the differences in the natural radioactive activity values in the samples examined. The radiation dose from the consumption of wheat flour and some cereal products has been found, to be lower than the annual world average of 290 μSv y^{-1} therefore, consumption of these crops has not been found, not to pose a threat to public health. The findings obtained from this study can be utilized as reference data to help identify likely changes in environmental radioactivity from nuclear, industrial and other people activities .

ACKNOWLEDGEMENTS
This study was supported as financial by Kafkas University Scientific Research Projects Coordinator ship (BAP 2017FM25).

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