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CENTRAL ASIAN STUDIES

Measuring the Risk Factors of Radionuclides and Their Radioactivity for Food Items Collected from Local Markets in the City of Hilla-Iraq

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Abstract: In this study, the concentration of natural radionuclide activity, risk factors, and annual effective dose in 18 samples of consumer food in the city of Hilla were calculated using a gamma-ray detector due to the high degree of accuracy in the spectroscopic measurement of the detector. The average activity concentrations of ^{232}Th, ^{238}U, and ^{40}K were found to be 9.67±0.149, 6.08±0.145, and 220.21±0.895 Bqkg^{-1}, respectively. The average radium equivalent activity in all samples was calculated as 36.87 Bqkg^{-1}, which is less than the permissible limit of 370 Bqkg^{-1}. The average values of the external risk indicators and internal risk indicators for the food samples were 0.10 and 0.12, respectively, which are less than unity in all models, which indicates that nutritional models are not harmful. The average gamma hazard index ($I\gamma$) was determined to be 0.28. The average annual effective dose equivalent was calculated as 135.67 μSvy^{-1}, It is less than the permissible limits recommended by the United Nations Committee on the Effects of Radiation. Radiation is 1000 μSvy^{-1}. These results may be useful for creating a database to evaluate the concentration of natural radioactivity in foodstuffs consumed in the city of Hilla.

Keywords: radioactivity, gamma spectrometer, risk factors, radium equivalent, food items.

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1. Introduction

Radioactive isotopes of the elements, or natural radionuclides, are found in the human body, food, and water. Natural radionuclides, including potassium, carbon, radium, and their decay products, can be found in trace amounts in some foods, but the amounts of radiation found in these foods are so small that they do not cause any harm [1]. There are multiple pathways for radioactivity to contaminate food and water. Plant roots can take it up from the soil, airborne particles can fall on crops, and animals can bioaccumulate it if they eat or drink plants, feed, or water that contains radioactive material [2]. Additionally, nuclear research facilities, military training facilities, civilian nuclear operations, and weapons manufacturers all contribute to environmental radioactive waste, which in turn contaminates food and water [3]. Radionuclides, both naturally occurring and artificially produced, can enter the food chain in the same manner as non-radioactive substances, whether they are naturally occurring or man-made [4,5]. The effects on human health are dose- and time-dependent for radionuclides. Radiation can be found in water and food, and the amount of naturally occurring radionuclides can change depending on things like weather and farming methods [6]. Radionuclides like uranium-238, uranium-234, radium-226, radium-228, lead-210, polonium-210, and thorium isotopes are the primary sources of the naturally occurring radioactivity in foods that exposes humans to radiation. Among man-made

radionuclides, caesium-137 is a key component in forest-based foods. Radionuclides are absorbed by plants and animals because they have chemical properties with nutrients[7]. This study aims to clarify the levels of radionuclide activity in several local food samples that represent the typical diet of the local residents of Hilla city. Babylon Health Department statistics indicate that the rationale for choosing to calculate radioactivity in the region is the increase in cancer rates. Hence, it was expected to contribute significantly to the total effective dose per year. A specialized spectroscopic approach using a NaI(Tl) spectrometer system was used to do this, among other measurement techniques to calculate the activity level of the radionuclides (^{232}Th, ^{40}K, and ^{238}U). While there are standards for goods traded abroad that contain artificial radioactive chemicals set by the Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA) [8], there are no such standards for domestically sourced food.

2. Materials and Method

2.1. Collection and preparation of samples

During the experiment year (2023), we collected eighteen samples of vegetables, fruits, grains, leafy vegetables, and milk from local markets in the city of Hilla, as shown in Table 1. We properly dried the collected samples to enable grinding them into powder. To create a consistent matrix for the reagent, we passed the crushed samples through a fine mesh sieve with a mesh size of 2 μm. This process removed any contaminants and yielded a fine-grained sample. After the samples' weights are recorded using a digital weighing scale, they are carefully packed in a nylon bag and marked with their respective names, weights, sample codes, and preparation dates, and then stored for approximately 30 days to achieve a secular balance between the ^{238}U and ^{232}Th series and their descendants. A NaI (Tl) spectrometer system was used to measure the radioactivity of the samples.

Table 1. Scientific names and symbols used to denote some foodstuffs in this study

No.	Commercial appellation	Scientific name	Specimen code
1	Sweet potato	*Solanum tuberosum*	FI_1
2	Banana	*Musa sp.*	FI_2
3	Sugar	*Saccharose sp.*	FI_3
4	American walnut	*Jugulans sp.*	FI_4
5	Wheat	*Triticum aestivum*	FI_5
6	Hummus	*Cicer arietinum*	FI_6
7	Lentils	*Lens culinaris*	FI_7
8	Beans	*Vicia faba*	FI_8
9	Cowpeas	*Vigna sp.*	FI_9
10	Powder Milk (Dialac)	------	FI_{10}
11	Powder Milk (Almudhish)	------	FI_{11}
12	Rice (Mahmoud)	*Oryza sp.*	FI_{12}
13	Rice (Basmati)	*Oryza sp.*	FI_{13}
14	Maize	*Zea mays*	FI_{14}
15	Spinach	*Spinacia oleracea*	FI_{15}
16	String beans	*Phaseolus vulgaris*	FI_{16}
17	Khistawi dates	*Phoenix dactylifera*	FI_{17}
18	Cucumber	*Cucumis sativus*	FI_{18}

2.2. Dose evaluation procedures

There is a basic divide within the field of radiation exposure assessment that classifies radiation dosage as either exterior or internal. Radiation is mostly classed

according to the spatial relationship between the source and the human body [9,10]. The "external dose" is the amount of radiation that an individual is exposed to when it comes from outside sources. Direct exposure to gamma radiation or interaction with items or materials containing radioactive compounds are two external sources of radiation that people might be exposed to. Internal radiation exposure, on the other hand, occurs when the radiation source is located inside the body [11]. A person usually experiences this kind of exposure by inhaling air polluted with radioactive particles or drinking water contaminated with radioactivity. As well as other pertinent characteristics, the International Commission on Radiological Protection (ICRP) supplies dosage coefficients for the target radionuclide [12,13]. These are commonly used in analytical procedures to determine exposure dosages, both internally and externally [14].

2.3. Experiment environment

An experimental setup consisting of a (3x3) inch NaI(Tl) scintillator detector was employed in this study. This detector is a gamma-ray detector that is widely used because of its strong light output and consistent energy resolution. An analog-to-digital converter (ADC) was employed to convert the optical signals from the detector into digital information. Prior to measuring the samples, background radiation was evaluated at the laboratory site using the same container used for gamma spectrum analysis. The backdrop and sample both required the same length of time to count, which was 18000 seconds. Accurate activity assessments from samples cannot be obtained without first assessing background radiation. This is especially true for all samples of food products. The procedure began with an energy efficiency calibration using a variety of standard radioactive sources, such as ^{60}C0, ^{133}Ba, ^{57}Co, ^{137}Cs, and ^{22}Na. Accurate power measurements can be achieved with the help of this calibration procedure [15,16].

3. Mathematical formulas in theoretical calculations

The concentration of naturally occurring radionuclides and their risk factors can be determined simply by calibrating the efficiency of the nuclear detector and detecting background radiation. In order to determine the potential danger of breathing or ingesting certain radioactive elements, the (ICRP) provides dose factors, also called "equivalent" and "effective dose" [17]. On the other hand, bioassay data (measurements taken inside the body) makes choosing the appropriate dosage parameter more complex. Several elements play a role here, including the type of radioactive material, its physical form (such as particle size), the route of entry (breathing or swallowing), and the amount of radioactive material and the time it was in the body [18]. These coefficients are explained in the following formulas:

*3.1. Specific activity (**A**)*

To determine the activity concentration of a specific radionuclide in the samples that were measured, the following factors are taken into account: the absolute full-energy peak efficiency for the energy that is of interest, the counting time, the number of counts under the full-energy peak areas (after correction for background peak areas), and the gamma-ray emission probability that corresponds to the peak energy [19]. The following formula gives the specific activity of radionuclides in samples:

$$\text{Specific Activity (Bq/Kg)} = \frac{N_{net}}{t \times \varepsilon \times I_{\gamma} \times W} \quad (1)$$

where:

A = activity of the sample in BqKg-1

ε = the counting efficiency of the gamma energy

Iγ = absolute intensity of the gamma ray and

W = net weight of the sample (gm).

3.2. Equivalent of Radium-232 (Ra_{eq})

The radium equivalent activity (Ra_{eq}) is a standard radiological indicator that measures the real activity level of ^{238}U, ^{232}Th, and ^{40}K in samples. It is used to account for the nonuniform distribution of natural radionuclides in samples [20] by the expression:

$$Ra_{eq}=1.0CU+1.430CTh+0.0770CK \quad (2)$$

where C_U, C_{Th}, and C_K are the specific activities of ^{238}U, ^{232}Th, and ^{40}K, respectively, in $Bqkg^{-1}$. The maximum allowable radium equivalent activity is 370 $Bqkg^{-1}$.

3.3. Absorbed dose rate in air (AD)

The absorbed dose rate at one meter above ground level is a direct relationship between concentrations of natural radioactivity and exposure to this radiation. The following formula is used to compute the absorbed dose rate based on the mean activity concentrations of ^{232}Th, ^{238}U, and ^{40}K ($Bqkg^{-1}$) [21] in the samples:

$$AD(nGy/h) = 0.4620A_U + 0.6210A_{Th} + 0.041070A_K \quad (3)$$

where AD is the dose average and A_U, A_{Th}, & A_K are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K.

3.4. Representative Level Index ($I\gamma$)

The Representative Level Index, or $I\gamma$, is a crucial statistic to take into account when evaluating the potential risks of gamma radiation from naturally occurring gamma emissions in materials. Estimating the $I\gamma$ (representative gamma index) danger associated with naturally occurring radio-elements in a certain chemical is usually done using the representative gamma index [22] as the equation indicates:

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (4)$$

3.5. Radiation Hazard Indices calculation

The External Hazard Index, or H_{ex}, is the term used to describe external exposure to gamma rays in the field of study. The following formula can be used to determine the value of external risks resulting from short-term food consumption [23]:

$$H_{ex}= \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

Radon and its short-lived derivatives can damage respiratory organs when inhaled. The Indoor Risk Index is a tool to evaluate exposure to radon and its derivatives found in foodstuffs, which is calculated using the following formula [24]:

$$H_{in}= \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

3.6. Annual effective dose equivalent

To calculate the annual effective organ equivalent dose, a conversion ratio of 0.70 Sv/Gy was used. This was used to convert the absorbed dose rate in air to an effective human dose, 0.20 for the outdoor occupancy factor suggested by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2020/2021) [25] This dose is obtained from food samples consumed and under study and is calculated in this way:

$$\mathrm{AEDE_{outdor}} = \mathrm{D_{out}} \times 1.2264\times10^{-3}\,(\mathrm{mSv/y}) \quad (7)$$

$$\mathrm{AEDE_{indoor}} = \mathrm{D_{in}} \times 4.9056\times10^{-3}\,(\mathrm{mSv/y}) \quad (8)$$

One of the most important instruments for assessing possible risks to health from ionizing radiation exposure is the AEDE parameter, which gives an annualized measurement of the effective dose equivalent in milliseconds (mSv/y). It is possible to estimate the annual effective dose D to persons from radio-nuclide ingestion using the following equation [26]:

$$\mathrm{H_{eef}} = \mathrm{A}\times\mathrm{I}\times\mathrm{E} \quad (9)$$

where:

H_{eff} = the annual effective dose due to natural radioactivity resulting from eating foodstuffs in units (Sv y^{-1})

A = radionuclides (^{238}U, ^{232}Th, and ^{40}K) in units (BqKg^{-1}).

I = annual food consumption in (Kgy^{-1}).

E = Radionuclide dose conversion factor (^{238}U, ^{232}Th, ^{40}K) in (Sv Bq^{-1}) [27].

According to ICRP (1990), the conversion factor E changes depending on the radioisotope and the age of the individual[13]. The conversion factor value specified by the International Commission on Radiological Protection was (0.0062) Sv/Bq for ^{40}K, and the conversion factor for ^{238}U was (0.045) Sv/Bq. Finally, the conversion factor for ^{232}Th was (0.23) Sv/Bq, depending on the age groups [28].

4. Results and Discussion

4.1. Concentrations of radionuclides in some essential consumer foods

Table 2 shows the results of activity effectiveness measurements taken on staple foods, fruits, and vegetables in Hilla City. The activity content of 238U in swamp cabbage varied between 1.49±0.913 Bq/kg for (FI1) and 11.7±0.176 Bq/kg for (FI9) among all the gathered and examined food items. The amount of ^{232}Th activity in common foods varies from 4.74±0.064 Bq/kg for (FI_8) to 15.06±0.011 Bq/kg for (FI_1). The concentration of ^{40}K activity varied between 20.989±0.21 Bqkg^{-1} for (FI_{16}) and 369.52±1.416 Bqkg^{-1} for (FI_{11}). The ^{40}K concentration is significantly higher than that of ^{238}U and ^{232}Th. The fact that radium and thorium do not easily move from soil to vegetables in their respective environments might be to blame[29]. The concentration of potassium may be high since it is a macronutrient. It is often believed that certain soil qualities facilitate the uptake of potassium by plants. The concentration of potassium activity was higher in vegetables compared to fruits, which in turn had a higher concentration of potassium than in grains and legumes.

Table 2. Concentration of natural radionuclides in some consumer food samples

Number	Specimen Code	Specific Activity [Bq/kg]		
		^{40}K	^{238}U	^{232}Th
1	FI_1	243.9±0.824	1.49±0.913	15.06±0.011
2	FI_2	136.33±0.890	3.54±0.231	7.23±0.013

3	FI_3	111.08±0.703	2.98±0.145	8.59±0.072
4	FI_4	330.17±0.366	4.75±0.011	9.33±0.009
5	FI_5	254.49±0.858	9.80±0.062	9.14±0.008
6	FI_6	286.82±1.246	8.2±0.074	12.97±0.049
7	FI_7	217.98±0.833	9.8±0.07	10.87±0.06
8	FI_8	245.43±0.441	4.65±0.034	4.74±0.064
9	FI_9	351.52±1.36	11.7±0.176	11.72±0.08
10	FI_{10}	120.05±0.741	6.03±0.026	12.75±0.005
11	FI_{11}	369.52±1.416	8.4±0.203	13.59±0.164
12	FI_{12}	283.1±1.932	3.23±0.006	5.908±0.007
13	FI_{13}	39.055±0.36	4.16±0.005	6.948±0.057
14	FI_{14}	271.17±1.001	5.9±0.055	12.03±0.107
15	FI_{15}	229.22±0.773	7.36±0.03	7.109±0.006
16	FI_{16}	20.989±0.21	4.95±0.158	8.604±0.037
17	FI_{17}	151.55±0.85	3.15±0.001	9.52±0.053
18	FI_{18}	301.38±1.32	9.4±0.203	8.03±0.105
Average		220.21±0.895	6.08±0.145	9.67±0.149

4.2. Radiological indices

Table 2 shows the results of radiation parameters such as radium equivalent (Ra_{eq}), absorbed dose rate (D), internal hazard index (H_{in}), hazard index (H_{ex}), and annual effective dose equivalent (AEDE) to estimate the radiation risk. In consumer food samples in the city of Hilla for the presence of ^{226}Ra, ^{232}Th, and ^{40}K. It was discovered that the levels of activity equivalent to radium differed in all samples, ranging from the highest value of 56.29±9.65 to the lowest value of 3.52±7.95, with an average for all samples of 36.87±7.9 in $Bqkg^{-1}$ units. These results fall within the upper limit allowed internationally in the report of the Scientific Committee on the Effects of Atomic Radiation of the United Nations, which is 370 $Bqkg^{-1}$[30]. The values of the external and internal risk indicators for all samples were less than one[30], ranging from 0.05±0.02 to 0.15±0.03 with an average value of 0.10±0.02, and from 0.06±0.02 to 0.18±0.04 with an average value of 0.12±0.03, indicating no risk to humans. The radionuclides present in the consumer foodstuffs of the study samples had a gamma hazard index of approximately 0.28±0.06, The estimated values for all samples are less than six, which is the value recommended by the United Nations Committee on the Effects of Radiation[30]. The equivalent annual effective dose has been calculated from 57.588±7.585 μSvy^{-1} to 210.61±14.51 μSvy^{-1} with an average value of **135.67±11.64 μSvy^{-1},** respectively, which is less than the recommended value for the United Nations Committee on the Effects of Radiation, which is 1000 μSvy^{-1}[25].

Table 3. Results of radiation risk coefficients and annual effective dose in food samples

Specimen Code	Radium Equivalent Activity (Raeq) (Bqkg-1)	External Hazard Index (Hex)	Internal Hazard Index (Hin)	The Representative Level Index (Iγ)	Absorbed Dose rate (D) **(nGy/h)**	AEDE (**μ**Svy-1)
FI1	41.81±7.97	0.11±0.02	0.12±0.02	0.32±0.06	20.21±3.6	152.69±12.35
FI2	24.38±6.63	0.07±0.02	0.08±0.02	0.19±0.05	11.81±3.0	87.978±9.376
FI3	23.82±6.73	0.06±0.02	0.07±0.02	0.18±0.05	11.34±3.1	84.38±9.182
FI4	3.52±7.95	0.12±0.02	0.13±0.03	0.35±0.06	21.76±3.7	164.6±12.82
FI5	42.47±8.68	0.11±0.02	0.14±0.03	0.33±0.06	20.82±4.0	157.35±12.54

FI6	48.83±9.32	0.13±0.03	0.15±0.03	0.38±0.07	23.8±4.30	180.36±13.42
FI7	42.13±8.98	0.11±0.02	0.14±0.03	0.32±0.06	20.37±4.1	153.9±12.40
FI8	30.33±6.48	0.08±0.02	0.09±0.02	0.24±0.05	15.33±3.0	115.06±10.72
FI9	55.53±9.76	0.15±0.03	0.18±0.04	0.43±0.07	27.34±4.5	207.62±14.4
FI10	33.51±8.41	0.09±0.02	0.11±0.03	0.25±0.06	15.71±3.8	118.02±10.86
FI11	56.29±9.65	0.15±0.03	0.17±0.03	0.44±0.07	27.73±4.4	210.61±14.51
FI12	33.48±6.57	0.09±0.02	0.1±0.02	0.27±0.05	16.97±3.0	127.7±11.30
FI13	17.10±6.29	0.05±0.02	0.06±0.02	0.12±0.04	7.865±2.8	57.588±7.585
FI14	43.98±8.66	0.12±0.02	0.13±0.03	0.34±0.06	21.5±4.0	162.65±12.75
FI15	35.18±7.69	0.09±0.02	0.11±0.03	0.27±0.05	17.37±3.5	130.83±11.43
FI16	18.87±6.77	0.05±0.02	0.06±0.02	0.13±0.05	8.505±3.0	62.518±7.903
FI17	28.43±7.13	0.08±0.02	0.09±0.02	0.22±0.05	13.69±3.2	102.43±10.12
FI18	44.10±8.45	0.12±0.02	0.14±0.03	0.34±0.06	21.9±3.9	165.68±12.87
Average	36.87±7.9	0.10±0.02	0.12±0.03	0.28±0.06	18±4.2	135.67±11.64

5. Conclusions

For this study, gamma spectrometry was the best way to find out how much ^{232}Th, ^{238}U, and ^{40}K was in different types of food because it had the best detector resolution and didn't change the nature of the samples like spectrophotometry did. It works very well for detecting gamma radiation emission lines in the context of studying radioactive contamination in the environment. After collecting and analyzing 18 consumer food samples, we determined radiation risk factors, the annual effective dose, and the natural radionuclide activity concentration. The average radionuclide activity values (^{232}Th, ^{238}U, and ^{40}K) in the study samples were 9.67 BqKg^{-1}, 6.08 BqKg^{-1}, and 220.21 BqKg^{-1}, respectively. The current result indicates that the levels of radionuclides in the analyzed samples, which include various age groups, fall within the limits set by the International Atomic Energy Agency. So, eating these types of food items is completely normal. The results showed that annual effective doses were well below the global limit of 200–800 mSv for all dose categories (UNSCEAR 2017) [30]. These study results can establish a standard for natural radioactivity and risk factor concentrations in food samples consumed in Hilla. In addition to assisting in the country's future radiation protection plans, it will help raise public awareness about the importance of health and the dangers of radiation.

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