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RESEARCH PAPER

Assessment of natural radioactivity levels in widely used food spices in the Iraqi Kurdistan region and their associated radiological risks

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A B S T R A C T:

In this research work, the activity concentration of naturally occurring radioactive nuclides in 19 widely consumed spices in the Iraqi Kurdistan Region was determined. Gamma-ray spectrometry equipment with high purity-germanium detectors (HP-Ge) was utilized. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs ranged from BMDA (Below Minimum Detectable Activity) (for cumin) to 4.65 ± 0.37 Bq kg^{-1} (for learners), 0.06 ± 0.02 (for ring) to 3.79 ± 0.26 Bq kg^{-1} (Learners), 37.8 ± 2.09 (for ring) to 869.95 ± 36.92 Bq kg^{-1} (for turmeric), and BMDA to 1.83 ± 0.63 Bq kg^{-1} (for cloves), respectively. On the basis of these results, the radiological hazard indices associated with the use of food spices were calculated. The total ingestion annual effective dose (IAED) of ^{226}Ra, ^{232}Th, and ^{40}K ranged between 0.25 and 5.66 µSv.y^{-1}. The dose of naturally occurring radionuclides was less than the recommended limit 0.1 mSv y^{-1}, and there are no radiological risks associated with the consumption of food spices. This sort of baseline information will probably be crucial for estimating population exposure.

KEY WORDS: Radioactivity; food spice; radiological hazards, HP-Ge detector, annual effective dose.
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1.INTRODUCTION :

Humans are regularly exposed to natural sources of ionizing radiation (Ononugbo, Avwiri and Ikhuiwu, 2017). Naturally occurring radioactive materials (NORMS) from terrestrial and extraterrestrial origin, and artificial resources utilized for a variety of medical, agricultural, industrial, scientific, and educational uses (WHO, 2011). If the amount of exposure is considerable, adverse health consequences may result. Exposure to high amounts of radiation above background levels may cause somatic and genetic consequences that tend to harm vital and radiosensitive organs, which might eventually result in death (Ononugbo, Avwiri and Ikhuiwu, 2017).

It is possible to find naturally occurring radioactive materials (NORM) in the air, water, food, soil, and even in people. Amount of naturally occurring radionuclides fluctuates based on a some variables, including geology, climate, and agricultural conditions (WHO, 2011; Ononugbo, Avwiri and Ikhuiwu, 2017). For decades, researchers have known that certain foods contain different kinds of radioactivity. This is due to both natural and anthropogenic radionuclides that penetrate the food chain through alternative paths and are subsequently consumed by people (Azeez, Mansour and Ahmad, 2019; Baydoun and Samad, 2022). Estimating radiation exposure in the environment is essential for preserving human health, particularly if radioactive particles penetrate the food chain (El-Taher and Al-Turki, 2014).

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During digestion, natural and anthropogenic radioactive particles in food combine to an effective internal dosage. It is believed that at least one-eighth of the typical annual dose acquired from natural sources is ingested through food (Hernández *et al.*, 2004). The quantities of radionuclides in spices are important because they provide significant data for monitoring environmental radiation. Spices are obtained from the seeds, roots, bark, or fruits of trees and plants and are utilized in cuisine to improve the taste of food. They are also vital to the overall composition of culinary art (Sahu, 2007). Food products as well as spices may be polluted by atmospheric deposition or water movement through the soil; introducing these radionuclide pollutants into the food chain presents a major danger to human health since they are ingested by people largely via the consumption of these food spices (Ononugbo, Avwiri and Ikhuiwu, 2017). Human health risks associated with radiation from natural and artificial radioactive elements have been quantified and verified by international research (Kadhim *et al.*, 2021).

There are natural isotopes and their progenies in almost all foodstuffs (Mlwilo, Mohammed and Spyrou, 2007; Tawalbeh *et al.*, 2011; Amin and Ahmed, 2013). Nonetheless, external sources of radiation, such as ^{137}Cs, may also impact the radioactivity of foodstuffs. After ingestion, radionuclides may concentrate in certain organs (Riyadh Abualhail, 2017). Consequently, radionuclide absorption from food consumption can account for a significant portion of the moderate levels of radiation to which multiple organs are exposed. This might be hazardous and lead to long-term health issues (Abojassim, Hady and Mohammed, 2016; Nyanda and Nkuba, 2017).

A gamma-ray spectrometer with a detector contained of high purity-germanium (HP-Ge) is a standard method for detecting the amounts of naturally occurring and artificial radioactive elements in environmental samples. This nondestructive methodology offers benefits in multi-element testing and sample preparation (i.e., no chemical separation step), and exact quantitative assessment of a sample's radioactive concentration (Ahmad, 2016; Garcêz *et al.*, 2019). Several natural and artificial radioactivity investigations have been conducted on food spices in many countries around the world (Amin and Ahmed, 2013; Azeez, Mansour and Ahmad, 2019).

The aim of the present study is to estimate the radioactivity concentrations of ^{226}Ra, ^{232}Th, ^{137}Cs, and ^{40}K in 19 types of food spices regularly consumed by Iraqi Kurdistan residents. In addition, the dose of these radionuclides ingested via food spices was assessed as part of this study.

2. Materials and Methods

2.1 Sample preparation

This study contains 19 different types of spice samples. These samples were gathered from local marketplaces in three governorates of the Iraqi Kurdistan region (Erbil, Sulaymaniyah, and Duhok). Samples of spices were labeled with unique identifiers, as illustrated in Table 1. The produced samples were weighed and kept for four weeks in a one-liter Marinelli beaker to enable radioactive equilibrium between parent and daughter radionuclides to be attained.

Table 1: The traditional brand and origin of spice samples in the study.

Samples Code	Traditional spices name	Origin
S1	Ginger	China
S2	Learners	China
S3	Paprika	China
S4	Cardamom	Guatemala
S5	Nutmeg	India
S6	Cumin	India
S7	Hot red pepper	India
S8	Sweet Bean	India
S9	Ring	India

S10	Turmeric	India
S11	Gulf	India
S12	Hill Sweat	India
S13	Cloves	Indonesia
S14	Kebab	Mexico
S15	Anise	Syria
S16	Cumin	Syria
S17	Coriander	Syria
S18	Black pepper	Vietnam
S19	White Pepper	Vietnam

2.2 Measurement Systems

The p-type vertical closed-end coaxial high purity-germanium detector was developed by Princeton Gamma Technology (PGT) in the United States and has the following features: The crystal has a diameter of 70.6 mm, a length of 70.7 mm, a resolution (FWHM) of 1.18 keV for ^{57}Co at 122 keV and a resolution (FWHM) of 1.97 keV for ^{60}Co at 1332 keV, and a relative efficiency of 73.8% for this energy. The device was calibrated for energy using standard gamma-ray point sources, including ^{60}Co (peak energies of 1173.2 and 1332.5 keV), ^{137}Cs (peak energy of 661.7 keV), and ^{226}Ra (peak energies of 186.1, 295, 351.9, 609, 665, 1120, and 1764 keV). With the exact same three standard references, the efficiency was calibrated. Using two radioactive samples made with potassium chloride (KCl) powder and uranyl ace ($UO_2(OCOCH_3)_2.2H_2O$) solution, the relative efficiency curve was standardized to the absolute volume efficiency curve in order to fit the geometrical requirements of the examined samples. The collected results were effectively fitted to yield the following power formula:

$$\varepsilon = 5.5458 \times E_{\gamma}^{-0.823} \quad (1)$$

where ε is the detector's absolute full peak efficiency and E is the gamma ray's energy. The graph in Figure 1 depicts the absolute complete peak efficiency and gamma ray energy.

To shield the measuring samples from background radiation, an HP-Ge detector was positioned inside a 10 cm-thick lead well. The samples were positioned on the detector for a minimum of 10 hours. A multiple-channel analyzer and computer software were used to investigate the spectra.

The spectral assessment of the detected gamma-rays accounted for the presence of naturally occurring radioactive nuclides. The concentration of ^{226}Ra activity was determined using the gamma-ray lines at 351.9 keV (35.8%) from ^{214}Pb decay and 609.3 keV (44.8%) from ^{214}Bi decay. The ^{232}Th activity concentration was calculated using the gamma-ray lines at 238.6 keV (43%) of ^{212}Pb decay and 583 keV (84.5%) of ^{208}TI decay. In addition, the activity concentration of ^{40}K was evaluated using the gamma-ray line at 1460.8 keV (10.7%). The activity concentration of ^{137}Cs was calculated directly with the gamma-ray line at 661.7 keV (85.2%).

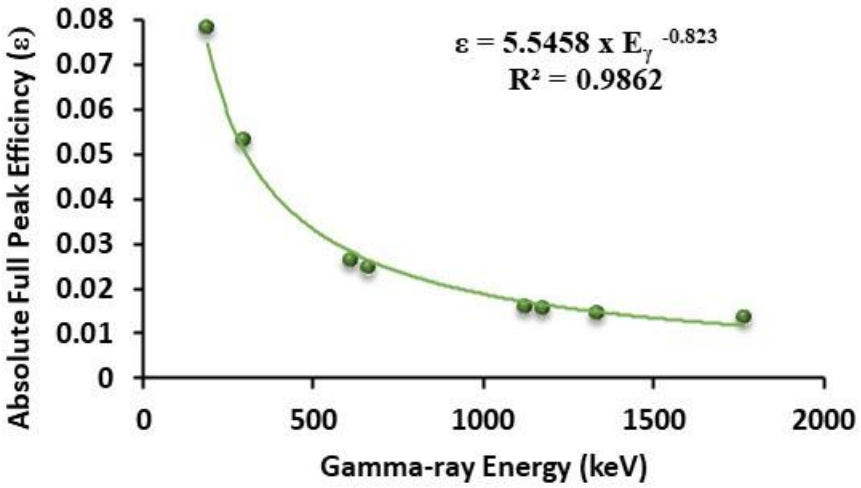

Figure 1: Depicts the absolute maximal efficiency of the HP-Ge detector as a function of gamma-ray energy.

2.3 Theoretical Formula

2.3.1 Activity Concentration (A):

The activity concentrations (A) of the radionuclides were calculated using the following formula (Azeez, Mansour and Ahmad, 2020):

$$A(Bq\ Kg^{-1}) = \frac{N - B}{t\ \times\ \varepsilon\ \times I\gamma\ \times m} \qquad (2)$$

where B and N indicate the background and sample areas underneath the gamma peak, respectively, and t is the time measurement (36000 seconds). $I\gamma$ denotes the potential for gamma emission. m represents sample mass, and ε is the detector's absolute gamma peak efficiency at a specific gamma radiation energy. The following formula was used to determine the minimal detectable activity (MDA) (Jafir, 2023):

$$MDA = \frac{2.71 + 4.66(\sigma)}{t\ \times\ \varepsilon\ \times I\gamma\ \times m} \qquad (3)$$

Where σ is the background standard deviation over the energy of interest and the denominator parameters are aforementioned. The $MDAs$ were found to be (0.009, 0.0057, and 0.133) Bq kg^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

The following formula calculates the relative combined standard deviation (σ_A) of the activity concentration.

$$\frac{\sigma_A}{A} = \sqrt{\frac{\sigma_N^2}{N} + \frac{\sigma_\varepsilon^2}{\varepsilon} + \frac{\sigma_{I_\gamma}^2}{I_\gamma} + \frac{\sigma_M^2}{M}} \qquad (4)$$

where σ_N represents the standard deviation of the N-count per second net rate. σ_ε, σ_{I_γ}, and σ_M , respectively, represent the standard deviations of the ε, I_γ and M (Smail, Ahmad and Mansour, 2022).

2.3.2 Internal Hazard Index (HI):

The internal hazard index calculates the risk of spontaneous gamma radiation by supposing that 185 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K generate identical gamma radiation doses. That may be determined using the formula below (Aswood, Abojassim and Al Musawi, 2019):

$$HI = \frac{A_{Ra}}{185Bq.kg^{-1}} + \frac{A_{Th}}{259Bq.kg^{-1}} + \frac{A_K}{4810Bq.kg^{-1}} \qquad (5)$$

where A_{Ra}, A_{Th}, and A_K represent the ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations, respectively.

In addition, the external hazard index, which is an estimate of the danger posed by naturally occurring gamma radiation, was calculated using

the hypothesis that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K generate equal quantities of gamma radiation. This index may be evaluated using the following relationship (Hameed, Pillai and Mathiyarasu, 2014; Azeez, Ahmad and Hanna, 2018):

$$HX = \frac{A_{Ra}}{370Bq.kg^{-1}} + \frac{A_{Th}}{259Bq.kg^{-1}} + \frac{A_K}{4810Bq.kg^{-1}} \qquad (6)$$

2.3.3 Ingestion Effective Dose:

The "ingested annual effective dose" (IAED) refers to radiation exposures from diverse radioactive sources. Ingestion of radionuclides is related with evaluating the health consequences of radiation. It is proportional to the total dose supplied to different organs by these radionuclides. The amount of radiation ingested was obtained by multiplying the activity concentration (Bq kg^{-1}) of a radioactive substance in food by the quantity of food consumed during a specified time frame (kg d^{-1} or kg y^{-1}). Using the dose conversion factor, the ingestion dose (Sv.Bq^{-1}) can be calculated. IAEA and ICRP doses through ingestion are described as follows (Azeez, Mansour and Ahmad, 2019):

$$Radiation\ Dose(IAED)(Sv.y^{-1}) = A \times I_A \times DCF \qquad (7)$$

where A denotes the activity concentration (Bq kg^{-1}), I_A annual ingestion (kg.y^{-1}), and DCF (Sv.Bq^{-1}), the standardized dose conversion factor equal to 0.0062, 0.23, and 0.28 Sv.Bq^{-1}, respectively, for ^{40}K, ^{232}Th, and ^{226}Ra.

2.3.4 Hereditary Cancer Risk (HCR):

To establish the hereditary cancer risk from spice ingestion, the International Commission on Radiological Protection's ICRP (1991) approach to evaluating cancer risk was utilized. ICRP regulations stipulate that the expected parameter for the general population is 4 $\times 10^{-2}$ Sv^{-1} (ICRP, 2012):

$$HCR = IAED \times Dl \times rF \qquad (8)$$

where HCR represents hereditary cancer risk, $IAED$ is the ingestion annual effective dose (Sv.y^{-1}), Dl expected lifespan (70 years), and rF is a risk factor (Sv^{-1}). The ICRP estimates a risk factor of 0.04 for the general population in regards to the probability impact (ICRP, 2012).

3. Results and Discussion

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in spice samples obtained from markets in the Iraqi Kurdistan Region (Erbil, Sulaymaniyah, and Duhok) were measured and displayed in Table 2, and the radionuclide distributions are depicted in Figure 2. In addition, the gamma-ray spectrum of sample S18 of spices is shown in Figure 3.

The measurements of this study reveal that the activity concentration of ^{226}Ra ranged from (BMDA) in cumin (S16) to (4.65 Bq kg^{-1}) in learners (S2) with an average value of (1.16 ± 0.29) Bq kg^{-1}, whereas the concentration values of the radionuclide ^{232}Th varied from (0.06 Bq kg^{-1}) in rings (S9) to (3.79 Bq kg^{-1}) in learners (S2) with an average of (0.65 ± 0.10) Bq kg^{-1}. Also, the activity concentration of ^{40}K ranged from (37.8 Bq kg^{-1}) in the ring (S9) to (869.95 Bq kg^{-1}) in turmeric (S10), with a mean of (400.17 ± 17.95 Bq kg^{-1}). ^{40}K was identified in all-spice food samples with appropriate activity levels. Lastly, the value obtained of ^{137}Cs varied from (BMDA) to (1.83 Bq kg^{-1}) for cloves (S13), with a mean of (1.23 ± 0.42 Bq kg^{-1}). The variation in the concentration level of radioactive nuclides in culinary spice samples may be attributable to the concentration of radioactive nuclides in the plant species, which is dependent on the radioactive nuclide amount present in the soil, along with the existence of the plant and also the metabolic features of the species of plants (Azeez, Mansour and Ahmad, 2019).

Table 2 demonstrates that the ^{40}K activity concentration was greater than that of ^{226}Ra and ^{232}Th, ^{40}K has a high concentration, strong mobility in soil, and excellent solubility in water (Zeng and Brown, 2000; Kumar *et al.*, 2008; IAEA, 2014; FAO, 2016). The plant has a greater biological requirement for ^{40}K, and plants have a predisposition to absorb potassium solubility in excess of their demands; this phenomenon is known as "luxury consumption."

Nonetheless, ^{40}K is an important biological element whose quantity in human tissue is tightly regulated by the metabolism. ^{226}Ra and ^{232}Th are maintained preferentially in the roots as opposed to the aboveground parts of the plant and have the lowest radioactive concentrations in the grains (Lindahl *et al.*, 2011), as well as a high fertilizer use and a larger transfer factor for ^{40}K (Azeez, Ahmad and Hanna, 2018).

Furthermore, the concentration of radionuclide activity in cereals, leafy vegetables, and roots is less than 1 Bq Kg^{-1} (UNSCEAR, 2000), with the exception of a few regions where the specific activity levels of food products are rather high. In the present investigation, the obtained activity concentrations of ^{226}Ra and ^{232}Th in (black pepper, learners, white pepper, and the gulf) are both greater than 1 Bq Kg^{-1}.

In Table 3, the activity concentration of radioactive nuclides in culinary spices from the current investigation is contrasted with findings from other regions throughout the globe. In the current investigation, the activity of ^{226}Ra and ^{232}Th in food spice samples was lower than that discovered in other countries. While the ^{40}K activity in the current study's sample of spices was more than that discovered in Ghana and Iraq (i.e., the Middle and South), it was lower than that reported in Saudi Arabia. This is due to the high quantities of ^{40}K in the soil, which are related to the farmers' extensive use of fertilizers and the greater ^{40}K transfer factor.

The cumulative doses of radiation from intake of the three naturally occurring radionuclides via food spices were also evaluated, as indicated in Table 4 and Figure 4. The annual effective dose (IAED) ranges for ^{226}Ra, ^{232}Th, and ^{40}K consumption are between 0 and 1.01 $\mu Sv.y^{-1}$, 0.01 and 0.83 $\mu Sv.y^{-1}$, and 0.23 and 5.39 $\mu Sv.y^{-1}$, respectively. Also, the total annual effective dose (IAED) of intake of ^{226}Ra, ^{232}Th, and ^{40}K ranges from 0.25 $\mu Sv.y^{-1}$ in the ring sample (S9) to 5.66 $\mu Sv.y^{-1}$ in the turmeric sample (S10). The combined dose of ^{226}Ra, ^{232}Th, and ^{40}K consumed is deemed to be below the recommended food dose limit of 290 $\mu Sv.y^{-1}$ (UNSCEAR, 2000; IAEA, 2010). This suggests that the dose of radiation associated with the intake of food spices in the Iraqi Kurdistan Region is lower than the worldwide average IAED value of 290 $\mu Sv.y^{-1}$ (UNSCEAR, 2000). In addition, Table 4 presents the calculates of the radiological hazard parameters, internal hazard index (HI), external hazard index (HX), and hereditary cancer risk (HCR), in relation to the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in spices. Figure 4 demonstrates that the HI and HX range from 0.008 to 0.185 and 0.008 to 0.183, respectively. All values of the HI and HX are below the UNSCEAR-recommended value of one (Ibrahim, Hashim and Abojassim, 2021).

Furthermore, the concentrations of natural radionuclides and radiological risk factors in the vast majority of the spice samples were well below the globally acceptable level. Therefore, it may be concluded that samples of spices can be consumed without posing radiological risks to the individual. Finally, Table 4 displays the computed cancer risk values associated with the use of food spices, which varied from (0.001×10^{-3}) in the S9 to (0.015×10^{-3}) in the S10, with an average of (0.0077×10^{-3}). Its average value is lower compared to other types of health concerns, resulting in a spice-related food risk factor of (0.048×10^{-4}) (Amin and Ahmed, 2013). In accordance with the general population exposure limit of 1mSv, In general, the current estimated values of cancer risk are substantially lower compared to the worldwide mean value of (2.9×10^{-4}) UNSCEAR 2000. Hence, the average (2.952) $\mu Sv.y^{-1}$ annual radiation dose related to the consumption of spices containing the three radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in the Iraqi Kurdistan Region would not constitute a substantial risk.

Table 2: Activity concentration in Bq Kg^{-1} of radioactive nuclides in Iraqi Kurdistan culinary spice samples.

Samples Code	Activity concentration of radioactive nuclides (Bq Kg^{-1})			
	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
S1	0.65 ± 0.21	0.14 ± 0.04	534.46 ± 23.08	BMDA
S2	4.65 ± 0.37	3.79 ± 0.26	96.91 ± 5.09	BMDA
S3	0.76 ± 0.29	0.28 ± 0.06	702.95 ± 30.2	BMDA
S4	1.97 ± 0.3	0.52 ± 0.16	733.18 ± 31.33	1.67 ± 0.59
S5	0.55 ± 0.13	0.18 ± 0.08	211.4 ± 9.62	BMDA

S6	0.99 ± 0.22	0.19 ± 0.06	558.12 ± 23.97	BMDA
S7	0.35 ± 0.11	0.24 ± 0.09	714.59 ± 30.51	BMDA
S8	0.29 ± 0.09	0.08 ± 0.03	250.43 ± 14.15	BMDA
S9	BMDA	0.06 ± 0.02	37.8 ± 2.09	BMDA
S10	0.71 ± 0.26	0.31 ± 0.11	869.95 ± 36.92	0.20 ± 0.06
S11	1.68 ± 0.28	1.01 ± 0.15	449.88 ± 19.57	BMDA
S12	0.72 ± 0.26	0.37 ± 0.13	327.63 ± 14.63	BMDA
S13	0.68 ± 0.13	0.61 ± 0.13	222.42 ± 9.95	1.83 ± 0.63
S14	0.76 ± 0.18	0.16 ± 0.06	243.44 ± 12.72	BMDA
S15	0.43 ± 0.15	0.27 ± 0.1	591.14 ± 25.45	BMDA
S16	BMDA	0.13 ± 0.04	116 ± 9.65	BMDA
S17	1.18 ± 0.29	0.27 ± 0.11	514.05 ± 22.23	BMDA
S18	3.6 ± 0.3	1.94 ± 0.2	390.16 ± 17.48	BMDA
S19	2.14 ± 0.23	1.82 ± 0.14	38.74 ± 2.43	BMDA
Average	1.16 ± 0.29	0.65 ± 0.10	400.17 ± 17.95	1.23 ± 0.42

BMDA is (Below Minimum Detectable Activity)

Table 3: Comparison of the activity concentration of radioactive nuclides in culinary spices with the published data from various countries.

Country	Activity concentration (Bq Kg^{-1})				References
	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	
Brazil (Black pepper, Cumin, Ginger)	ND	< 2 – 7.5	379-702	ND	(Garcêz *et al.*, 2019)
Nigeria	1.13 – 21.90	0.2 – 176.38	13.86 – 2097.17	ND	(Ononugbo, Avwiri and Ikhuiwu, 2017)
Ghana	0.35 – 1.19	0.69 – 1.02	1.92 – 2.42	0.04 – 0.08	(Kansaana *et al.*, 2013)
Egypt	10.4 – 77.9	5.9 – 57.4	130 – 1416	ND	(Amin and Ahmed, 2013)
Saudi Arabia	6.08- 105.02	3.02 – 124.23	229.95 – 1116.56	ND	(Al-Ghamdi, 2014)
Iraq	0.43 – 1.72	0.16 – 0.67	18.74 – 220.45	ND	(Kadhim *et al.*, 2021)
Iraq(Kurdistan)	BMDA – 4.65	0.06 – 3.79	37.8 – 869.95	BMDA – 1.83	present study

ND is Not Detected.

Table 4: Radiological hazard indices of the measured spice samples.

Samples Code	Ingestion annual effective dose μSv y^{-1}				HI	HX	HCR $\times 10^{-3}$
	^{226}Ra	^{232}Th	^{40}K	Total			
S1	0.18 ± 0.06	0.03 ± 0.01	3.31 ± 0.14	3.53 ± 0.21	0.115	0.113	0.009
S2	1.3 ± 0.1	0.83 ± 0.06	0.6 ± 0.03	2.74 ± 0.19	0.059	0.047	0.007
S3	0.21 ± 0.08	0.06 ± 0.01	4.36 ± 0.19	4.63 ± 0.28	0.151	0.149	0.012
S4	0.55 ± 0.09	0.11 ± 0.04	4.55 ± 0.19	5.21 ± 0.31	0.165	0.159	0.014
S5	0.15 ± 0.06	0.04 ± 0.02	1.31 ± 0.06	1.51 ± 0.14	0.047	0.046	0.004
S6	0.28 ± 0.06	0.04 ± 0.01	3.46 ± 0.15	3.78 ± 0.23	0.122	0.119	0.01
S7	0.1 ± 0.05	0.05 ± 0.02	4.43 ± 0.19	4.58 ± 0.27	0.151	0.15	0.012
S8	0.08 ± 0.04	0.02 ± 0.01	1.55 ± 0.09	1.65 ± 0.13	0.053	0.053	0.004
S9	0	0.01 ± 0.01	0.23 ± 0.01	0.25 ± 0.02	0.008	0.008	0.001
S10	0.2 ± 0.07	0.07 ± 0.03	5.39 ± 0.23	5.66 ± 0.33	0.185	0.183	0.015
S11	0.47 ± 0.08	0.22 ± 0.03	2.79 ± 0.12	3.48 ± 0.23	0.106	0.101	0.009
S12	0.2 ± 0.07	0.08 ± 0.03	2.03 ± 0.09	2.32 ± 0.19	0.073	0.071	0.006
S13	0.19 ± 0.07	0.14 ± 0.03	1.38 ± 0.06	1.7 ± 0.16	0.052	0.05	0.004
S14	0.21 ± 0.05	0.04 ± 0.02	1.51 ± 0.08	1.76 ± 0.14	0.055	0.053	0.004
S15	0.12 ± 0.04	0.06 ± 0.02	3.67 ± 0.16	3.85 ± 0.22	0.126	0.125	0.01
S16	0	0.03 ± 0.01	0.72 ± 0.06	0.75 ± 0.07	0.024	0.024	0.002
S17	0.33 ± 0.08	0.06 ± 0.03	3.19 ± 0.14	3.58 ± 0.25	0.114	0.111	0.01
S18	1.01 ± 0.09	0.43 ± 0.05	2.42 ± 0.11	3.86 ± 0.24	0.108	0.098	0.01
S19	0.6 ± 0.06	0.4 ± 0.03	0.24 ± 0.02	1.24 ± 0.11	0.026	0.02	0.003
Average	0.325	0.143	2.481	2.952	0.0915	0.0884	0.0077
UNSCEAR2000	6.3	0.38	170	290	≤ 1	≤ 1	0.29

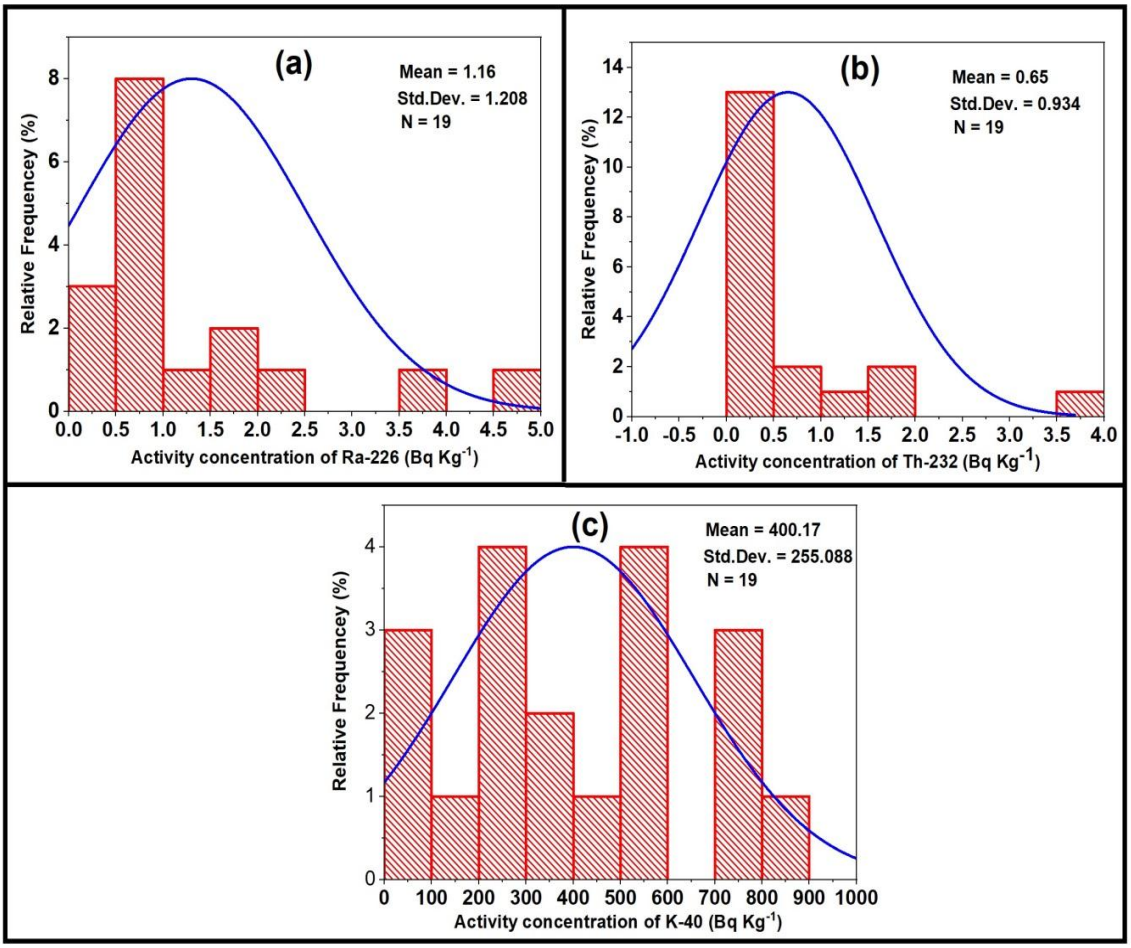

Figure 2: The frequency distributions of a) ^{226}Ra, b) ^{232}Th, and c) ^{40}K in food spice samples from Iraqi Kurdistan.

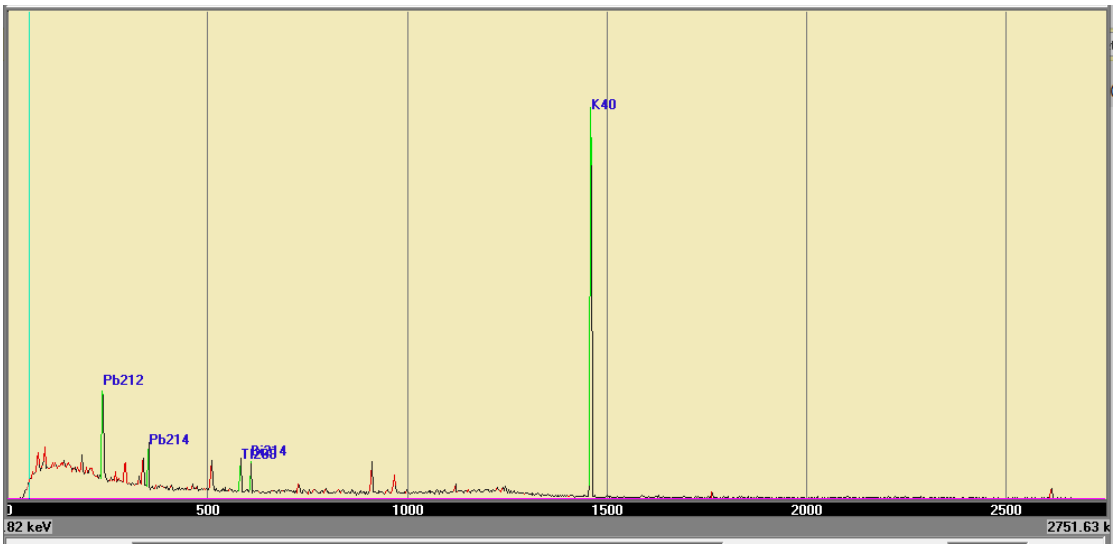

Figure 3: Gamma-ray spectrum of spice sample S18.

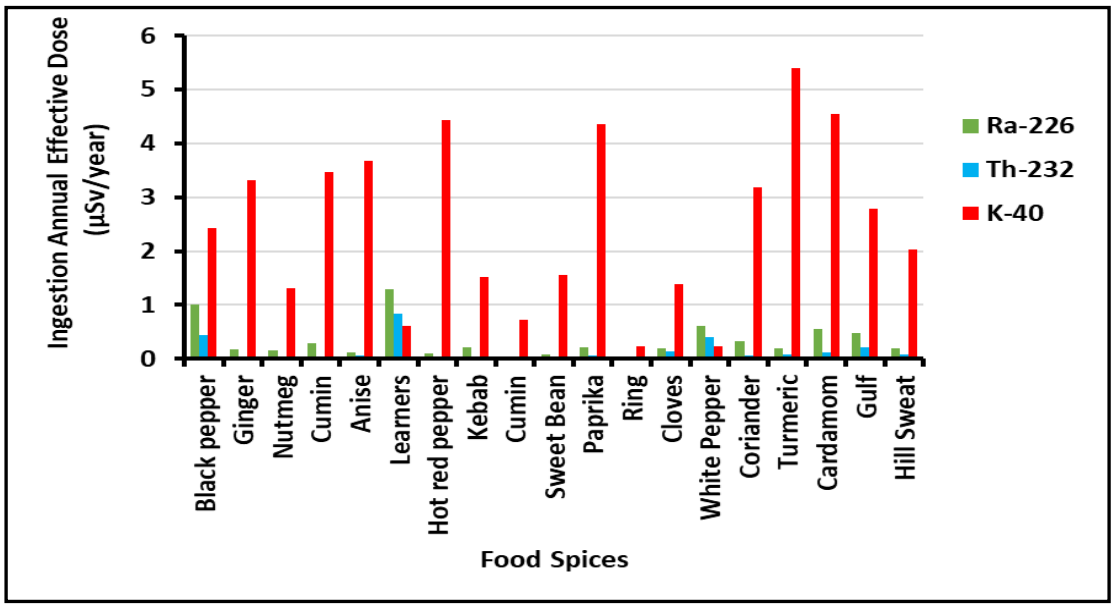

Figure 4: Annual effective dose attributable to the consumption of radioactive nuclides from Iraqi Kurdistan's food spices.

4. Conclusions

A gamma-ray spectrometry system with high purity-germanium detectors (HP-Ge) was employed to evaluate the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs radionuclides in numerous types of commonly consumed food spices in the Iraqi Kurdistan region. The observed activity concentrations of specific radionuclides were lower than the values reported from other countries, including Nigeria, Egypt, and Saudi Arabia. China recorded the highest levels of radiation for ^{226}Ra and ^{232}Th, while India recorded the lowest levels for ^{40}K. The difference in radioactive nuclide concentration levels in samples of food spices may be related to the concentration of radioactive nuclides in the species of plants, which is influenced by the radioactive nuclides present in the soil. The radiation dose resulting from the intake of food spices in the Iraqi Kurdistan Region was confirmed to be below the acceptable limit of 290 µSv.y^{-1} and poses no radiological threat to public health.

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Conflict of interest
The authors declare no conflicts of interest.

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