



Research Article

Monitoring Radioactive Contamination of Agricultural Crops (wheat and barley) in Different Regions of Iraq

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Abstract:

Background: Since wheat and barley are vital food supplies for both people and animals, it is critical for public health to check their radiological safety. Long-term health hazards may result from exposure to naturally occurring radionuclides, especially radon (Rn) and radium (Ra). The purpose of this study was to assess the radon concentration (C_{Rn}), effective radium content (C_{Ra}), radon emission rate (RER), alpha index (I_α), and effective dose rate (EDR) in wheat and barley crops grown throughout Iraq.

Materials and Methods: A total of 22 samples of wheat and barley were collected from 11 Iraqi governorates. CR-39 detectors were used for alpha-track detection in order to quantify C_{Rn} , C_{Ra} , RER, I_α , and EDR.

Results: A wheat sample from the Basra Governorate had the greatest values of C_{Rn} , C_{Ra} , RER, I_α , and EDR (79.328 Bq/m³, 4.070 Bq/kg, 0.003 Bq·m⁻³·h⁻¹, 0.020, and 150.500 μ Sv/year, respectively), whereas samples from Anbar had the lowest values. The southern governorates showing the highest radiological impact. Northern regions showed intermediate values, while central regions recorded the lowest amounts. In certain samples, improper application of agricultural fertilizers was also linked to elevated radioactivity. Every measured value stayed below the suggested safety limits set by the WHO and ICRP.

conclusion: Despite regional variations, radiological evaluations show that Iraqi wheat and barley meet international safety criteria. These results emphasize the need for ongoing agricultural product monitoring to guarantee food safety and identify possible radioactive environmental sources.

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The concentration of radiation on the Earth varies depending on its radioactive concentration in the soil. Natural radionuclides can be found in all environments, including the ground, water, air, food, and our bodies. The main cause of exposure is the ingestion of radionuclides with long half-lives, such as uranium and radium. Uranium is the main isotope, producing a long series of decay products, including radium and radon [1]. Uranium and its products are radioactively and chemically toxic, posing a threat to the ecological balance and the human body [2,3]. Weathering of the Earth's crust releases radionuclides into the soil, the primary source of natural background radiation. Radionuclides are absorbed by plants through roots or leaves, and by animals through plant diet, phosphate-based mineral supplements, and soil. Radionuclides can be ingested through animal flesh, milk, or plant-based foods. Radionuclides in food and drink contribute significantly to the average radiation doses received by the human body, particularly the skeleton [4]. Fertilizers can also contaminate food crops, causing increased levels of uranium-series radionuclides in crops. The distribution of nuclides in plants is influenced by chemical characteristics, soil conditions, and other factors [5,6]. Environmental studies indicate that dietary intake of uranium ranges from (15 to 17) mBq/day in the USA, (12 to 45) mBq/day in Europe, and (11 to 60) mBq/day in Japan, with the highest values found in areas of uranium mining and milling[7,8]. Cereal crops are used by humans for both food and animal feed. Grain consumption has a significant impact on human health since it is 170 kg annually worldwide and 210 kg annually in West Asia [9]. Because radiation can harm animals and have detrimental effects on human health when consumed in the form of meat and dairy products, it is vital to monitor their concentration. The main sources of radioactive elements in plants are the soil, air, and water. Plants absorb radioactive materials from the earth through their roots and directly absorb them through their aerial parts. Through the food

chain, radioactive elements from plants reach the bodies of humans and animals.

This study uses CR-39 alpha-track detectors to measure radon (Rn-222) levels in wheat and barley in order to evaluate radioactive contamination in Iraqi agricultural commodities. By precisely determining the radon concentration, effective radium content, radon emission rate, alpha index, and effective dose rate in the examined samples, this measurement technique makes it possible to assess the possible health risks of eating crops grown in areas impacted by environmental pollution and previous military operations.

2. Experimental Method

This study was based on the study of selected food crops from cereals, such as wheat and barley. Samples were collected from various Iraqi governorates, located in northern, southern, and central Iraq. In this study, the closed-cup technique was used to determine radon (C_{Rn}) and effective radium content (C_{Ra}) in food crops (wheat and barley).

The use method was created to test the amount of radon in wheat and barley grains using a sensitive plastic CR-39 alpha-path detector that is 1×1 cm² and 0.5mm thick (Preshore Molding Ltd, UK). According to earlier papers, this method is easy to use and efficient for detecting radon traces in various samples[10-12]. Sand was removed from all samples by cleaning them with distilled water. A manual mill was used to finely grind each sample after it had been dried in an electric oven set to 100 °C. It was then stored in plastic vials after being sieved through a 75µm screen to produce a sample powder with a uniform particle distribution, providing a radiological equilibrium between ²²⁶Ra and ²²²Rn. The powdered food crop samples were kept in designated containers for 30 days. After being weighed, about 5g of food powder was put into plastic cups that were 5 cm high and 4 cm in diameter. To stop any radon leaks, the detectors were firmly fastened to the plastic cups' inner lids. As seen in Fig. 1, the detectors were exposed for 60 days while housed inside

the plastic cups containing the samples. Following this exposure time, the plastic cups' CR-39 alpha detectors were removed to start the chemical etching procedure in a NaOH solution. Using a sodium hydroxide (NaOH) solution at

6.25 N and 60°C for five hours (3-5), the tracers were chemically etched. A light microscope set to 400x magnification was used to count the traces left by the etched tracks after they had been cleaned with distilled water.

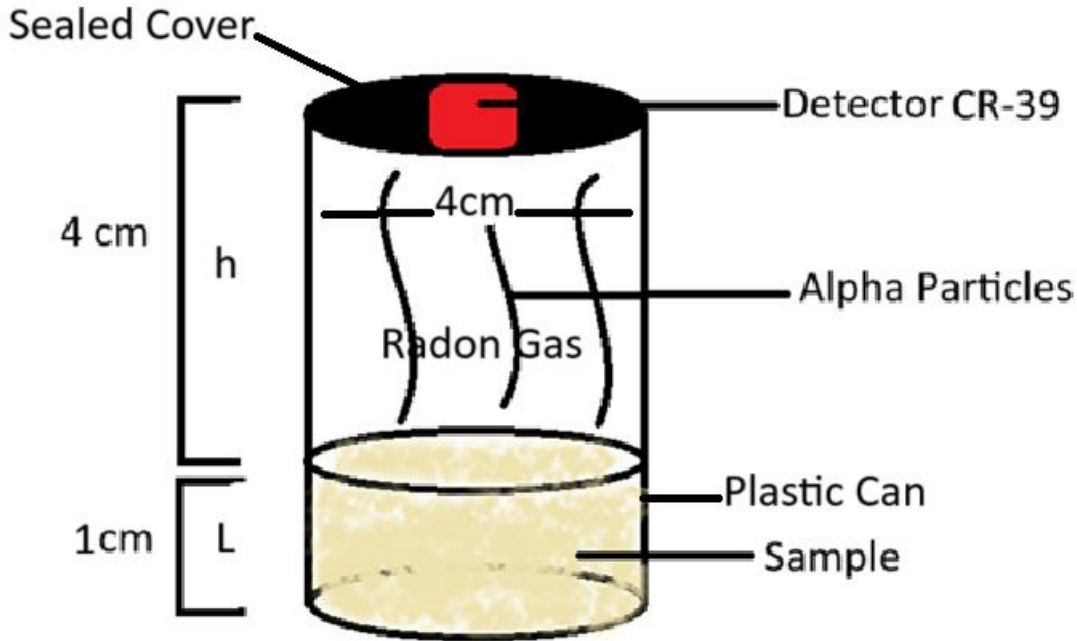


Fig. 1: Storage of the detector and samples inside the tube.

2.1 Calculation of Radon and Uranium

The number of tracks recorded on the CR-39 detector was used to determine the amount of radon present in grain samples. The density P_{Rn} of the track in the sample is determined using the formula provided by [13],

$$P_{Rn} = \frac{N}{A}$$

(1) The number of radon sample tracks is N. The optical microscope's viewing area is denoted by A.

The amount of radon present in the tube's air is calculated using [14],

$$C_{Rn}^a = \frac{P_{Rn}}{K t}$$

(2) P_{Rn} is the density of tracks in grain samples ($Tr./cm^2$), t is the exposure duration (60 days), K is the calibration factor or sensitivity factor (Tr/cm^2 per Bq/m^3), and C_{Rn} is the radon concentration in the air tube (Bq/m^3) [15],

$$K = \frac{1}{4} r (2 \cos \theta_c - \frac{r}{R_\alpha})$$

(3) R_α indicates the range of alpha particles in

the air (4.14 cm), θ_c is the critical angle of the CR-39 detector (35°) [14], and r is the storage tube's radius (2 cm). The calibration factor K , as determined by equation (3), was 0.5776 ($\text{Tr}/\text{cm}^2\text{d}^{-1}$ per Bq/m^3).

The activity of Radon in grain samples A_{Rn}^S can be determined using the equation,

$$A_{Rn}^S (\text{Bq}) = C_{Rn}^S V^S$$

(4) V^S (m^3) represents the sample size used in the study, which can be found by Eq. 5

$$V^S = \pi \ell r^2$$

(5) The effective radium concentration in the samples used can be calculated using the equation [16][17],

$$C_{Ra} \left(\frac{\text{Bq}}{\text{kg}} \right) = \rho h A / K T_e M$$

(6) where ρ represents the trace density, h represents the distance between the detector and the sample surface, and K is the detector calibration used in the study. M is the mass of the sample. T_e is the effective detection time, which can be calculated using Eq 7. [18]

$$T_e = T - \frac{(1 - e^{-\lambda_{Rn} T})}{\lambda_{Rn}}$$

(7) where T is the exposure time, and λ_{Rn} is the radon decay constant (h^{-1}). According to researchers [16], Eq. 8 can be used to calculate the radon emission rate (RER) in grain samples.

$$RER \left(\frac{\text{Bq}}{\text{m}^2\text{h}} \right) = C_{Rn} \lambda V / A_s T_e$$

(8) where A_s is the sample's surface area (m^2), V is the cup's volume (m^3), and C_{Rn} is the radon exposure ($\text{Bq} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$).

The effective dose for food consumption is useful for calculating potential exposure to various radionuclides, which may originate from a variety of radioactive sources. A dose conversion factor (Sv/Bq) is provided for each radionuclide and can be applied as needed. Radiation doses can be calculated by measuring the activity concentration (Bq/kg) of the radionuclide in the food and then multiplying it by the mass of the food consumed over a specified period (kg/year) [19].

$$AED = \sum A_f I_f F_{DCF}$$

(9) The formula is as follows: F_{DCF} = internal dose conversion factor for radionuclide intake (Sv/Bq), A_f = radionuclide activity concentration in the sample (Bq/kg), I_f = annual food intake (kg/year), and annual effective dose = AED as determined by radionuclide intake ($\mu\text{Sv}/\text{year}$). The ingested dosage of a radionuclide is assessed using dose conversion factors of $0.28 \mu\text{Sv}/\text{Bq}$ for radium and $0.035 \mu\text{Sv}/\text{Bq}$ for radon, and whole-body ingestion doses are computed [20].

Several "alpha indices" or "internal indices" have been developed to assess excess alpha radiation resulting from the inhalation of radon gas from materials. The following formula has been used to calculate alpha indices I_α ,

$$I_\alpha = C_{Ra} / 200 (\text{Bq kg}^{-1})$$

(10) Where C_{Ra} is the active radium content (Bq kg^{-1}). In the context of food samples, this index

is used to assess the potential impact of elevated radium-²²⁶Ra activity concentrations exceeding a threshold of 200. Such high concentrations could lead to elevated air radon levels exceeding the recommended limit of 200 due to the inhalation of radon from radioactive materials. The threshold value must not exceed one for the radiation hazard to be considered negligible [21].

3. Results

Table 1 displays the analytical data for radon concentration (C_{Rn}), effective radium content

(C_{Ra}), radon emission rate (RER), alpha index (I_α), and annual effective dose (AED) in barley samples gathered from different governorates in Iraq. The results show that Anbar Governorate had the lowest values of C_{Rn} , C_{Ra} , and RER, which were 38.126 Bq/m³, 1.956 Bq/kg, and 0.001 Bq·m⁻³·h⁻¹, respectively. The Basra Governorate, on the other hand, had the highest values: C_{Rn} was 72.563 Bq/m³, C_{Ra} was 3.723 Bq/kg, and RER was 0.002 Bq·m⁻³·h⁻¹.

Table 1: Analytical results of radon gas concentration (C_{Rn}), effective radium content (C_{Ra}), radon emission rates (RER), alpha coefficient (I_α), and effective dose rate (EDR) in grain samples (barley) in the governorates of Iraq.

Region	C_{Rn} Bq/m ³	C_{Ra} Bq/kg	RER Bq·m ⁻³ ·h	I_α	AED μSv/year
Wasit	47.966	2.461	0.00154	0.0123	91.000
Baghdad	51.040	2.618	0.00164	0.0131	96.833
Najaf	50.425	2.587	0.00162	0.0129	95.667
Karbala	46.121	2.366	0.00148	0.0118	87.500
Anbar	38.126	1.956	0.00123	0.0098	72.333
Mosul	55.345	2.839	0.00178	0.0142	105.000
Diyala	63.544	3.260	0.00204	0.0163	120.556
Basra	72.563	3.723	0.00233	0.0186	137.667
Dhi Qar	68.874	3.533	0.00221	0.0177	130.667
Qadisiyah	54.730	2.808	0.00176	0.0140	103.833
Maysan	67.644	3.470	0.00217	0.0174	128.333
min	38.126	1.956	0.001	0.010	72.333
mix	72.563	3.723	0.002	0.019	137.667

In a similar vein, the wheat sample data (Table 2) showed significant heterogeneity amongst

governorates. Anbar also had the lowest C_{Rn} (37.512 Bq/m³), C_{Ra} (1.924 Bq/kg), and RER

($0.001 \text{ Bq}\cdot\text{m}^{-3}\cdot\text{h}^{-1}$), whereas Basra had the highest values (C_{Rn} at 79.328 Bq/m^3 , C_{Ra} at 4.070 Bq/kg , and RER at $0.003 \text{ Bq}\cdot\text{m}^{-3}\cdot\text{h}^{-1}$).

Table 2: Analytical results of radon gas concentration (C_{Rn}), effective radium content (C_{Ra}), radon emission rates (RER), alpha coefficient (I_α), and effective dose rate (EDR) in grain samples (wheat) in the governorates of Iraq.

Region	C_{Rn} Bq/m^3	C_{Ra} Bq/kg	RER $\text{Bq}\cdot\text{m}^{-3}\cdot\text{h}$	I_α	AED $\mu\text{Sv/year}$
Wasit	55.96	2.871	0.0018	0.0144	106.167
Baghdad	70.104	3.596	0.00225	0.018	133
Najaf	67.644	3.47	0.00217	0.0174	128.333
Karbala	62.109	3.186	0.002	0.0159	117.833
Anbar	37.512	1.924	0.00121	0.0096	71.167
Mosul	64.569	3.312	0.00207	0.0166	122.5
Diyala	61.494	3.155	0.00198	0.0158	116.667
Dhi Qar	71.948	3.691	0.00231	0.0185	136.5
Qadisiyah	65.799	3.376	0.00211	0.0169	124.833
Basra	79.328	4.07	0.00255	0.0203	150.5
Maysan	57.805	2.965	0.00186	0.0148	109.667
min	37.512	1.924	0.001	0.010	71.167
mix	79.328	4.070	0.003	0.020	150.500

The trends in geographic distribution are presented in Table 3. With mean C_{Rn} levels of 58.666 Bq/m^3 and 46.736 Bq/m^3 , respectively, the central governorates had the lowest mean values for both wheat and barley. In contrast, the southern governorates had the highest average

C_{Rn} concentrations for barley (65.953 Bq/m^3) and wheat (68.720 Bq/m^3), along with the highest C_{Ra} and RER values. The intermediate concentrations in the northern governorates were in line with the region's transitional environmental features.

Table 3: Statistical analysis of data on the relationship between radiation concentrations in grains among governorates.

Region	Type	C_{Rn} Bq/m ³	C_{Ra} Bq/kg	RER Bq.m ⁻³ .h	I_{α}	AED μSv/year
Central Iraq	wheat	58.666	3.010	0.00189	0.015	111.300
	barley	46.736	2.398	0.00150	0.012	88.667
Northern Iraq	wheat	63.032	3.234	0.00203	0.016	119.583
	barley	59.445	3.050	0.00191	0.015	112.778
Southern Iraq	wheat	68.720	3.525	0.00221	0.018	130.375
	barley	65.953	3.383	0.00212	0.017	125.125

Overall, anthropogenic, geological, and environmental factors—most notably the widespread use of phosphate fertilizers and the known legacy of military contamination in southern Iraq—are substantially linked to the geographical variability seen in C_{Rn} , C_{Ra} , and RER. The higher radiological signatures seen in the southern samples as compared to the middle and northern regions are a result of these causes. For both crop types, the mean alpha index varied between 0.012 and 0.018 among locations, staying considerably below the suggested safety level ($I_{\alpha} < 1$). Furthermore, the annual effective dose (AED) from grain eating varied from 71.167 to 150.500 μSv/year, all of which were below the globally recognized threshold of 320 μSv/year, suggesting that food intake posed no appreciable radiological danger.

Overall, anthropogenic, geological, and environmental factors—most notably the widespread use of phosphate fertilizers and the known legacy of military contamination in southern Iraq—are substantially linked to the geographical variability seen in C_{Rn} , C_{Ra} , and RER. The higher radiological signatures seen in the southern samples as compared to the middle and northern regions are a result of these causes.

4. Discussion

The study's findings show that in wheat and barley samples taken from Iraqi governorates, there are distinct regional differences in radon concentration (C_{Rn}), effective radium content (C_{Ra}), radon emission rate (RER), alpha index

(I_{α}), and annual effective dose (AED). Anbar had the lowest C_{Rn} values for wheat (37.512 Bq/m³) and barley (38.126 Bq/m³), while Basra had the highest C_{Rn} values (72.563 Bq/m³ for wheat and 79.328 Bq/m³ for barley). For radon in environmental materials, these results stay below the WHO recommendation of 100 Bq/m³, suggesting no surpassing of global safety limits[23].

C_{Ra} also showed the similar regional pattern. Basra had the greatest amounts (3.723 Bq/kg and 4.070 Bq/kg, respectively), while Anbar had the lowest (1.956 Bq/kg for barley and 1.924 Bq/kg for wheat). As noted by Ghosh et al. (2008) [25] and Al-Hamzawi (2022)[8], these results are consistent with worldwide research that links increased C_{Ra} in crops to environmental contamination, particularly in areas impacted by industrial pollution or previous military operations. These worldwide findings are supported by the fact that the southern part of Iraq, which is renowned for long-term exposure to depleted uranium, routinely exhibits greater radioactive indications. With minimum values of 0.001 Bq.m⁻³.h⁻¹ (Anbar) and maximum values of 0.002–0.003 Bq.m⁻³.h⁻¹ (Basra), RER exhibited the similar trend. These levels are in line with global data from high-background agricultural regions like Upper Egypt [12] and southwest India[5], where reported RER values usually fall between 0.001 and 0.004 Bq.m⁻³.h⁻¹.

In this study, the AED values varied from 71.167 μSv/year in Anbar to 150.500 μSv/year in Basra.

According to UNSCEAR and ICRP, the global permitted limit for ingesting exposure (320 $\mu\text{Sv}/\text{year}$) is much higher than any measured AED levels [24]. This comparison demonstrates that grain consumption is still radiologically safe for the populace, despite the fact that some parts of Iraq, especially the south, have comparatively high radioactive levels.

Overall, this study's geographical variations are a result of anthropogenic, geological, and environmental factors, such as soil type, fertilizer use, and contamination from war. These results support the necessity of ongoing monitoring to guarantee food safety and public health protection and are consistent with global research trends.

5. Conclusion

In wheat and barley samples taken from Iraqi governorates, the current study showed distinct regional differences in radon concentration and effective radium content. The southern region,

especially Basra, consistently had the highest values, while the center region, especially Anbar, had the lowest levels. Despite these fluctuations, all measured C_{Rn} , C_{Ra} , RER, I_{α} , and AED values stayed within the WHO and ICRP-recommended worldwide safety limits, suggesting that eating these grains poses no radiological danger. Lower values in central Iraq indicate limited anthropogenic and geological effects, while higher levels in the south point and environmental contamination. To improve radiation risk assessment for foods in Iraq, future research should investigate more radionuclides and broaden sampling coverage.

Conflict of Interest: "The authors declare no conflict of interest." Zainab A. Rasheed*1 1. Data Analysis 2. Writing the Research 3. Interpretation of Results 4. Practical Part , Saja A. Abdul Sahib2 1. Writing the Research Adie D. Salman3 1. Data Collection 2. Supervision of the Work

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