

Radon Concentration, Effective Radium Content and Radon Exhalation Rates in Culinary Herbs and Spices from Iraqi Markets using CR-39 Detectors

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ABSTRACT

Culinary herbs and spices are widely consumed in Iraq, making the assessment of their natural radioactivity important for establishing baseline radiological data. This study aimed to determine radon concentration, effective radium content, surface radon exhalation rate, and mass radon exhalation rate in twelve selected herbs and spices using CR-39 solid-state nuclear track detectors. The measured radon concentration ranged from 174.33 to 292.74 Bq·m⁻³, with a mean of 235.06 ± 34.35 Bq·m⁻³, while the effective radium content ranged from 0.965 to 1.621 Bq·kg⁻¹, with an average of 1.301 ± 0.193 Bq·kg⁻¹. The surface and mass radon exhalation rates ranged from 0.102 to 0.171 Bq·m⁻²·h⁻¹ and 0.0085 to 0.0143 Bq·kg⁻¹·h⁻¹, respectively. Garlic exhibited the highest values for the investigated radiological parameters, whereas cumin showed the lowest values. The results provide baseline radiological data for the investigated herbs and spices and may support future studies and environmental radioactivity monitoring, and further dose and risk assessments of plant-derived food products in Iraqi markets.

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INTRODUCTION

Culinary herbs and spices are plant-derived products obtained from different plant parts, including seeds, fruits, roots, bark, leaves, and bulbs. They are widely used worldwide to enhance the flavor, aroma, color, and preservation of foods. In addition to their culinary importance, spices possess medicinal, antioxidant, antimicrobial, and anti-inflammatory properties, making those valuable components of traditional medicine and the food industry (Hossen et al., 2025; Gottardi et al., 2016). In recent decades, the consumption of spices has increased considerably due to the growing demand for natural food additives and herbal products. In Iraq, spices are widely used in daily diets and traditional remedies because of their availability, affordability, and cultural and dietary importance. Therefore, ensuring the radiological safety of these widely consumed products has become an important public health concern (Spahiu et al., 2022; Kheder et al., 2020).

Naturally occurring radioactive materials (NORMs) are widely distributed in environmental media, including soil, rocks, water, and air (International Atomic Energy Agency [IAEA], 2011). Radionuclides belonging to the uranium decay series, particularly uranium (²³⁸U), radium (²²⁶Ra), and radon (²²²Rn), are among the most important contributors to natural radiation exposure due to their widespread occurrence and radiological significance (International Commission on Radiological Protection [ICRP], 2020). These radionuclides can be transferred from soil to plants through root uptake, irrigation water, atmospheric deposition, fertilizers, and other agricultural processes. The uptake and accumulation of naturally occurring radionuclides in plants can be influenced by several factors, including soil composition, geological conditions, climatic variations, cultivation methods, storage conditions, and the physiological characteristics of the plant species (Shuaibu et al., 2025; Mahmoud & El-Zohry, 2025). Since spices are frequently consumed with minimal processing, the accumulation of radionuclides in these

products may result in their transfer into the human body through the food chain, thereby raising concerns regarding radiological safety and public health (Abdelfadeel et al., 2023).

Radon gas (²²²Rn) is one of the most important naturally occurring radioactive decay products originating from the decay of radium (²²⁶Ra) in the uranium decay series. Radon is a colorless, odorless, and chemically inert radioactive gas characterized by its ability to diffuse through porous materials and accumulate in enclosed environments (Gil-Oncina et al., 2022; Bello et al., 2025). The radioactive progeny of radon emit highly ionizing alpha particles that can damage biological tissues and increase the probability of developing lung cancer after prolonged exposure (Rajan & Pandey, 2021; Henry et al., 2024). According to the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP), radon exposure represents the second leading cause of lung cancer after smoking and is considered one of the major contributors to natural radiation dose received by humans (WHO, 2009; ICRP, 2019).

Although natural radioactivity in food products, medicinal plants, and culinary spices has been investigated in Iraq and other countries, the levels of naturally occurring radionuclides may vary considerably among plant species, plant parts, geographical locations, and environmental conditions. Therefore, continued assessment of widely consumed herbs and spices remains important for expanding the available radiological database. This study aims to determine radon concentration, effective radium content, and surface and mass radon exhalation rates in selected culinary herbs and spices available in Iraqi markets using CR-39 solid-state nuclear track detectors. The findings contribute to the available information on radon levels in commonly consumed herbs and spices in Iraq.

MATERIALS AND METHODS

Sample Collection and Preparation

Based on their widespread consumption in Iraq, twelve commonly used culinary herbs and spices available in local markets were selected for this study. Three independent samples were collected for each type. The samples were obtained from major suppliers in Baghdad, Iraq, who distribute these products to different regions and governorates of the country. According to the suppliers, most of the investigated products were imported from India, Iran, and

Gulf countries; however, the specific agricultural origin of each sample could not be independently verified. The samples were carefully cleaned to remove dust, impurities, and foreign materials, then air-dried when necessary and ground into fine, homogeneous powders to ensure uniformity. For each measurement, 20 g of the prepared sample was used. The reported values for each herb or spice represent the mean of three independent samples. The investigated culinary herbs and spices are shown in Figure 1, while their sample codes, scientific names, and plant parts used are listed in Table 1.

Table 1. Investigated Culinary Herbs and Spices with their Scientific Names and Plant Parts Used

Sample Code	Common Name	Scientific Name	Plant Part Used
S1	Cumin	<i>Cuminum cyminum</i>	Seeds
S2	Coriander	<i>Coriandrum sativum</i>	Seeds
S3	Mint	<i>Mentha</i> spp	Leaves
S4	Bay Leaf	<i>Laurus nobilis</i>	Leaves
S5	Thyme	<i>Thymus vulgaris</i>	Leaves
S6	Garlic	<i>Allium sativum</i>	Bulb
S7	Onion	<i>Allium cepa</i>	Bulb
S8	Turmeric	<i>Curcuma longa</i>	Rhizome
S9	Cinnamon	<i>Cinnamomum verum</i>	Bark
S10	Black Pepper	<i>Piper nigrum</i>	Fruits
S11	Sumac	<i>Rhus coriaria</i>	Fruits
S12	Ginger	<i>Zingiber officinale</i>	Rhizome



Figure 1: Culinary herbs and spices investigated in this study.

Radon Measurement Using the CR-39 Detector

Solid-state nuclear track detectors (SSNTDs) of type CR-39 were employed to measure radon concentration released from the investigated culinary herbs and spices. CR-39 detectors are widely used for environmental radon measurements because of their high sensitivity and their ability to record alpha-particle tracks emitted by radon and its radioactive progeny (Salman & Alasadi, 2023; Takahashi et al., 2021). The prepared samples were placed inside cylindrical plastic irradiation chambers with a height of 8 cm and a diameter of 5 cm. Each chamber was filled with the powdered sample to a height of approximately 1 cm from the bottom (Figure 2).

A CR-39 detector with dimensions of 1.5×1.5 cm was fixed to the inner upper surface of the chamber lid and positioned directly above the sample to detect alpha particles emitted from radon accumulated inside the sealed chamber. The chambers were tightly sealed with adhesive tape to prevent radon leakage and maintain a closed system suitable for radon accumulation. The sealed chambers were stored for 60 days to establish radioactive secular equilibrium between radium, radon, and its short-lived progeny, thereby ensuring sufficient alpha-track accumulation on the detector surface (Al-Hamzawi & Kareem, 2022; Jameel, 2025).

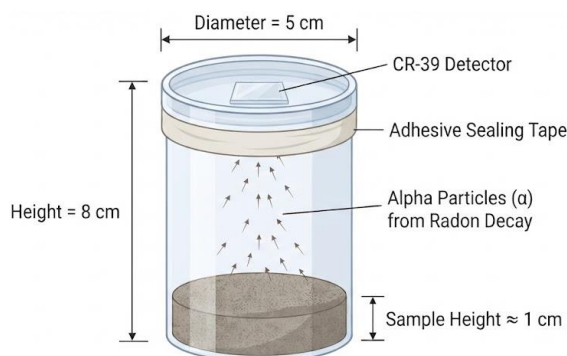


Figure 2: Schematic diagram of the sealed cylindrical chamber used for radon measurements using a CR-39 detector

After the exposure period, the CR-39 detectors were removed and chemically etched in a 6.25 N sodium hydroxide (NaOH) solution at 60 °C for 5 h to reveal the latent alpha-particle tracks formed on the detector surface. The detectors were subsequently washed with distilled water, air-dried, and examined under an optical microscope at 40× magnification. Alpha tracks were counted manually in several randomly selected microscopic fields for each detector to reduce counting uncertainty (Al Ani et al., 2022).

Radiological Calculations

The radon gas concentration was estimated from the number of alpha tracks recorded on CR-39 solid-state nuclear track detectors after exposure to samples. The calculation was performed using the following equation:

$$C_{Rn} = \rho / (KT) \quad (1)$$

Where C_{Rn} represents the radon concentration in the sample ($Bq \cdot m^{-3}$), ρ represents the track density recorded on the developed CR-39 detector, calculated by dividing the total number of alpha tracks by the effective detector area ($tracks \cdot cm^{-2}$), and T denotes the exposure duration in days (Kheder et al., 2019; Azeez et al., 2022), and K is the calibration factor of the detection system ($0.223 \pm 0.011 tracks \cdot cm^{-2} \cdot day^{-1} / Bq \cdot m^{-3}$) (Hashim et al., 2024). To ensure measurement accuracy and reproducibility, all samples were analyzed under identical experimental conditions. Background track density was measured using unexposed CR-39 detectors and subtracted from the measured values before calculating radon concentrations.

The effective radium content was determined because ^{226}Ra is the parent radionuclide responsible for radon generation within the investigated samples. It was calculated using the following equation:

$$C_{Ra} = \frac{\rho h A}{KM[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \quad (2)$$

where C_{Ra} is the effective radium content in ($Bq \cdot kg^{-1}$), A is the area of the spice samples in contact with the radon diffusion volume (cm^2), M is the mass of the spice samples (kg), h is the distance value between the spice samples surface and the detector (cm), λ is the decay constant of radon gas ($0.1814 day^{-1}$) (Waad & Hashim, 2025; Hassan Kadim et al., 2019).

The surface and mass radon exhalation rates were subsequently calculated to evaluate radon release from the

investigated culinary herbs and spices using the following equations:

$$E_s = \frac{\rho \lambda V}{KA[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \quad (3)$$

$$E_M = \frac{\rho \lambda V}{KM[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \quad (4)$$

Where E_s is the surface radon exhalation rate in units ($Bq \cdot m^{-2} \cdot h^{-1}$), E_M is the mass radon exhalation rate in units ($Bq \cdot kg^{-1} \cdot h^{-1}$), and V is the effective volume of the diffusion chamber expressed in (m^3) (Jameel, 2022).

RESULTS AND DISCUSSION

The measured radon concentration, effective radium content, surface radon exhalation rate, and mass radon exhalation rate obtained for the investigated culinary herbs and spices are summarized in Table 2.

Radon concentration values ranged from 174.33 to 292.74 $Bq \cdot m^{-3}$ as shown in (Figure 3), the overall mean value of radon concentration was $235.06 \pm 34.35 Bq \cdot m^{-3}$. The highest concentration was recorded in garlic (292.74 $Bq \cdot m^{-3}$), followed by cinnamon (290.26 $Bq \cdot m^{-3}$), whereas cumin (174.33 $Bq \cdot m^{-3}$) exhibited the lowest concentration among the analyzed samples.

The observed variations in radon concentration among the investigated samples can be attributed to differences in the natural occurrence of uranium-series radionuclides in the soils where the plants were cultivated, as well as variations in radionuclide uptake, plant characteristics, and agricultural conditions. Previous studies have demonstrated that radionuclide accumulation in edible plants is influenced by soil composition, geological setting, radionuclide bioavailability, and cultivation practices rather than by a single environmental factor alone (Shuaibu et al., 2025; Mahmoud & El-Zohry, 2025).

The measured radon concentrations varied among the investigated herbs and spices, reflecting differences in their effective radium content and the associated radon release under the experimental conditions. The higher values observed in garlic and cinnamon indicate relatively greater radon accumulation in the sealed chambers compared with the other investigated samples. These results provide baseline data on radon concentrations in the selected culinary herbs and spices and can be useful for comparison with future studies of similar plant-derived food products.

Table 2: Radon Concentration, Effective Radium Content, Surface Radon Exhalation Rate, and Mass Radon Exhalation Rate of the Investigated Culinary Herbs and Spices

Sample Code	Radon Concentration (Bq·m ⁻³)	Effective Radium Content (Bq·kg ⁻¹)	Surface Radon Exhalation Rate (Bq·m ⁻² ·h ⁻¹)	Mass Radon Exhalation Rate (Bq·kg ⁻¹ ·h ⁻¹)
S1	174.33	0.965	0.102	0.0085
S2	254.42	1.408	0.148	0.0124
S3	227.51	1.259	0.133	0.0111
S4	241.11	1.335	0.141	0.0118
S5	218.82	1.211	0.128	0.0107
S6	292.74	1.621	0.171	0.0143
S7	228.15	1.263	0.133	0.0112
S8	221.47	1.226	0.129	0.0108
S9	290.26	1.607	0.169	0.0142
S10	201.95	1.118	0.118	0.0099
S11	214.32	1.186	0.125	0.0105
S12	255.64	1.415	0.149	0.0125
Minimum	174.33	0.965	0.102	0.0085
Maximum	292.74	1.621	0.171	0.0143
Overall Mean ± SD	235.06 ± 34.35	1.301 ± 0.193	0.137 ± 0.020	0.0115 ± 0.0017

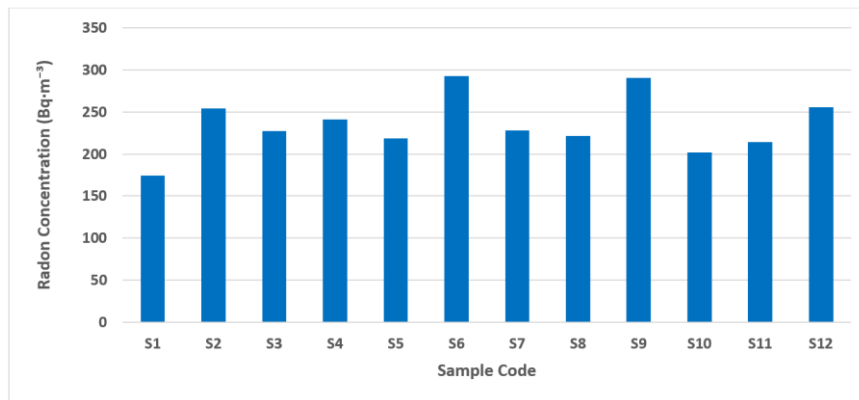
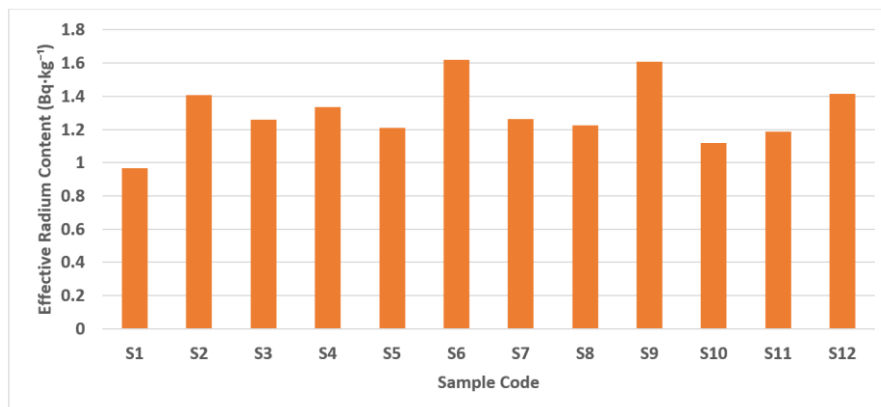
Figure 3: Distribution of radon concentration (Bq·m⁻³) in the investigated culinary herbs and spices.

Figure 4 presents the effective radium content for the studied samples, which ranged from 0.965 to 1.621 Bq.kg⁻¹, with an average value of 1.301 ± 0.193 Bq.kg⁻¹. Garlic exhibited the highest effective radium content, whereas cumin recorded the lowest value. The obtained distribution closely followed the measured radon concentrations because radium is the parent

radionuclide responsible for the continuous production of radon. The relatively low effective radium contents indicate that the investigated samples contain only naturally occurring levels of radium, reflecting its occurrence in agricultural soils and its subsequent transfer to edible plants (Al-Hamzawi & Kareem, 2022).

Figure 4. Effective radium content (Bq·kg⁻¹) in the investigated culinary herbs and spices

The surface and mass radon exhalation rates are presented in Figure 5 for the studied samples. The surface radon exhalation rate ranged from 0.102 to 0.171 Bq.m⁻².h⁻¹, with an average value of 0.137 ± 0.020 Bq.m⁻².h⁻¹, whereas the mass radon exhalation rate varied from 0.0085 to 0.0143 Bq.kg⁻¹.h⁻¹, with an overall mean of 0.0115 ± 0.0017 Bq.kg⁻¹.h⁻¹. Garlic exhibited the highest exhalation rates, while cumin showed the lowest values.

Both exhalation parameters followed the same trend observed for radon concentration and effective radium content,

suggesting that radon release is strongly influenced by the amount of radium present within the sample. The relatively low surface and mass exhalation rates obtained in the present study indicate limited radon release from the investigated culinary herbs and spices under the experimental conditions employed. These findings are consistent with the measured radon concentrations and effective radium contents of the investigated samples.

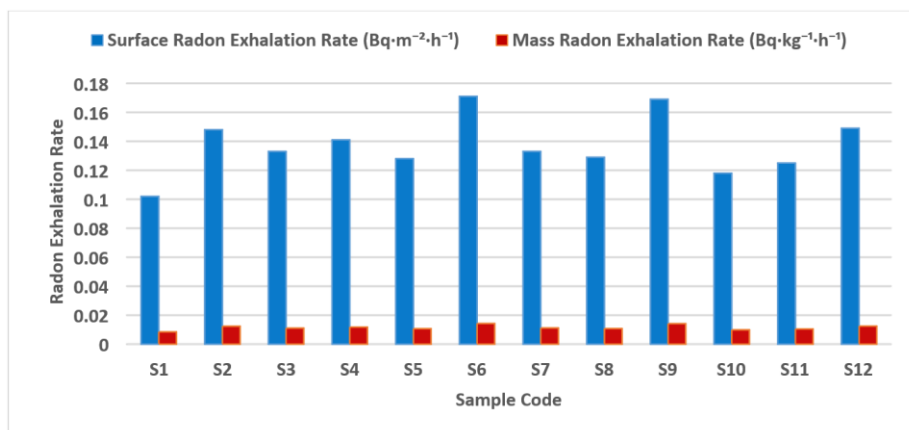


Figure 5: Surface and mass radon exhalation rates in the investigated culinary herbs and spices

CONCLUSIONS

This study investigated radon concentration, effective radium content, surface radon exhalation rate, and mass radon exhalation rate in selected culinary herbs and spices commonly consumed in Iraq using CR-39 detectors. The results showed variations among the investigated samples, with the highest values generally recorded in garlic and the lowest in cumin, while cinnamon also showed a relatively high radon concentration. The obtained results provide baseline data for the investigated products. However, the measured parameters reflect the experimental conditions and cannot be directly interpreted as consumer ingestion or inhalation doses. Future studies should include radionuclide-specific gamma spectrometry, larger geographically traceable sampling, replicate measurements with uncertainty assessment, and dose and risk evaluation. Such efforts would provide a more comprehensive assessment of the radiological characteristics of plant-derived food products.

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