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Experimental investigation of uranium concentration, radium content and radon exhalation rates in food crops consumed in Babil governorate, Iraq

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► ***Original article***

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ABSTRACT

Background: This study focuses on the uranium concentration (UC), radium content (RC) and radon exhalation rates (RER) in selected food crops consumed in Babil governorate, in the centre of Iraq. ***Materials and Methods:*** Neutron activation technique and sealed cup with CR-39 alpha track detector were used respectively to investigate the natural radioactivity of selected food crops collected from Babil governorate, Iraq. ***Results:*** In the current study, the highest UC was found to be 0.0346 ppm in the turnip crop, whereas the lowest value of UC (0.0142 ppm) was found in grape crop. The highest RC was found to be 0.651 Bq/kg in turnip, while the lowest RC (0.169 Bq/kg) was found in the fig crop. The values of RER ranged from 0.016 Bq/m^2.h found in the fig to 0.065 Bq/m^2.h found in the turnip. ***Conclusion:*** The levels of UC in food crops were lower than 1.7 ppm, the recommended limits of UNSCEAR. A strong direct correlation was found between the UC and RC in selected food crops.

INTRODUCTION

The natural radiation of a terrestrial origin varies from one place to another depending upon the variation of radionuclide concentration in soil. Radioactive material is always present everywhere in the environment air, water, soil and plants. The largest contribution to the exposure of ingestion comes from the long half-life radionuclides such as uranium and radium. Uranium is the dominant isotope which forms a long chain of decay products that include the key radionuclides such as radium and radon [1, 2]. Uranium and its products have both radiological and chemical toxicity. This in its turn, constitutes a threat to the ecological balance and the human body [3 - 5]. The main pathways for the entry of radionuclides into the human body are the inhalation particles of dust that are bearing radionuclides, ingestion of food and drinking water which is polluted by radionuclides. Radionuclides are deposited mainly in the bones, kidney, lung and other soft tissues which cause many health-problems for the human body [6 - 8]. Food crops may be exposed to direct and indirect pollution of uranium-series radionuclides due to the fertilizers which leads to the increase of uranium series nuclides in vegetables. Chemical properties and several parameters of the plant and soil are responsible for the distribution of these nuclides in different parts of the plant [9, 10]. To provide comprehensive information about food safety consumed, many researchers show a wide interest in estimating the level of radionuclides in consumed vegetables [11 - 14]. In some countries the environmental studies about naturally occurring sources of radioactive contamination in food have mentioned that the dietary intake of uranium was found to range from 15 to 17 mBq/day in the USA, 12 to 45 mBq/day in several European countries and from 11 to 60 mBq/day in Japan, the highest values found in areas of uranium mining and milling [15 - 18]. Evaluation of the uranium concentrations and radium activity in food crops are important from the health protection point of view, so effective and simple analytical methods must be available. The radiological analysis of food crops is the preferred method for monitoring the internal exposure of radiological contaminants. There is not adequate information about uranium and radium levels in food crops consumed in Babil governorate. Therefore, the present study focuses on the determination of the uranium concentrations, effective radium activity and radon exhalation rate in varying foodstuffs which include vegetables and fruit like (carrot, cauliflower, cucumber, date, fig, grape, lettuce, okra, onion, orange, pomegranate, potato, radish, spinach and turnip) because they are commonly available and

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consumed in Babil city, the center of Iraq. The results of the investigation are compared with the allowable levels worldwide.

MATERIALS AND METHODES

Samples collection

The present study was based on the investigation of selected food crops vegetables and fruit, like carrot, cauliflower, cucumber, date, fig, grape, lettuce, okra, onion, orange, pomegranate, potato, radish, spinach and turnip which are varied in type and included root, leaf and fruit crops. The samples were collected from Babil governorate which is located in the center of Iraq, nearly (100 km) south of Baghdad as shown in (figure1). Babil city has extended over an area of 5,119 km^2 and the population has been estimated to be 2,065,042 people, where the population density is 403.4 people/km^2. The city is situated in a predominantly agricultural region which is extensively irrigated with water provided by the Euphrates River and famous for producing a wide range of food crops.

Figure 1. A map shows the sampling area of the current study.

Experimental method

Uranium concentration (UC)

In the present investigation two effective techniques which are fission track analysis and sealed cup technique have been applied to determine UC, RC and RER in food crops. Fission track analysis (FTA) technique with sensitive plastic alpha-track detector CR-39 its dimensions (1×1cm^2) and 500 µm thicknesses (Preshore Moulding Ltd, UK) has been developed for measuring the UC in food crops. This technique is considered simple and effective to determine the trace quantities of uranium in different samples as reported elsewhere [3, 4, 19, 20]. About 1 kg of various food crops are sufficient for getting the required amount for the analysis. All samples were washed by distilled water and clean to remove the sands. Each sample was dried by means of an electric oven at 100 °C. Then, sufficiently grinded by using a hand mill. After that sieved by a fine mesh of 75 µm to obtain a sample powder with a homogenous distribution of the grain size and stored in plastic vials. The powders collected in the form of 0.5 g of a dried sample were mingled with 0.1 g of methylcellulose which is used as a binder. The mixture was pressed in to a pellet with a dimension of 1 cm and 1.5 cm for diameter and thickness, respectively. The powder of the food crops was covered with CR-39 detector on both sides. The pellets were irradiated with a thermal neutron source from (Am-Be) for seven days with a thermal flounce (3.024×10^9 n cm^{-2}) in order to cause latent damage to the CR-39 detector due to the reaction of ^{235}U (*n, f*) as shown in (figure 2). After the irradiation procedures, the chemical etchant of detectors was done by using NaOH solution under ideal conditions 6.25 N at 60 °C for 5 h [3 - 5]. The etched detectors were rinsed with distilled water and then the tracks were counted using optical microscope with magnification of *066x.*

The uranium concentration (UC) in the food crops samples was carried out by comparison between track densities of the food crops samples and that of the standard samples by using equation (1) as given by the researchers [4, 20].

$$UC(ppm) = \rho_x \times \left(\frac{U_s}{\rho_s}\right) \quad (1)$$

Where UC andU_S (ppm) represent the uranium concentration for the unknown sample and the standard sample,ρ_x and ρ_s (tracks / mm^2) illustrate the fission track density for the unknown sample and the standard sample.

Radium content (RC) and radon exhalation rate (RER)

The sealed cup technique with CR-39 detector (its dimensions are 1.5 × 1.5 cm^2) was used to measure RC and RER in the studied samples [14, 21 - 23]. The powder of food crops samples was stored in special containers for 30 days for the sake of the radioactive equilibrium between the ^{226}Ra and ^{222}Rn. About 20gr of food powder was weighed and then placed in plastic cups, where the height and inner diameter of the used plastic cup were 7.5cm and 4.5cm, respectively. The detectors were fixed on the internal cover and the lid of the plastic can was tightly closed to prevent any radon leakage. The detectors were left inside plastic cups with samples for 90 days as a period of exposure, as shown in (figure 3) [24]. After this period of exposure, CR-39 alpha detectors were collected from plastic cups to start up the stage of chemical etching in NaOH solution under controlled conditions as mentioned above, and then the detectors were washed by distilled water and dried well with air. Optical microscope at a magnification of

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400X was used to count the numbers of alpha tracks for each detector [25].

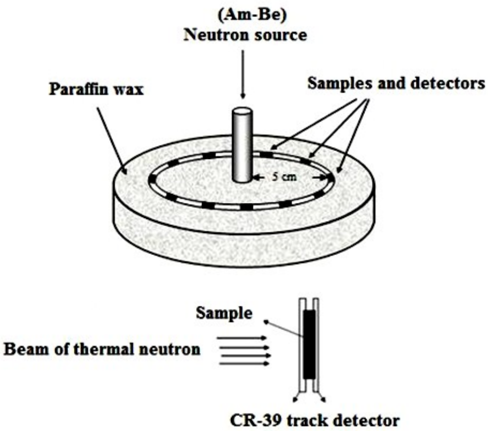

Figure 2. Irradiation process of fission track technique for the determination of the uranium content.

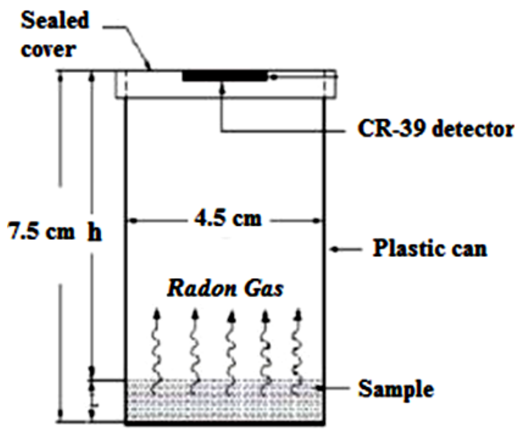

Figure 3. Sealed cup technique for determination of alpha particles.

Radon concentrations for food crops samples (vegetables and fruits) have been calculated by relation (2) [26 – 28]:

$$C_{Rn}(Bq/m^3) = \frac{\rho}{K.T} \quad (2)$$

Where ρ represents the density of the tracks on the surface of the detectors (*track / mm²*), T represents the exposure time equivalent to 90 days, K is the calibration factor of the CR-39 detector (*track. cm^{-2}*) / (*Bq. day. m^{-3}*) as reported elsewhere [21, 29].

Effective radium content (RC) in food samples can be found according to equation (3) [30, 31].

$$RC\ (Bq/Kg) = \frac{\rho hA}{KT_e M} \quad (3)$$

Where ρ is the alpha track density, h is the distance between the sample and the detector, K is factor of calibration of the used detector, M is the mass of the food samples and T_e represents effective exposure time which can be found by means of applying equation (4) [25].

$$T_e = T - \frac{(1 - e^{-\lambda_{Rn} T})}{\lambda_{Rn}} \quad (4)$$

Where λ_{Rn} is the radon decay constant (h^{-1}), T represents the exposure duration. In regard to the radon exhalation rate (RER) in food crops, it can be determined by equation (5) as reported by the researchers [27, 30].

$$RER\ (Bq/m^2 h) = \frac{C_{Rn} \lambda V}{A\, T_e} \quad (5)$$

Where C_{Rn} represents the radon exposure (*Bq.m^{-3}.h*), A is the surface area of the sample (m^2); V is the volume of the cup (m^3).

Statistical analysis

The obtained results of the foodstuffs samples were statistically analyzed using Statistical Package of the Social Sciences (SPSS) and the significance of the probability level (P) of the food crops was estimated by means of using correlation and independent sample *t-test*.

RESULTS

The data of uranium concentrations (UC) in fifteen types of food crops consumed in Babil governorate are presented in (table 1). Accordingly, the highest value of obtained UC was 0.0346 ppm found in turnip crop, whereas the lowest value of UC was 0.0142 ppm found in grape crop. The average value of UC in the studied sampling food crops was 0.01927±0.0054 ppm. The results indicated that the concentration of uranium in turnip was higher than the other sampling vegetables because that turnip crop belongs to the root plants where the higher transfer of radionuclides from the soil to these plants is higher and this finding agrees with those of other studies [13, 31].

The analytic results of effective radium content (RC) and radon exhalation rates (RER) in the studied sampling food crops collected from Babil governorate are presented in (table 2). Accordingly, the minimum RC was 0.169 Bq/kg found in fig crop, while the maximum RC was 0.651 Bq/kg found in turnip; with the mean value of RC in food crops was 0.287±0.0117 Bq/kg. As regarded to the radon exhalation rates the heights RER (0.064 Bq/m^2.h) was found in turnip, whereas the lowest RER was found as (0.015 Bq/m^2.h) in fig crop; with the mean value of RER was found as 0.0425±0.0161 Bq/m^2.h.

Table 3 illustrates the mean value of UC, RC and RER in food crops as a function of the food kind; where the studied sampling crops were varied between root vegetables, leafy vegetables and fruit. Accordingly, the UC in root, leafy and fruit vegetables were 0.0234±0.0079 ppm, 0.019±0.0013 ppm and 0.0154±0.0008 ppm, respectively. The mean value of RC in food crops were 0.378±0.0194 Bq/kg, 0.301±0.0287 Bq/kg and 0.184±0.0171Bq/kg for the root, leafy and fruit crops respectively. Whereas the

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mean value of RER in root, leafy and fruit crops were 0.059±0.0039 Bq/m².h, 0.045±0.0053 Bq/m².h and 0.023±0.0069 Bq/m².h, respectively. The obtained results indicated that the mean value of UC, RC and RER in root vegetables was significantly higher than other types of foodstuffs. Thus, the proportion of naturally radionuclides in the food crops was in the following order: root>leafy>fruit. The independent sample *t-test* confirmed statistically significant difference in the uranium, radium content and radon exhalation rates among root, leafy and fruit crops (P<0.05).

Table 2. Radium content and radon exhalation rates in food crops.

No. of the samples	Food crops	Uranium concentration
1	Carrot	0.0172
2	Cauliflower	0.0216
3	Cucumber	0.0187
4	Date	0.016
5	Fig	0.0156
6	Grape	0.0142
7	Lettuce	0.0178
8	Okra	0.0185
9	Onion	0.0202
10	Orange	0.0151
11	Pomegranate	0.0162
12	Potato	0.0286
13	Radish	0.0164
14	Spinach	0.0184
15	Turnip	0.0346
Mean ± std. dev.		**0.01927± 0.0054**

Table 3. Mean value of UC, RC and RER in food crops as a function of the plant kind.

Food crops	Uranium content (ppm)	Radium content (Bq/kg)	Exhalation rates (Bq/m^2.h)
Root vegetables			
Carrot Onion Potato Radish Turnip	0.0234±0.0079	0.378±0.0194	0.059±0.0039
Leafy vegetables			
Cauliflower Cucumber Okra Lettuce Spinach	0.0190±0.0013	0.301±0.0287	0.045±0.0053
Fruit			
Date Grape Fig Orange Pomegranate	0.0154±0.0008	0.184±0.0171	0.023±0.0069
P - value	P<0.05		

Figure 4 shows the relation between the results of UC and RC in the studied sampling food crops. According to (figure 4), a strong direct correlation has been observed between the uranium and radium content in food crops which confirms the radiological relationship between them.

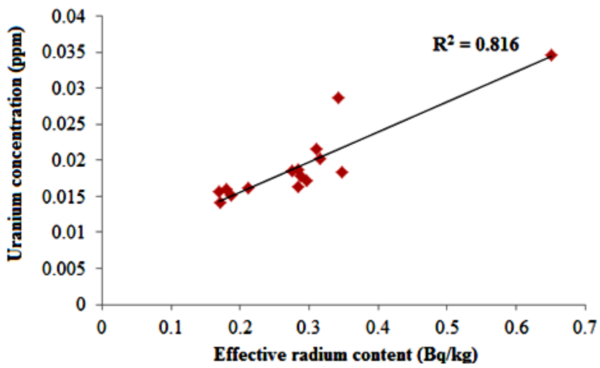

Figure 4. Showing the correlation between uranium and radium content.

DISCUSSION

According to the obtained results, the levels of uranium content (UC), radium content (RC) and radon exhalation rates (RER) varied depending on the food crop's type. The highest value of UC, RC and RER obtained was 0.0346 ppm, 0.651 Bq/kg and 0.064 Bq/m².h respectively, found in turnip crop. The reason that stands for such results is because turnip crop belongs to the root plants which absorbs higher amounts of radionuclides from the soil and this finding agrees with other researchers [13, 31].

As shown in table 1 and 2 there are variations in the values of uranium and effective radium concentrations among sampling food crops which could be referred to the difference in the levels of uranium content in the soil where the samples are grown or due to the different mechanisms of the transfer of radioactive materials to the samples. Also the climate and agricultural conditions that prevail. Moreover, the using of chemical and organic fertilizers rich in radioactive materials in the agriculture. Based on the of the present results, it is concluded that there are differences in the degree of translocation of radioactive materials to food crops depending upon physiological properties of the samples or the radionuclides themselves in addition to the properties of soil and water transmission.

As mentioned in (table 3) the levels of UC, RC and RER were the highest in the root vegetables, which included carrot, onion, potato, radish and turnip than another types of leafy vegetables and fruit. This finding is due to the transfer factors of the radioactive materials from the soil to the plant as well as the difference in the nature of the plant [22, 31].

The levels of uranium concentrations in all studied food crops were lower than the allowed limits for public (1.7 ppm) given by (UNSCEAR) [22, 32]. The values of radium content in various types of foodstuffs of other countries are different and as summarised in table 4. This table shows that the results of the present study are higher than the levels in USA and India [32, 33] and lower than maximum values in Brazil and Egypt [34, 35]. As the present study was the first evaluation to involve variable foodstuffs

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carried out in Babil governorate in the centre of Iraq. The data obtained can serve as the reference database for future studies.

Table 4. A comparison of radium activity (Bq/kg) in this study with other countries [32, 33].

Country	Root vegetables	Leafy vegetables	Reference
USA	0.007 – 0.047	0.056	32
India	-------	0.03	33
Brazil	0.597 – 0.928	0.21 – 0.429	34
Egypt	0.32 – 0.80	0.32 – 1.05	35
Turkey	1.56	-------	36
Iraq – Babil	0.285 – 0.651	0.276 – 0.347	Present study

CONCLUSION

The concentrations of uranium, radium and radon exhalation rates in the selected food crops consumed in Babil governorate, in the centre of Iraq have been measured by means of neutron activation technique with CR-39 alpha detectors and cup technique method. The levels of UC, RC and RER were found to be higher in root plants than in the leafy vegetables and fruit. The obtained value of uranium levels was found to be less than the permissible limit recommended by (UNSCEAR). A statistically significant correlation was found between UC and RC in food crops. At last, the results revealed that the selected foodstuffs were safe as far the health hazard effects are concerned.

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Ethical considerations: Food crops were collected from local markets and fields in the study area. The results of the research were within the safety levels, so these crops are considered safe and free of risks for consumers.

Conflicts of interest: None declared.

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Author contribution: The idea of the present investigation entitled: "Experimental investigation of uranium concentrations, radium content and radon exhalation rates in food crops consumed in Babil governorate, Iraq" was suggested by the authors Anees A. Al-Hamzawi and Nada A. Kareem. The analytic measurements of the samples were carried out by the authors in the nuclear physics laboratory in physics departments, college of education, university of Al-Qadisiyah, Iraq. The writing of the article and the discussion of the present results were performed by the authors.

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