Natural radioactivity levels in some vegetables and fruits commonly used in Najaf Governorate, Iraq

Ali Abid ABOJASSIM, Heiyam Najy HADY, Zahrah Baqer MOHAMMED
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Níveis de radioatividade natural em alguns vegetais e frutas comumente comercializadas na província de Najaf, Iraque.

ABSTRACT

Radioactivity in Food may be contaminated with radioactive materials due to the natural and a nuclear emergency. The vegetables and fruits will become radioactive by deposit of radioactive materials falling on that from the air or through rain water. The aims of the present work were to measure the specific activity and annual effective dose as a result of the intake of vegetables and fruits collected from local market in Najaf governorate. Natural radioactivity was measured in samples using gamma ray spectrometer in this study. The results show that the average specific activities in vegetables samples for $^{238}U$, $^{232}Th$ and $^{40}K$ were 5.21, 4.76, and 186.15 Bq kg$^{-1}$, respectively, the average specific activities for $^{232}Th$, $^{40}K$ in fruit samples were 2.53, 211.64 Bq kg$^{-1}$, while the total average annual effective dose in vegetables samples for adults, children (10 years old) and infants is estimated to be 0.117, 0.122, and 0.179 mSv, respectively, while the total average annual effective dose in fruit samples for adults, children (10 years old) and infants is estimated to be 0.141, 0.295, and 0.388 mSv, respectively. The values found for specific activity and the annual effective dose in all samples in this study were lower than worldwide median values for all groups according to UNSCEAR (2000) and ICRP (1996) respectively; therefore, these values are found to be safe.

Keywords: Natural Radioactivity. Vegetables and Fruits. Gamma ray spectrometer. Iraq food
INTRODUCTION

Radionuclides are found throughout nature and it exists in the soil, water and food. These radionuclides have half-lives that are approximately Earth’s age or older (i.e. about 4 to 5 billion years). Natural radioactive decay series such as $^{238}$U and $^{232}$Th as well as singly occurring radionuclides such as $^{40}$K exist in the earth and atmosphere in varied levels. The radioactivity present on air or in the agricultural land and in soil may transfer to the crops grown on it. It happens, however, that an amount of some radioactive elements find their way into human bodies. Generally, the plants (vegetables and fruits) may cause accumulation of radionuclides in their organs, which may additional rely on the chemical and physical properties of the soil. So, there may be multiplied risk to human population via food chain. The main sources of components from the environment to plants are: air, water and also the soil. There are two ways for transferring of the radionuclides present in the environment in to plants by indirect and direct methods. The first method (indirect) happens by uptake from soil through roots. When plants are grown in the contaminated soil, the radioactivity is transferred from the soil to the roots and then in shoots plant. In the end, the radioactivity is shifted to the human diet. These radionuclides will get transferred into plants together with the nutrients throughout mineral uptake and accumulation in varied components and even reach edible portions. The second method (direct) happens by absorption through aerial elements of the plants. Presence of emission (alpha, beta and gamma) in plant organs has been reviewed by varied staffs.

The are many published researches on radioactive food contamination within the environment and its transfer or pathway mechanism to plants, animals and human population. Uptake of natural radionuclides depends on the consumption rate of food, water and also the radionuclide concentrations. There are some studies which found the levels of natural radioactivity in Vegetables and Fruits samples consumed in different countries in the world. High level of NORM has already been found in Iraq soil, especially once during the war 2003. Plants are the first recipients of the radionuclides from soil. These radionuclides will get transferred into plants alongside the nutrients throughout mineral uptake and accumulate in numerous elements and even reach edible parts. In addition to it, it was chosen vegetable and fruits samples for study. As a result of within the surroundings of Iraq it grows around the year and mass folks. Thus, around the year it’s a widely taken food for mass individuals. So, the present study aimed to discover radioactive content of the vegetables and fruits consumed by infants, children and adults in Najaf Governorate, Iraq. The present study also aimed to estimate annual effective doses from consumption samples under study among various age groups.

MATERIAL AND METHODS

Sample collection and preparation

This work focuses on the vegetables and fruits consumed by the overall public in Najaf Governorate, Iraqi. Samples from thirty one vegetables and nine fruits samples were collected in study area presented in Table 1 and Table 2 respectively.

The vegetables and fruits samples were cleaned with normal water and weighed as fresh (wet) for human consumption, each sample is placed in a plastic bag and labeled by name and country of origin. Then they were kept moisture-free before radioactivity measurement in an oven for (2-4) days at a temperature of 42-44°C in order to reach a constant weight and avoid any humidity adsorption. Then the samples were crushed electronically, using electric mill for homogeneity (the loss ratio of samples when are sieved that it is very small according to mass of fresh samples), the samples were sieved (0.8-mm-pore-size sieve). Samples were packed in marinelli beakers that it is constant volume, to attain a good homogeneity of the vegetables and fruits samples for study. A high sensitive digital weighing balance (using a high sensitive digital weighing balance with a percent of ± 0.06%). At the end, the marinelli beakers were stored for about 1 month before measuring, to permit secular equilibrium to be investigated between $^{226}$Ra and $^{222}$Rn.

NaI(Tl) Gamma Ray Spectroscopy

Gamma ray spectroscopy with scintillation detector NaI(Tl) from ORTEC has an active area of "3×3" inches (Figure1), energy resolution 7.9% and efficiency of 4.6% at the 662 KeV. Energy calibration
### Table 1. Food categories of vegetables samples.

| No. | Scientific Name              | Trade Name | Code of samples | Country of origin   |
|-----|------------------------------|------------|-----------------|---------------------|
| 1   | *Solanum lycopersicum*       | Tomato     | Veg1            | Iraq (Kufa)         |
| 2   | *Solanum tuberosum*          | Potato     | Veg 2           | Iraq (Kufa)         |
| 3   | *Solanum melongena*          | Eggplant   | Veg 3           | Iraq (Kufa)         |
| 4   | *Allium cepa*                | Onion      | Veg 4           | Iraq (Kufa)         |
| 5   | *Abelmoschus esculentus*     | Okra       | Veg 5           | Iraq (Babylon)      |
| 6   | *Abelmoschus esculentus*     | Okra       | Veg 6           | Iraq (Kuw)          |
| 7   | *Cucumis melo flexuosus*     | Cucumber   | Veg 8           | Iraq (Yousefah)     |
| 8   | *Cucumis sativus*            | Cucumber   | Veg 9           | Iraq (Kufa)         |
| 9   | *Capsicum annuum*            | Pepper     | Veg 10          | Iraq (Kufa)         |
| 10  | *Apium graveolens*           | Celery     | Veg 11          | Iraq (Kufa)         |
| 11  | *Petroselinum crispum*       | Parsley    | Veg 12          | Iraq (Kufa)         |
| 12  | *Beta cicla*                 | Chard      | Veg 13          | Iraq (Kufa)         |
| 13  | *Brassica oleracea var. capitata* | Cabbage | Veg 14          | Iraq (Kufa)         |
| 14  | *Mintha virdis*              | Spearmint  | Veg 15          | Iraq (Kufa)         |
| 15  | *Ocimum basilicum*           | Basil      | Veg 16          | Iraq (Kufa)         |
| 16  | *Allium porrum*              | Leek       | Veg 17          | Iraq (Kufa)         |
| 17  | *Trigonella foenum-graecum*  | Fenugreek  | Veg 18          | Iraq (Kufa)         |
| 18  | *Portulaca oleracea*         | Purslane   | Veg 19          | Iraq (Kufa)         |
| 19  | *Solanum lycopersicum*       | Tomato     | Veg 20          | Iran                |
| 20  | *Solanum tuberosum*          | Potato     | Veg 21          | Iran                |
| 21  | *Solanum melongena*          | Eggplant   | Veg 22          | Iran                |
| 22  | *Allium cepa*                | Onion      | Veg 23          | Iran                |
| 23  | *Anethum graveolens*         | Dill       | Veg 24          | Iran                |
| 24  | *Lactuca sativa*             | Lettuce    | Veg 25          | Iran                |
| 25  | *Cucurbita pepo*             | Zucchini   | Veg 26          | Iran                |
| 26  | *Daucus Carota*              | Carrot     | Veg 27          | Iran                |
| 27  | *Brassica oleracea var. botrytis* | Cauliflower | Veg 28     | Iran                |
| 28  | *Capsicum annuum*            | Pepper     | Veg 29          | Iran                |
| 29  | *Capsicum annuum*            | Chili Pepper | Veg 30      | India               |
| 30  | *Allium sativum*             | Garlic     | Veg 31          | China               |

### Table 2. Food categories of Fruits samples

| No. | Scientific Name              | Trade Name | Code of samples | Country of origin |
|-----|------------------------------|------------|-----------------|-------------------|
| 1   | *Citrus aurantium*           | Rearrange  | Fr1             | Iraq              |
| 2   | *Punica granatum*            | Pomegranate| Fr2             | Iraq              |
| 3   | *Pyrus communis*             | Pear       | Fr3             | Iraq              |
| 4   | *Citrus lanatus*             | Watermelon | Fr4             | Iran              |
| 5   | *Malus domestica*            | Apple      | Fr5             | Iran              |
| 6   | *Musa acuminata*             | Banana     | Fr6             | Egypt             |
| 7   | *Citrus sinensis*            | Orange     | Fr7             | Egypt             |
| 8   | *Citrus limon*               | Lemon      | Fr8             | Turkey            |
| 9   | *Prunus armeniaca*           | Apricot    | Fr9             | Turkey            |
and efficiency calibration of gamma spectrometer were carried out using ($^{60}$Co, $^{137}$Cs, $^{24}$Na and $^{54}$Mn) from the Nuclear Lab. in Physics department, which has seven gamma-ray emitters ranging from 511 KeV to 2500 KeV. The lowest limit of detection (BLD) for $^{238}$U, $^{232}$Th and $^{40}$K were 3.17 Bq.kg$^{-1}$, 1.2 Bq.kg$^{-1}$ and 11.54 Bq.kg$^{-1}$ respectively.

The standard source put over the detector with a geometric match exactly to the geometrical sample form and with same distance between the sample and the detector.

In some circumstances, there may be radioactive sources present in the counting room, other than the one being measured (called radioactive background).

Thus, shield must be used to reduce the radioactive background; the shielding used in this study consists of two layers: the first one of stainless steel with width (30 mm) and the second layer lead (100 mm).

The specific activity of $^{238}$U and $^{232}$Th was measured using property of secular equilibrium with their decay products such as transition lines of $^{214}$Bi (1765 KeV) and transition lines of $^{208}$Tl (2614 KeV) respectively. While $^{40}$K was measured directly from the photo peak at 1460 KeV. The measuring time for all samples under study was 24 h.

Figure 1. The diagram of the NaI(Tl) detector.

Data Analysis & Mathematical Formula

The specific activity for each detected photo-peak was calculated in (Bq/kg) by equation:$^{14-16}$

$$A_r\left(\frac{Bq}{kg}\right) = \frac{N - N_o}{I \cdot \varepsilon \cdot m \cdot t} \quad \text{Eq.(1)}$$

Where:
- $A_r$ is the specific activity of the radionuclide in the sample;
- $N$ is the net counts of a given peak for a sample;
- $N_o$ is the background of the given peak;
- $I$ is the number of gamma photons per disintegration, $\varepsilon$ is the detector efficiency at the specific gamma-ray energy;
- $m$ is the mass of the measured sample (fresh weight in kg); and
- $t$ is the measuring time for the sample.

During this study, it was also calculated the annual effective dose. Asa result of the intake of foods was performed supported the metabolic model developed by ICRP$^{17}$ which it’s can be determined using equation:$^{5,18}$

$$D_{rf}\left(\frac{Sv}{y}\right) = \sum (C_r \cdot A_{rf}) \cdot R_f \quad \text{Eq.(2)}$$

Where:
- $D_{rf}$ is the annual effective dose;
- $C_r$ is the effective dose conversion factor of the nuclide (r) (Table 3);
- $A_r$ is the specific activity of the nuclide (r) in the ingested food (f, Bq/kg, fresh weight); and
- $R_f$ is the consumption rate of the food item (f, kg/y) table(4).$^{7,8,19}$
### Table 3. Dose convection factors for different Radionuclides in nSv.Bq\(^{-1}\)\(^{16}\)

| Age Groups          | \(^{238}\)U | \(^{232}\)Th | \(^{40}\)K |
|---------------------|------------|------------|------------|
| Adults              | 280        | 230        | 6.2        |
| Children (10year old)| 800        | 290        | 13         |
| Infant              | 960        | 450        | 42         |

### Table 4. Consumption rates for vegetables and fruits\(^{20}\)

| Food categories | \(^{*}\)Average of Consumption Rates (kg.y\(^{-1}\)) |
|-----------------|--------------------------------------------------|
|                 | Adult | Children(10 year old) | Infant |
| Green vegetables| 45    | 20                 | 10     |
| Potatoes        | 120   | 85                 | 35     |
| Root            | 170   | 110                | 60     |
| Fruit           | 75    | 50                 | 35     |

* These rates are the 97.5th percentile of the distribution across all consumers.

### Table 5. The specific activity of \(^{238}\)U, \(^{232}\)Th, and \(^{40}\)K in vegetables samples

| No. | Code of samples | \(^{238}\)U Specific activity (Bq.kg\(^{-1}\)) | \(^{232}\)Th Specific activity (Bq.kg\(^{-1}\)) | \(^{40}\)K Specific activity (Bq.kg\(^{-1}\)) |
|-----|----------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|
| 1   | Veg1           | 5.12±0.22                                  | 2.22±0.05                                  | 219.99±1.29                               |
| 2   | Veg 2          | 4.24±0.17                                  | 3.11±0.07                                  | 116.91±0.07                               |
| 3   | Veg 3          | 6.47±0.37                                  | 10.56±0.18                                 | 209.56±1.35                               |
| 4   | Veg 4          | 3.63±0.20                                  | 3.08±0.05                                  | 274.65±3.07                               |
| 5   | Veg 5          | BLD*                                      | 5.15±0.08                                  | 138.64±0.86                               |
| 6   | Veg 6          | BLD                                        | 6.64±0.11                                  | 141.51±0.92                               |
| 7   | Veg 7          | BLD                                        | 6.47±0.13                                  | 164.93±1.05                               |
| 8   | Veg 8          | BLD                                        | 5.67±0.10                                  | 193.73±1.17                               |
| 9   | Veg 9          | BLD                                        | 5.06±0.10                                  | 226.56±1.34                               |
| 10  | Veg 10         | BLD                                        | 5.76±0.12                                  | 147.16±0.95                               |
| 11  | Veg 11         | BLD                                        | 5.14±0.10                                  | 156.67±0.96                               |
| 12  | Veg 12         | BLD                                        | 5.23±0.10                                  | 206.35±1.21                               |
| 13  | Veg 13         | BLD                                        | 4.38±0.11                                  | 140.95±0.90                               |
| 14  | Veg 14         | BLD                                        | 4.90±0.09                                  | 131.52±0.84                               |
| 15  | Veg 15         | BLD                                        | 5.12±0.10                                  | 179.53±1.14                               |
| 16  | Veg 16         | BLD                                        | 4.83±0.11                                  | 236.39±1.43                               |
| 17  | Veg 17         | BLD                                        | 6.54±0.14                                  | 274.46±1.71                               |
| 18  | Veg 18         | BLD                                        | 3.75±0.08                                  | 276.89±1.35                               |
| 19  | Veg 19         | BLD                                        | 3.04±0.04                                  | 108.99±1.40                               |
| 20  | Veg 20         | 6.99±0.20                                  | 3.95±0.08                                  | 155.86±0.99                               |
| 21  | Veg 21         | 5.02±0.15                                  | 2.30±0.04                                  | 155.40±0.72                               |
| 22  | Veg 22         | 6.26±0.01                                  | 8.98±0.16                                  | 317.75±2.17                               |
| 23  | Veg 23         | 3.99±0.01                                  | 2.84±0.05                                  | 238.72±1.49                               |
| 24  | Veg 24         | BLD                                        | 6.29±0.11                                  | 180.98±1.11                               |
| 25  | Veg 25         | BLD                                        | 2.21±0.05                                  | 319.21±1.74                               |
| 26  | Veg 26         | BLD                                        | 3.11±0.07                                  | 139.92±0.88                               |
| 27  | Veg 27         | BLD                                        | 5.24±0.11                                  | 124.06±0.83                               |
| 28  | Veg 28         | BLD                                        | 3.42±0.07                                  | 140.25±0.97                               |
| 29  | Veg 29         | BLD                                        | 3.96±0.08                                  | 139.38±0.91                               |
| 30  | Veg 30         | BLD                                        | 5.23±0.10                                  | 159.27±1.03                               |
| 31  | Veg 31         | BLD                                        | 3.55±0.09                                  | 154.64±1.09                               |

Average ± S.D: 5.21±0.47, 4.76±0.34, 186.15±10.78

Worldwide median value: 35, 30, 400

* BDL a, below detection limit and b Data from UNSCEAR\(^{21}\)
Table 6. The specific activity of $^{238}$U, $^{232}$Th, and $^{40}$K in fruit samples.

| No. | Code of samples | Specific activity (Bq kg$^{-1}$) |
|-----|----------------|---------------------------------|
|     |                | $^{238}$U $^{232}$Th $^{40}$K | $^{238}$U $^{232}$Th $^{40}$K |
| 1   | Fr1            | BLD 2.85±0.06                  | 285.83±1.85       |
| 2   | Fr2            | BLD 2.04±0.05                  | 223.74±1.51       |
| 3   | Fr3            | BLD 2.51±0.06                  | 206.61±1.38       |
| 4   | Fr4            | BLD 2.63±0.06                  | 144.35±1.20       |
| 5   | Fr5            | BLD 2.14±0.05                  | 185.73±1.27       |
| 6   | Fr6            | BLD 2.92±0.05                  | 154.26±0.94       |
| 7   | Fr7            | BLD 2.58±0.06                  | 195.50±1.46       |
| 8   | Fr8            | BLD 2.73±0.06                  | 218.57±1.46       |
| 9   | Fr9            | BLD 2.37±0.05                  | 290.20±1.78       |

Average ± S.D BLD 2.53±0.106 211.64±17.96

Worldwide median value $^b$ 35 30 400

* BDL $^a$, below detection limit and $^b$ Data from UNSCEAR.21

RESULTS AND DISCUSSION:

The results of specific activity in the food samples for natural radionuclides such as $^{238}$U, $^{232}$Th and $^{40}$K, are given in Table(5) and Table(6). The highest concentrations displayed in Table 5 correspond to the naturally occurring radionuclide $^{40}$K. The highest concentration of $^{40}$K was 319.21±1.74 Bq kg$^{-1}$ which it is measured in sample Veg 25 (Lettuce, made in Iran). The spread of measured values is rather large, sample Veg 19 (Portulaca, made in Iraq) was the lowest concentration: 108.99±1.40 Bq kg$^{-1}$ with an average 186.15±10.78 Bq kg$^{-1}$. $^{40}$K was found to be the highest contributor to the activity in all food samples. In this context, $^{40}$K is a key biological element in human tissue through metabolic control. Sample Veg 20 (Tomato, made in Iran) was the food type that contained the highest concentration of $^{238}$U, at 6.99±0.20 Bq kg$^{-1}$, while the lowest concentration, at 3.63±0.20 Bq kg$^{-1}$, was measured in sample Veg 4 (Onion, made in Iraq) with an average 5.21±0.47 Bq kg$^{-1}$. The highest concentration of $^{232}$Th was 10.56±0.18 Bq kg$^{-1}$ in sample Veg 3 (Eggplant, made in Iraq), the lowest concentration of $^{232}$Th was 2.21±0.05 Bq kg$^{-1}$ in sample Veg 25 (Lettuce, made in Iran) with an average 4.76±0.34 Bq kg$^{-1}$. $^{238}$U and $^{232}$Th concentrations in all samples were lower than concentrations from other countries. The highest concentrations displayed in Table (6) correspond to the naturally occurring radionuclide $^{40}$K. The highest concentration of $^{40}$K was 290.20±1.78 Bq kg$^{-1}$ in sample Fr 9 (Apricot, made in Turkey). The spread of measured values is rather large, sample Fr 4 (Watermelon, made in Turkey) was the lowest concentration 144.35±1.20 Bq kg$^{-1}$ with an average 211.64±17.96 Bq kg$^{-1}$. All values of the specific activity of $^{238}$U were below limit detection. The highest concentration of $^{232}$Th was 2.92±0.05 Bq kg$^{-1}$ in sample Fr 6 (Banana, made in Egypt), while the lowest concentration of $^{232}$Th was 2.04±0.05 Bq kg$^{-1}$ in sample Fr 2 (Pomegranate, made in Iran) with an average 2.53±0.106 Bq kg$^{-1}$. As seen in Tables (7),(8) and fig.(2), annual effective dose from vegetables and fruits consumption by infant is larger than the dose from consumption by adults and children. This larger value for infant is due to the dose conversion factor for the radionuclide. This indicates that the annual effective dose in all vegetables and fruits samples was lower than the permissible limit of 1 mSv recommended by the International Commission on Radiological Protection.17 The table (9) consist of comparison of specific activity (Bq Kg$^{-1}$) of $^{238}$U, $^{232}$Th and $^{40}$K, in the in vegetables and fruits samples at different countries.
Table 7. Summation of annual effective dose in vegetables samples at different age groups (adults, children (10 year old) and infants).

| No. | Code of samples | Annual effective dose (mSv/y) |    |    |
|-----|----------------|-------------------------------|----|----|
|     |                | Adults                        |    |    |
| 1   | Veg 1          | 0.147                         |    |     |
| 2   | Veg 2          | 0.313                         |    |     |
| 3   | Veg 3          | 0.149                         |    |     |
| 4   | Veg 4          | 0.136                         |    |     |
| 5   | Veg 5          | 0.091                         |    |     |
| 6   | Veg 6          | 0.107                         |    |     |
| 7   | Veg 7          | 0.112                         |    |     |
| 8   | Veg 8          | 0.112                         |    |     |
| 9   | Veg 9          | 0.115                         |    |     |
| 10  | Veg 10         | 0.1                            |    |     |
| 11  | Veg 11         | 0.096                         |    |     |
| 12  | Veg 12         | 0.111                         |    |     |
| 13  | Veg 13         | 0.084                         |    |     |
| 14  | Veg 14         | 0.086                         |    |     |
| 15  | Veg 15         | 0.102                         |    |     |
| 16  | Veg 16         | 0.114                         |    |     |
| 17  | Veg 17         | 0.143                         |    |     |
| 18  | Veg 18         | 0.115                         |    |     |
| 19  | Veg 19         | 0.068                         |    |     |
| 20  | Veg 20         | 0.171                         |    |     |
| 21  | Veg 21         | 0.091                         |    |     |
| 22  | Veg 22         | 0.258                         |    |     |
| 23  | Veg 23         | 0.129                         |    |     |
| 24  | Veg 24         | 0.115                         |    |     |
| 25  | Veg 25         | 0.111                         |    |     |
| 26  | Veg 26         | 0.071                         |    |     |
| 27  | Veg 27         | 0.078                         |    |     |
| 28  | Veg 28         | 0.074                         |    |     |
| 29  | Veg 29         | 0.078                         |    |     |
| 30  | Veg 30         | 0.098                         |    |     |
| 31  | Veg 31         | 0.07                          |    |     |
|     |                | Annual effective dose (mSv/y) |    |    |
|     |                | Children (10 year old)        |    |     |
| 1   | Veg 1          | 0.15                          |    |     |
| 2   | Veg 2          | 0.493                         |    |     |
| 3   | Veg 3          | 0.218                         |    |     |
| 4   | Veg 4          | 0.146                         |    |     |
| 5   | Veg 5          | 0.065                         |    |     |
| 6   | Veg 6          | 0.074                         |    |     |
| 7   | Veg 7          | 0.079                         |    |     |
| 8   | Veg 8          | 0.082                         |    |     |
| 9   | Veg 9          | 0.087                         |    |     |
| 10  | Veg 10         | 0.071                         |    |     |
| 11  | Veg 11         | 0.069                         |    |     |
| 12  | Veg 12         | 0.083                         |    |     |
| 13  | Veg 13         | 0.061                         |    |     |
| 14  | Veg 14         | 0.062                         |    |     |
| 15  | Veg 15         | 0.075                         |    |     |
| 16  | Veg 16         | 0.089                         |    |     |
| 17  | Veg 17         | 0.108                         |    |     |
| 18  | Veg 18         | 0.092                         |    |     |
| 19  | Veg 19         | 0.049                         |    |     |
| 20  | Veg 20         | 0.173                         |    |     |
| 21  | Veg 21         | 0.568                         |    |     |
| 22  | Veg 22         | 0.234                         |    |     |
| 23  | Veg 23         | 0.141                         |    |     |
| 24  | Veg 24         | 0.083                         |    |     |
| 25  | Veg 25         | 0.094                         |    |     |
| 26  | Veg 26         | 0.054                         |    |     |
| 27  | Veg 27         | 0.062                         |    |     |
| 28  | Veg 28         | 0.055                         |    |     |
| 29  | Veg 29         | 0.058                         |    |     |
| 30  | Veg 30         | 0.071                         |    |     |
| 31  | Veg 31         | 0.06                          |    |     |

Average ± S.D 0.117±0.009 0.122±0.021 0.179±0.031
Table 8. Summation of annual effective dose in fruits samples at different age groups (adults, children (10 year old) and infants).

| No. | Code of samples | Adults | Annual effective dose (mSv.y⁻¹) | Children (10 year old) | Infants |
|-----|-----------------|--------|---------------------------------|------------------------|---------|
| 1   | Fr1             | 0.181  | 0.226                           | 0.464                  |         |
| 2   | Fr2             | 0.139  | 0.435                           | 0.36                   |         |
| 3   | Fr3             | 0.139  | 0.17                            | 0.693                  |         |
| 4   | Fr4             | 0.112  | 0.968                           | 0.253                  |         |
| 5   | Fr5             | 0.122  | 0.151                           | 0.306                  |         |
| 6   | Fr6             | 0.121  | 0.142                           | 0.271                  |         |
| 7   | Fr7             | 0.134  | 0.164                           | 0.327                  |         |
| 8   | Fr8             | 0.148  | 0.181                           | 0.363                  |         |
| 9   | Fr9             | 0.174  | 0.222                           | 0.463                  |         |

Average ± S.D 0.141±0.008 0.295±0.094 0.388±0.101

Figure 2. Summation of Annual effective dose (mSv.y⁻¹) in vegetables and fruits by all age groups.
Table 9. Comparison of specific activity (Bq/kg) of natural radio-nuclides in vegetables and fruits at different countries.

| Region/country   | Food categories | Specific activity (Bq.kg\(^{-1}\)) | Ref.  |
|------------------|-----------------|-------------------------------------|-------|
|                  |                 | \(^{238}\)U   | \(^{232}\)Th | \(^{40}\)K     |       |
| Qena/Egypt       | vegetables      | 0.01±0.02  | 0.01±0.05  | 26.65±1.24  | [5]   |
|                  | Fruits          | 2.56±1.11  | 1.22±0.56  | 536.64±23.03|       |
| Bangladesh       | vegetables      | 64.77±38.47| 83.53±0.5  | 1691.45±244.98| [6] |
|                  | Fruits          |           |           |               |       |
| Elazig’/Turkey   | vegetables      | 0.64±0.26  | 0.65±0.14  | 13.98±1.22  | [7]   |
|                  | Fruits          | 1.52±0.34  | 0.98±0.23  | 18.66±1.13  |       |
| Rize/Turkey      | Eggplant        | 0.20±0.02  | 0.52±0.06  | 517.19±51.91| [8]   |
|                  | Pepper          | 1.73±0.33  | 0.57±0.06  | 421.20±14.48|       |
|                  | Cucumber        | 1.20±0.18  | 1.37±0.41  | 366.17±19.49|       |
|                  | Tomato          | 9.43±1.28  | 1.35±0.35  | 373.03±9.67 |       |
|                  | Parsley         | 8.36±0.92  | 2.64±1.51  | 1014.72±42.64|     |
|                  | Apple           | 0.50±0.07  | 0.38±0.08  | 49.15±1.17  |       |
|                  | Lemon           | 0.36±0.04  | 0.45±0.07  | 50.47±1.20  |       |
|                  | Pear            | 0.29±0.02  | 0.25±0.03  | 40.39±0.74  |       |
| South India      | Leafy vegetable | 0.03±0.01  | 1.03±0.5   | 49.5±8.4    | [10]  |
|                  | Cucumber        | 0.097±0.02 | 0.14±0.04  | 29.67±9.1   |       |
|                  | Tomato          | 0.06±0.03  | 0.17±0.02  | 71.92±8.4   |       |
|                  | Banana          | 0.094±0.02 | 1.1±0.2    | 136.2±8.3   |       |
| Southwest India  | Cucumber        | 0.07±0.03  | 0.14±0.06  | 29.64±9.1   | [11]  |
|                  | Tomato          | 0.08±0.02  | 0.17±0.01  | 71.92±8.4   |       |
|                  | Banana          | 0.12±0.04  | 0.965±0.4  | 136.2±41.1  |       |
| Alexandria/Egypt | Carrot          | -          | -          | 42.38±3.93   |       |
|                  | Cucumber        | -          | -          | 68.55±4.34  |       |
|                  | Tomato          | 0.96±0.30  | -          | 49.48±3.45  |       |
|                  | Lettuce         | 1.05±0.48  | -          | 166.0±16.69 |       |
|                  | Potato          | 0.80±0.49  | -          | 118.75±2.34 |       |
|                  | Green okra      | 0.86±0.05  | -          | 117.98±7.32 | [12]  |
|                  | Apple           | 1.25±0.35  | -          | 32.27±2.70  |       |
|                  | Water-melon     | 0.85±0.32  | -          | 40.37±3.07  |       |
|                  | Root            | -          | -          | 210 - 448   |       |
|                  | Vegetables      | -          | -          | 490 - 510   |       |
|                  | Fruit           | -          | 2.53±0.106 | 211.64±17.96|       |
| Paraná/ Brazil   | Potato          | -          | -          | 166.7       | [22]  |
| Najaf/Iraq       | Vegetable       | 5.21±0.47  | 4.76±0.34  | 186.15±10.78| Present study |
|                  | Fruit           | -          | 2.53±0.106 | 211.64±17.96|       |

CONCLUSIONS

Natural radioactivity (\(^{238}\)U, \(^{232}\)Th and \(^{40}\)K) and annual effective dose in some samples of vegetables and fruits produced and frequently consumed in Najaf, Iraq were determined in this study. Specific activity of these radionuclides in samples under study were lower than those reported by UNSCEAR. Also it was found that...
annual effective doses due to the ingestion of all three natural radionuclides by adults, children, and infants are below the recommended limit by the World Health Organization and by the International Commission on Radiological Protection for radiological safety.

AUTHOR CONTRIBUTION

The author Ali Abid Abojassim carried out the Nuclear radiation studies, participated in the sequence alignment and drafted the manuscript. Heiyam Najy Hady read and approved the final manuscript. Zahrah Baqer Mohammed collected and arranged samples, also contributed to the collection of references of scientific.

COMPETING INTERESTS

The authors declare there are no competing interests.

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