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Transfer factor of natural radionuclides from clay loam soil to sesame and Cowpea: radiological hazards

R. Elsaman[1*], G.A.M. Ali[2*], M.A.M. Uosif[3], A. El-Taher[1], K.F. Chong[4*]

[1]Physics Department, Faculty of Sciences, Al-Azhar University, Assiut, 71524, Egypt
[2]Chemistry Department, Faculty of Science, Al-Azhar University, Assiut, 71524, Egypt
[3]Physics Department, College of Science, Jouf University, P.O. Box: 2014, Sakaka, Saudi Arabia
[4]Faculty of Industrial Sciences & Technology, Universiti Malaysia Pahang, Gambang, 26300 Kuantan, Malaysia

► ***Original article***

***Corresponding authors:**
Dr. Reda Elsaman,
Dr. G.A.M. Ali,
Dr. K.F. Chong,
E-mail:
reda_m8282@yahoo.com,
gomaasanad@azhar.edu.eg,
ckfeng@ump.edu.my

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ABSTRACT

Background: This work investigated the transfer factor of radionuclides from clay loam soil to sesame and cowpea plants. ***Materials and Methods*:** Twenty samples from the plant and twenty samples from its soil were collected from five different locations (farms). Gamma-ray spectrometry was used to determine the activity concentration for the samples. In addition, the soil physicochemical characteristics such as pH value, the amount of organic content and texture of soil were investigated by pH meter, Walkley-Black and particle size distribution (Pipette) methods, respectively. ***Results:*** The average activity concentrations, respectively, of ^{226}Ra, ^{232}Th, and ^{40}K were 12.75, 10.20 and 131.75 Bq kg^{-1} for the clay loam soil, 5.20, 4.15 and 171.00 Bq kg^{-1} for sesame and 6.70, 5.60 and 182.90 Bq kg^{-1} for cowpea. The transfer factor from soil to sesame and cowpea was discussed. The average values of transfer factor were 0.51, 0.53 and 1.36 (for cowpea) and 0.42, 0.43 and 1.33 (for sesame), respectively for ^{226}Ra, ^{232}Th and ^{40}K. The results showed that the transfer factor in cowpea is much greater than that in sesame. As a result of the ingestion of the radionuclides from the plants, the average annual dose was lower than the 290 µSv y^{-1} world average. ***Conclusion:*** Accordingly, the radiological risk due to the intake of the natural radionuclides in these plants was immaterial.

Keywords: *Natural radionuclides, clay Loam soil, transfer factor, radiological hazards.*

INTRODUCTION

Natural radionuclides such as uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K) that are produced constantly in the atmosphere are presented and broadly distributed in the earth's crust and the atmosphere (1). In addition, these nuclides usually exist in soil, waste, water, and plants (2). To provide basic information on radiation, it requires studying the levels of radiation and distribution of radionuclides in the environment. This information is necessary to understand human exposure from natural and man-made radiation sources and it is crucial for the development of radiation protection rules and regulations (3). Measuring the radioactivity in food is excessively important for restraint radiation levels to which humankind is exposed (4). Moreover, importation of contaminated nutrient from any region that faced a nuclear catastrophe can affect people wellness (5).

The elementary track of the radionuclides entrance into the human being body is planted through the food chain; therefore, the intake assessment of these radionuclides is crucial (6). The natural radioactivity in plants is important because some of them can be used as a biochemical tracer in the human food chain. Among all parameters used to estimate the concentrations of the radionuclide in plants, soil-to-plant transfer factor (TF) is the most important. Some factors affect the radioactivity transfer from soil to plants such as plant type, fertilization and the soil properties [7]. Sesame is the most conventional oilseed crop cultivated for its wholesome oil in the sub-continent. It has high oil content (50-60%) of its seeds [8]. Sesame oil is used as food, medicine and soap making. On the other hand, cowpea (Vigna unquiculata) is one of the existence of dicotyledonous leguminous nourishment crops and a major crop in many countries [9]. It is a base source of the protein for human and animal nutrition [10].

The aims of this study are: (1) to investigate the TF of radionuclides for clay loam soil to different plants (sesame and cowpea), consequently, it could be decided which plant types are preferred to grow in this soil, (2) to measure the radiological risk for providing radioactive background data for the area of investigation and (3) to determine the annual effective dose from sesame and cowpea consumption. This study helps in the establishment of a database of transfer factor and radioactivity exposure to the community from the consumption of sesame and cowpea.

MATERIALS AND METHODS

Samples elaboration

For each plant, 10 samples from the plant and 10 samples from its soil were collected from five different locations (farms) in Minia governorate in Egypt (figure 1). The five different locations are coded by (S1 to S5) as shown in figure 1. The geographical area of Minia governorate is about 32279 km^2 and it is located about 225 km south of Cairo. Minia is considered as an important agricultural region in Egypt where it has around 6% of the total agricultural lands and it produces potatoes, cotton, corn, and wheat. Its climate is classified as a hot desert and it has a wide difference of temperatures between days and nights among all Egyptian areas. It has unforgiving and nippy chilly winter climate and exceptionally sweltering yet non-muggy summers.

The elemental analysis of the soil was performed using X-ray fluorescence. The soil physicochemical characteristics such as pH value, the amount of organic content and texture of soil were investigated by pH meter, Walkley-Black and particle size distribution (Pipette) methods, respectively. Soil samples usually collected from plow depth (0-30 cm). Sesame and cowpea were collected from the same type of soil (clay loam) at harvest time. Soil specimens were dried at 110 °C for 24 h, while sesame and cowpea were dried at 70 °C. Plant samples (seeds) were ground at first and then sieved. The soil specimens were crushed, homogenized and sieved (200 µm). Sesame and cowpea samples were sieved through a 555-µm sieve. Polyethylene (250 mL) beaker was used as a container for each sample. To reach secular equilibrium, the sample containers were closed for 28 days when the decay rate of the daughters and parent becomes equal [11].

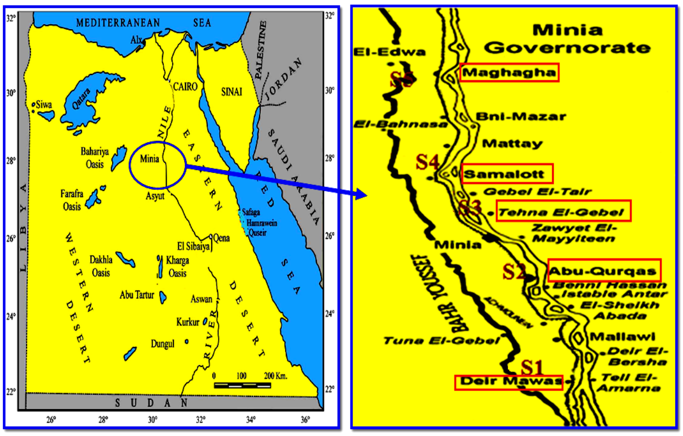

Figure 1. Locations map of the studied samples.

Radioactivity determinations

The samples were analyzed using a gamma-ray spectrometer, employing a NaI (Tl) 3×3 inch (Model 802) scintillation detector with a 2048 multichannel analyzer (MCA, Canberra Co., USA) and nuclear analysis software (Genie 2000). To absorb X-rays generated in the shield, it contained an inner concentric cylinder of copper (0.3 mm thick). To correct the net peak area of the gamma rays of the measured isotopes, an empty sealed beaker was used as a plank to investigate the background distribution in the detector environment. The 351.9 keV γ-peaks of ^{214}Pb and 609.3 keV, 1120.3 keV, 1728.6 keV, and 1764 keV γ-peak of ^{214}Bi have been used to estimate ^{226}Ra radionuclide. Moreover, the 911.2 keV γ-peak of ^{228}Ac and the 238.6 keV γ-peak of ^{212}Pb have been used to estimate the ^{232}Th radionuclide. While the 1461 keV γ-peak from ^{40}K itself has been used to estimate the ^{40}K radionuclide (12). The lower limit of detection (LLD) was 2.4, 1.4 and 5.8 Bq kg^{-1} (soil) and 1.2, 1.3 and 5 Bq kg^{-1} (plants) for ^{226}Ra, ^{232}Th and ^{40}K, respectively. ^{60}Co (1173.2 and 1332.5 keV), ^{133}Ba (356.1 keV) and ^{137}Cs (661.9 keV) were used as standard sources for detection array energy calibration. In addition, the efficiency calibration curve was obtained using the International Atomic Energy Agency (IAEA-314) reference materials which contains these radionuclides with known specific activities. Figure 2 shows an example of the energy spectra of the plant sample which compare the gamma-ray lines to the background.

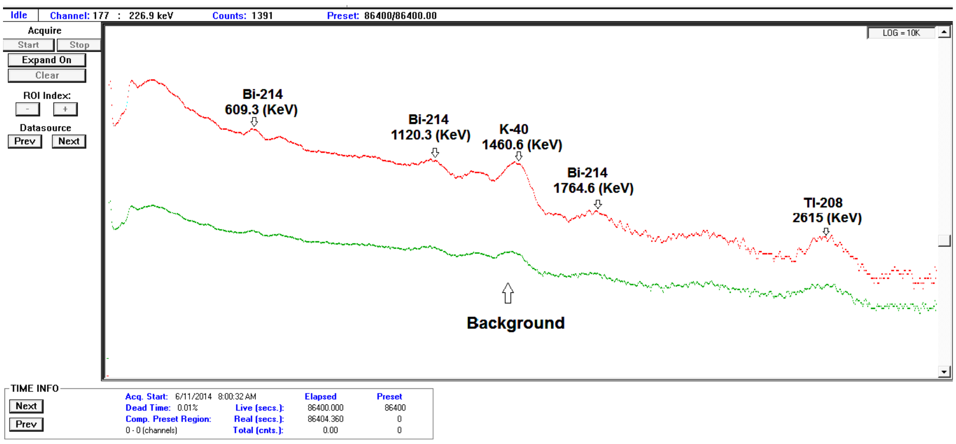

Figure 2. Typical gamma-ray lines spectrum of plant sample and background.

Activity concentrations

The values of activity concentrations (C_A) of ^{226}Ra, ^{232}Th, and ^{40}K in the collected samples of soil and plants were calculated by equation (1) (13).

$$C_A = \frac{C_n}{\varepsilon \times P_\gamma \times m} \quad (1)$$

Where C_n is the count rate under the corresponding peak, ε is the detector efficiency, P_γ is the absolute transition probability of the specific γ-ray and m is sample weight (kg).

The uncertainty of activity determinations

On the other hand, the uncertainty of activity (u(A)) was calculated to correct the specific activity to actual activity using equation (2) (14, 15).

$$u(A) = \sqrt{[u(N_P)(N_P)]^2 + [u(\eta)(\eta)]^2 + [u(m)(m)]^2} \quad (2)$$

Transfer factor determinations

TF was obtained as the ratio of the radionuclide concentrations in the plants (P) and soil (S) as TF=P/S (16).

Radiological hazards estimations

Radium equivalent activity (Ra_{eq}) as defined by equation (3) (3, 17) is a widely used hazard index (18, 19).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (3)$$

Where A_{Ra}, A_{Th}, and A_K are ^{226}Ra, ^{232}Th, and ^{40}K activities, respectively.

Assuming the uniform distribution of the naturally occurring radionuclides, the dose rate (D, nGy h^{-1}) at 1 m above the ground surface [20, 21], the representative level index (I_γ) and the annual effective dose rate (D_{AE}, μSv y^{-1}) are calculated by equations (4), (5) and (6), respectively [3, 22, 23]. Excess Lifetime Cancer Risk (ELCR) is determined using equation (7) [24, 25].

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.417A_K \quad (4)$$

$$I_\gamma = 0.0067A_{Ra} + 0.01A_{th} + 0.00067A_K \quad (5)$$

$$D_{AE} = D \times T \times F \quad (6)$$

$$ELCR = AED \times DL \times RF \quad (7)$$

Where T is the outdoor occupancy time and F is the conversion factor. DL is the duration of life (30-70 y) and RF is risk factor (Sv^{-1}).

Finally, the committed effective radiation dose (M (Sv y^{-1})) was estimated by equation (8) [26, 27]:

$$M = A \times E \times I \quad (8)$$

Where E is the dose conversion factor and I is the annual intake of these plants (kg). E values (0.2800, 0.2300 and 0.0062 mSv Bq^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively) were selected based on the International Commission on Radiological Protection classifications for adults. Values of I were taken as 28 kg y^{-1} for cowpea and 68 kg y^{-1} for sesame.

Statistical analysis

The statistical analysis is the science of collecting, exploring and presenting large amounts of data to discover underlying patterns and trends. Statistics are applied every day – in research and industry to become more scientific about decisions that need to be made. The environmental system could be managed through the multivariate treatment of environmental data which is commonly used to describe the relationship of the variables [28, 29]. The main statistical software used was SPSS 22.

RESULTS AND DISCUSSION

The elemental analysis and physicochemical characteristics

The major range values of elemental analysis were: MgO (1.2-1.9%), Al_2O_3 (9.5-12.5%), SiO_2 (39.7-56.1%), K_2O (1.2-1.3%), CaO (5.4-7.3%), TiO_2 (2.2-4.7%), MnO (0.2-0.6%) and Fe_2O_3 (15.6 -21.7%). The pH range was 7.7-8.0, the quantity of organic matter ranged from 0.8 to 1.6% and texture of soil was clay loam. The effect of soil pH on radionuclides uptake can be illustrated based on the action of hydrogen and hydroxyl bonding with the cations [30]. Briefly, at low pH (acidic soils), there are more available adsorbed cations to plants as a result of its replacement with hydrogen. Therefore, high transfer of these radionuclides to plants takes place and consequently, their radionuclides in the soil decreased. On the other hand, at high pH (alkaline soils) the radionuclides form insoluble precipitates with COO^-, OH^- or S^{-2} which reduce the availability of radionuclides for plants. Therefore, less transfer from soil to plants takes place and still have a high concentration in the soil.

Soil radioactivity

The activity concentrations and its total uncertainties resulting from ^{226}Ra, ^{232}Th, and ^{40}K for soil samples have been listed in table 1. The activity concentrations values in soil ranged from 9±0.5 to 18± 0.9, 7±0.3 to 13±0.6 and from 119±5.8 to 149±7.9 Bq kg^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively. Based on the world average concentrations [26] which recommends a reference level for ^{226}Ra (30 Bq kg^{-1}), ^{232}Th (35 Bq kg^{-1}) and ^{40}K (400 Bq kg^{-1}), it is observed that the values of specific activities in the soil samples of this study are less than the world average limits. The detected radionuclides in soil and plants were ^{226}Ra, ^{232}Th, and ^{40}K and their levels are displayed in table 1. The table gives the relationships between ^{226}Ra, ^{232}Th and ^{40}K concentrations in the plants and soil. It can be seen that the higher radionuclide concentration in the soil leads to a higher concentration in plants.

Table 1. Activities of ^{226}Ra, ^{232}Th, and ^{40}K in clay loam soil, sesame, and cowpea.

Soil Texture	Activity Concentrations in (Bq Kg^{-1})					
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
	Soil			**Sesame**		
Clay loam	12±0.6	10±0.5	140±7.9	3±0.1	3±0.2	189±9.2
	13±0.7	11±0.4	133±7.1	4±0.1	7±1	166±8.9
	9±0.5	8±0.4	125±6.8	4±0.1	4±0.1	130±6.2
	11±0.5	10±0.5	135±7.3	6±0.3	4±0.2	150±7.3
	10±0.4	10±0.6	123±6.5	3±0.1	4±0.2	180±9
	11±0.5	11±0.6	123±6.4	6±0.3	4±0.2	177±8.5
	13±0.5	9±0.5	120±6.1	7±0.3	3±0.1	185±8.7
	15±0.7	10±0.5	119±5.8	7±0.3	4±0.2	180±8.6
	18±0.9	12±0.6	133±7.1	7±0.3	5±0.2	170±7.9
	11±0.5	7±0.3	137±7.6	5±0.2	3.5±0.1	183±8.8
	Soil			Cowpea		
	16±0.8	13±0.6	137±8	8±0.4	7±1	184±9.1
	11±0.5	10±0.5	130±6.9	6±0.2	4±0.3	186±9
	12±0.6	10±0.5	133±7	5±0.2	8±1.1	182±9
	13±0.7	11±0.6	138±8	7±0.3	8±0.4	186±9.1
	11±0.5	10±0.5	136±7.5	6±0.2	5±0.2	181±8.9
	14±0.6	11±0.5	131±6.5	7±0.3	6±0.2	180±8.7
	16±0.8	11±0.6	134±6.6	9±0.5	5±0.2	185±9
	11±0.5	9±0.4	138±8	6±0.3	4±0.1	183±8.5
	13±0.5	10±0.5	135±6.5	6±0.3	4±0.1	183±8.5
	15±0.6	11±0.5	135±6.6	7±0.4	5±0.2	179±8

	Soil			**Sesame**			**Cowpea**		
Min.	9±0.5	7±0.3	119±5.8	3±0.1	3±0.2	130±6.2	5±0.2	4±0.3	179±8
Max.	18±0.9	13±0.6	140±7.9	7±0.3	7±1	189±9.2	9±0.5	8±0.4	186±9.1

The average of the activity concentrations in soil was compared with those listed in table 2. As can see from table 2, ^{226}Ra, ^{232}Th and ^{40}K values from the present work are less than the studies in the listed countries, except data reported for Nigeria [(1)]. The radiation activity change in soils of different countries is maybe due to the wide change in geological formations of various types of soils [(31)].

Statistical behavior includes the mean, median and standard deviation (SD). Table 3 shows the statistical values of the experimental data. The basic statistics show that the mean of activity concentrations are different from each other but are close within the SD.

Table 2. Comparison of the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil, sesame, and cowpea with other reported values.

Country, location (year)	Samples	Activity (Bq kg^{-1})			Ref.
		^{226}Ra	^{232}Th	^{40}K	
Egypt, Minia (2017)	Soil	12.75	10.20	131.75	Present work
Nigeria, Gombe state (2017)	Soil	11.90	17.72	70.44	(1)
Turkey, Rize province (2010)	Soil	85.75	51.08	771.57	(13)
Jordan, Ma'an (2014)	Soil	57.70	18.10	138.10	(3)
Algeria, Sétif (2011)	Soil	53.20	50.03	311.00	(32)
Egypt, Minia (2017)	Sesame	5.20	4.15	171.00	Present work
	Cowpea	6.70	5.60	182.90	
Egypt, Inshas (2008)	Sesame	7.80	14.30	195.200	(33)
Turkey, Gediz Basin (2007)	Cowpea	52.80	9.80	1099.29	(34)

Table 3. Descriptive statistics of specific activities (in Bq kg^{-1}).

Variables	Soil			Sesame			Cowpea		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
Mean	12.80	10.20	131.75	5.20	4.15	171.00	6.70	5.60	182.90
Median	12.50	10.00	133.5	5.50	4.00	178.50	6.50	5.00	183.00
Std. deviation	2.31	1.32	6.34	1.62	1.16	18.29	1.16	1.58	2.42

Sesame and cowpea radioactivity

The radionuclide concentrations and its total uncertainties in sesame and cowpea grains are presented in table 1. The activity concentrations values in sesame ranged from 3±0.1 to 7±0.3, 3±0.2 to 7±1 and from 130±6.1 to 189±9.2 Bq kg^{-1}, while in cowpea ranged from 5±0.2 to 9±0.5, 4±0.3 to 8±0.4 and from 179±8 to 186±9.1 Bq kg^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively. The highest radionuclides concentrations in cowpea samples are for ^{226}Ra and ^{232}Th, while in sesame samples ^{40}K shows the highest concentration. The differences in the concentration of the radionuclides might be due to variations in the plants geographical area and the radiological composition of the soil. Where the levels of natural radionuclides concentration are not normalized around the world, also the ability of the plant to consume the elements. Observably, the radionuclides activity concentration varies based on their half-life [35]. The high concentration of K detected in the sesame and cowpea plants is due to using of K-containing fertilizers to the soil [35]. So the high activity concentration of ^{40}K in most soil is attributed to the high applications of potassium-containing fertilizer. As well as, ^{40}K showed higher values in the plant samples than the soil. This could be attributed to ^{40}K activities have a tendency to decrease in the deep layers of agricultural soil. The decrease of ^{40}K with depth is due to the action of irrigation water which dissolves Th and K compounds [36]. Moreover, the uptake, retention and distribution profile of radionuclides in plants are strongly affected by the soil characteristics such as pH, clay mineral, Ca, K and organic contents, and fertilizer used.

Transfer factor for natural radioactivity

Average obtained TF results are presented in table 4. The transfer factor is in the range of 0.25 -0.55, 0.30-0.64 and 1.04-1.54 for the ^{226}Ra, ^{232}Th, and ^{40}K, respectively, for sesame. While in cowpea the transfer factor varies in the range of 0.46-0.56, 0.40-0.80 and 1.33-1.43 for the ^{226}Ra, ^{232}Th, and ^{40}K, respectively. These values are higher than the default values (0.04, 0.05 and 1 for ^{226}Ra, ^{232}Th, and ^{40}K, respectively). The average values of the transfer factor are 0.51, 0.53 and 1.36 (for cowpea) and 0.42, 0.43 and 1.33 (for sesame), respectively for ^{226}Ra, ^{232}Th and ^{40}K. This may be related to the morphological characteristics of the plants such as higher weight and size of cowpea seed which allows a high amount of the radionuclides to be collected and accumulated. In addition, sesame has high mineral content, giving a low chance to accept a high amount of radionuclides [37]. The high TF for ^{40}K may be due to the continuous accumulation of ^{40}K through root uptake where K is an essential macronutrient for metabolism and taken up by plants from the soil in varying amounts [38]. In addition, ^{232}Th compounds have low solubility [38]. It was noticed that the transfer in cowpea plant is higher than that in sesame, which may indicate why cowpea has higher concentrations than sesame for the detected radionuclide .In addition, other factors such as the type of radionuclide and type of plant may alter the radioactivity transfer rate [7]. The average values of transfer factor for ^{226}Ra, ^{232}Th, and ^{40}K from clay loam soil to sesame and cowpea in comparison with some other reported studies are listed in table 5. It could be seen, the mean values of TF are very close to those obtained for other plants.

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Table 4. Transfer Factor from Soil to Sesame and Cowpea.

Soil Type	Transfer Factor (TF)					
	Sesame			Cowpea		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
Clay loam	0.25	0.30	1.35	0.50	0.54	1.34
	0.31	0.64	1.25	0.55	0.40	1.43
	0.44	0.50	1.04	0.42	0.80	1.37
	0.55	0.40	1.11	0.54	0.73	1.35
	0.30	0.40	1.46	0.55	0.50	1.33
	0.55	0.36	1.44	0.50	0.55	1.37
	0.54	0.33	1.54	0.56	0.45	1.38
	0.47	0.40	1.51	0.55	0.44	1.33
	0.39	0.42	1.28	0.46	0.40	1.36
	0.45	0.50	1.34	0.47	0.45	1.33
Average+SE	0.42+0.03	0.43+0.03	1.33+0.05	0.51+0.02	0.53+0.04	1.36+0.01

Table 5. Comparison of average transfer factors from clay loam soil to sesame and cowpea with other studies.

Country, location (year)	Sample type	Transfer factor			Ref.
		^{226}Ra	^{232}Th	^{40}K	
Egypt, Minia (2017)	Cowpea	0.51	0.53	1.36	Present work
	Sesame	0.42	0.43	1.33	
Ghana, Greater Accra (2017)	Vegetables	0.53	----	13.29	(39)
Malaysia, Penang (2015)	Rice	0.018	0.009	0.235	(40)
Malaysia, Sungai Besar (2015)	Rice	0.26	0.37	0.91	(41)
Palestine, Tulkarem (2014)	Leaves	0.60	0.31	1.70	(42)
Saudi Arabia, Qassim (2013)	Plants	0.12	----	0.16	(43)
International Atomic Energy Agency, Vienna (1982)	Plants	0.04	0.05	1.00	(44)

Radiation dose estimation

Ra_{eq}, I_γ, ELCR, D as well as D_{AE} due to external exposure of the ^{226}Ra, ^{232}Th, and ^{40}K from the soil samples are summarized in table 6. The values of Ra_{eq} were calculated using equation (2) and varied from 29.1 to 44.5 Bq kg^{-1} with 36.2 Bq kg^{-1} a mean value. To keep the external dose <59 nGy y^{-1}, the maximum value of Ra_{eq} should be less than 370 Bq kg^{-1} (45). The D values were in the range: 14.5 to 21.4 nGy h^{-1} with arithmetic mean value of 17.3 nGy h^{-1}, those are lower than the allowed maximum value of 59 nGy h^{-1} (19). On the other hand, D_{AE} values were in the range from 17.6 to 25.9 µSv y^{-1} with arithmetic mean value of 21.4 µSv y^{-1}, the findings are lower than the world average values at 70 µSv y^{-1} (19). Both D and D_{AE} values follow the trend of the distribution of the naturally occurring radionuclide and in an agreement with early radiation survey predictions. The Iγ values for the samples under investigation are lower than unity (20). Finally, from table 6, the highest average of excess lifetime cancer risk (ELCR) is 9.07×10^{-5}, this value is lower than the international limit 29×10^{-3} (26).

Ingestion dose

The ingestion dose due to each radionuclide showed that the consumption total dose received from all radionuclides of sesame (96.97, 64.91, 72.09 and 233.97 µSv y^{-1} for ^{226}Ra, ^{232}Th, ^{40}K and the total, respectively) and cowpea (125.19, 87.58, 77.11 and 289.88 µSv y^{-1} for ^{226}Ra, ^{232}Th, ^{40}K and the total, respectively) for the adult was found to be lower than the 290 mSv y^{-1} world average of the ingestion exposure declared by UNSCEAR (26).

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Table 6. The equivalent radium (Raeq), dose rate (D), annual effective dose (DAE), hazard index (Iγ) and excess lifetime cancer risk (ELCR) for soil.

Soil texture	Ra_{eq} (Bq kg^{-1})	Dose rate (nGy h^{-1})	DAE (μSv y^{-1})	Hazard indices	
				$I_γ$	ELCR $×^{5-}$10
Clay loam	34.7	16.9	20.5	0.26	7.17
	36.9	17.9	21.7	0.27	7.61
	29.1	14.5	17.6	0.22	6.16
	33.0	16.1	19.6	0.25	6.86
	31.8	15.7	19.0	0.25	6.66
	34	16.4	20.0	0.26	6.99
	34	16.5	20.0	0.25	7.01
	38	18.1	22.0	0.28	7.71
	44.5	21.4	25.9	0.33	9.07
	29.5	14.5	17.7	0.23	6.18
	44.2	21.3	25.9	0.33	9.07
	34.4	16.9	20.5	0.26	7.19
	35.6	17.5	21.2	0.27	7.42
	38.4	18.8	22.8	0.29	7.98
	34.8	17.2	20.8	0.27	7.30
	38.9	18.9	22.9	0.29	8.03
	41.1	19.9	24.1	0.31	8.45
	33.5	16.6	20.1	0.26	7.05
	36.8	18.0	21.8	0.28	7.64
	40.2	19.5	23.7	0.30	8.29
Min.	29.1	14.5	17.6	0.22	6.16
Max.	44.5	21.4	25.9	0.33	9.07
Mean+SD	36.2+4.2	17.3+1.9	21.4+2.3	0.27+0.029	7.49+0.82

CONCLUSION

The transfer factor for ^{226}Ra, ^{232}Th, and ^{40}K from the soil to sesame and cowpea was studied and discussed. The obtained results show that the values of transfer factor are very close to those reported in the literature, therefore, it is recommended to grow the sesame in clay loam soil. On the other hand, the consumption annual effective dose of sesame (96.97, 64.91, 72.09 and 233.97 μSv y^{-1} for ^{226}Ra, ^{232}Th, ^{40}K and the total, respectively) and cowpea (125.19, 87.58, 77.11 and 289.88 μSv y^{-1} for ^{226}Ra, ^{232}Th, ^{40}K and the total, respectively) were found to be of extremely less than the the ingestion exposure world average (290 μSv y^{-1}). This study helps in the establishment of a database of transfer factor and radioactivity exposure to the community from the consumption of sesame and cowpea.

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