Chapter 13
Natural Radioactivity, Transfer Factor and Associated Radiological Risk in Commercially Cultivated Yam (*Dioscorea Rotundata*) in Northcentral Nigeria

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Abstract Human food chain can become contaminated either by direct radionuclide deposition, absorption from radionuclide-polluted soil and water by plant roots and direct ingestion of polluted plants, soil or water by animals. In this study, activity concentrations of primordial radionuclides in soil and yam (*Dioscorea rotundata*) samples from a commercially cultivated yam farm in northcentral Nigeria were analyzed using a $3'' \times 3''$ NaI(Tl) gamma detector. Results show that mean specific activities of ^{238}U, ^{232}Th and ^{40}K in soil and yam samples were 40.36 ± 3.97, 14.71 ± 0.80, 385.63 ± 16.54 Bq kg^{-1}, and 31.11 ± 4.00, 11.82 ± 0.72, 466.96 ± 27.20 Bq kg^{-1} respectively, which are within limits of safety set by the United Nations Scientific Committee on the Effect of Atomic Radiation. The average absorbed dose for soil samples was 43.63 nGy h^{-1} with corresponding mean annual effective dose of 0.05 mSv y^{-1}. Yam samples recorded mean absorbed dose rate of 42.61 nGy h^{-1} with corresponding mean annual effective dose of 0.05 mSv y^{-1}, which were within international safety limits. Computed average soil-to-yam transfer factor was 0.70, 0.83 and 1.23 respectively for ^{238}U, ^{232}Th and ^{40}K. Transfer factors for ^{238}U and ^{232}Th

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were below unity, while for ^{40}K was significantly moderate, showing that bioaccumulation of natural radionuclides in the Nigerian grown yam does not pose any immediate radiological threat for public consumption. The yam tubers are therefore fit, not just for consumption, but also for export to other nations from a radiological perspective. Routine radiological checks of food crops are however encouraged in compliance with the ALARA provisions.

13.1 Introduction

Radiological contamination of dietary pathways by naturally occurring radionuclides has attracted great attention from a radiation protection perspective [1, 2]. The human food chain can become radiologically contaminated either by direct radionuclide deposition on plant leaves, uptake from contaminated soil and water by plant roots, and direct ingestion of contaminated plants, soil, water and animals [3]. Additional contamination pathway is fertilizer application to cultivated farms. Fertilizers, especially the phosphate based ones, are known to contain appreciable concentration of naturally occurring radioactive materials (^{238}U, ^{232}Th, and ^{40}K) and their radioactive daughters. Thus, extensive use of fertilizers in the agriculture sector for improved nutrient supply and increase crop yield can increase the amount of radionuclides in soils and consequential ingestion by humans through the food chain. One of the most potent exposure routes by which radionuclides get into the human body is by direct and/or indirect ingestion of contaminated agricultural and livestock products [4]. Radionuclides that enter the human body contribute essentially to the total radiation dose to different human body organs and constitute a long-term challenge to human health and safety [5, 6]. It is therefore important that the contamination levels of agricultural soils and agricultural products be investigated and the rate of radionuclide uptake be assessed via the transfer factor.

A very essential index for accurately predicting radionuclide migration from soil to plants and adequately estimating radionuclide concentrations in plants is the soil-to-plant transfer factor (TF) [7, 8]. TF is the proportion of radionuclide activity in a given plant to its corresponding activity in soil. It is one of the essential parameters in assessing the internal dose to humans via the ingestion route. TF is a critical parameter in the study of the impact of radionuclide releases in the human environment. Bioaccumulation of radionuclides in soils and their subsequent migration to plants are greatly affected by the nature of vegetation, soil types and soil pH, climatic conditions and solid/liquid distribution coefficient [9, 10]. It is therefore expedient to constantly undertake a localized assessment of TFs to estimate dose impact on the human population and assure food safety from the perspective of radiation protection. It will also help in modelling and predicting the future accumulation of primordial radionuclides in locally cultivated food crops. Several studies have been conducted in many countries to evaluate soil-to-plant transfer factors (TF) of natural and artificial radionuclides for most staple food crops. This study is one of the few that has been conducted in Nigeria.

Yam (*Dioscorea rotundata*) is one of the most staple food in Nigeria. North central Nigeria in particular is a region that is known for the cultivation and consumption of yam tubers. With the current drive by the Nigerian government towards making the agricultural sector the sole alternative economic base, Nigeria is now targeting huge foreign exchange earnings from the export of this commodity. This investigation has therefore become necessary to ensure that all agricultural products exported out of Nigeria meet international safety standards from a radiation protection perspective.

According to Jibiri et al. [5], "the three principal objectives pursued by the United Nations for sustainable food security include (i) ensuring access of all people to sufficient, nutritionally adequate and safe food; (ii) continued and sustainable contribution of agriculture to economic and social progress, and (iii) conservation and sustainable utilization of natural resources, including land, water, and genetic resource base for food and agriculture". In compliance with the protocols for sustainable food security of the United Nations [11], therefore, it is paramount that radiological safety of all foodstuffs meant for human consumption at all levels is not compromised. This study therefore is aimed at determining the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Nigerian yam tubers and to evaluate the bioaccumulation status of these radionuclides. Results from this research will help in setting up radiometric control standards that will keep the effective doses due to ingestion of Nigerian foodstuffs as low as reasonably achievable.

13.2 Materials and Method

13.2.1 Sample Collection

Fifteen (15) commercially cultivated yam (*D. rotundata*) samples and their corresponding soil samples were collected randomly throughout the farm for analysis. This ensures that each yam plant and soil has equal probability of being sampled thus eliminating biased representation. At every sample collection point, the soil samples were cleaned of every contaminant like shrubs and pebbles. The samples were thereafter packaged into well labelled polyethylene bags for proper identification and preservation. Similarly, yam samples were thoroughly cleaned and sun-dried for about 3 h to eliminate surface moisture after which they were packed in clean, well-labelled bags for proper identification. Both the yam and the corresponding soil samples were finally transported to the laboratory for further preparation.

13.2.2 Sample Preparation

Soil samples were dried openly at room temperature for 72 h in the laboratory until a constant weight was achieved; indicating complete elimination of moisture content.

The dry soil samples were grounded thoroughly into powder and sieved with 2 mm sieving mesh. 371.9 ± 0.2 g of each soil sample was packed into sample containers, correctly labeled and tightly closed to stop radon gas from leaking away, since its daughter product, ^{214}Bi which is used to evaluate the concentration of the parent nuclide (^{238}U), must be allowed to accumulate with time. The sealed samples were then stored for a period of thirty five (35) days to allow for secular equilibrium between the primordial radionuclides and their decay daughters [12, 13].

Likewise, yam samples were peeled. The edible portions were sliced into pieces, thoroughly washed with deionized water and dried at room temperature for 72 h to guarantee zero moisture content in the samples. The dry yam samples were grounded into powder, sieved with 2 mm mess sieve and assiduously homologized. 180.8 ± 0.1 g of the homologized samples were filled into plastic sample containers which were labelled accurately, sealed at three levels and finally stored for thirty five (35) days for radiological equilibration before gamma spectrometric analysis.

13.2.3 Sample Analysis

Each sample (soil and yam) was radiometrically analysed using a 3″ × 3″ NaI(Tl) detector by Scintillation Technologies USA, at Ladoke Akintola University of Science and Technology Ogbomosho (LAUTECH), Nigeria. The detector which is coupled to a computer based multichannel analyzer (MCA) with ACCUSPEC computer program used for data acquisition and gamma spectra analysis is housed in a 6 cm thick lead shield to reduce the background radiation levels. The inside of the detector is also lined with cadmium and copper sheets to minimize spectrum interference by foreign frequencies. Efficiency and energy calibration of the detector was carried out before analysis using ^{137}Cs and ^{60}Co standard isotopic sources over the energy range of 200 keV to 2.810 meV. The background was obtained by counting an empty sealed sample container similar to that of the samples for 36,000 s. Each sample was afterward counted for the same period as the empty container. Activity concentration of ^{238}U was determined from the 1764 keV gamma ray line of ^{214}Bi, while ^{232}Th activity was evaluated from 2614 keV gamma ray line of ^{208}Tl. Activity concentration of ^{40}K was obtained from its single gamma transition of 1460.822 keV. Activity concentrations, A, of ^{238}U, ^{232}Th and ^{40}K were calculated using the equation [14–16]:

$$A\left(\text{Bq kg}^{-1}\right) = \frac{C}{\varepsilon_\gamma \times I_\gamma \times M} \tag{13.1}$$

where C (counts per second) is the net count rate of each sample, ε_γ (E) is the detector photo-peak efficiency (%) at respective gamma-ray peak, I_γ is the corresponding gamma ray intensity and M is the sample mass in kg.

13.2.4 Computation of Radiation Hazard Indices

Hazard indices used in this study to quantify the radiation burden on the population as a result of exposure are as follows:

Radium Equivalent Activity (Ra_{eq}). Cumulative assessment of radiation hazard associated with ^{238}U, ^{232}Th and ^{40}K was done using radium equivalent activity. It's a single index computed based on the fact that same gamma dose is produced by 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K[17–19]. Ra_{eq} was calculated from the equation [12, 17]:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \tag{13.2}$$

where A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively in Bq kg^{-1}.

Absorbed Dose Rate (D_R). Dose rate in air at 1 m above ground level due to gamma ray emissions from primordial radionuclides was computed using the equation [12, 18, 19]:

$$D_R\left(nGy\ h^{-1}\right) = 0.462A_U + 0.604A_{Th} + 0.0417A_K \tag{13.3}$$

where A_U, A_{Th} and A_K are the respective activity concentrations obtained from Eq. (13.1), 0.462, 0.604 and 0.0417 Bq kg^{-1} are conversion factors for ^{226}Ra, ^{232}Th and ^{40}K respectively provided by UNSCEAR [20].

Annual Effective Dose Equivalent (AEDE). The factor of 0.70 Sv Gy^{-1} which converts absorbed dose rate to effective dose, and the outdoor occupancy factor of 0.2, were used in computing the annual effective dose equivalent. It was assumed that about 20% of the total time of an individual is spent outdoor [12]. AEDE (measured in mSv y^{-1}) in outdoor air, was computed from Eq. (13.4).

$$AEDE\left(mSv\ y^{-1}\right) = D_R \times 1.21 \times 10^{-3} \tag{13.4}$$

External Hazard Index (H_{ex}). Radiation hazard acquired by an individual due to gamma dose exposure was evaluated using the external hazard index. H_{ex} was calculated from the equation [12, 18]:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{13.5}$$

Internal Hazard Index (H_{in}). Internal hazard index give an indication of the likelihood of radiation incidence occurring in respiratory organs as a result of internal susceptibility to radon and its daughters. H_{in} was computed using the equation [12]:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{13.6}$$

where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. UNSCEAR [12] provides the limit of unity for both H_{ex} and H_{in} below which any radiation incidence is inconsequential.

Excess Life Cancer Risk (ELCR). A measure of probability of occurrence of cancer incidence due to radiation exposure is expressed by the excess life cancer risk. ELCR was computed using the calculated AEDE from the equation [19, 21]:

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \tag{13.7}$$

where DL is the stipulated life span of 70 years and RF is risk factor of 0.05 Sv^{-1} for stochastic effects [22].

13.2.5 Transfer Factor (TF)

The rate of migration of radionuclides from soil to plants in evaluated using the transfer factor. TFs which were obtained from the activity concentrations of primordial radionuclides in both soil and yam samples were computed from the equation [23, 24]:

$$TF = \frac{Activity\ concentration\ of\ a\ given\ radionuclide\left(\text{Bq kg}^{-1}\ dry\ weight\right)}{Activity\ concentration\ of\ the\ radionuclide\ in\ soil\left(\text{Bq kg}^{-1}\ dry\ weight\right)} \tag{13.8}$$

For the computation of TFs in this research, average activity concentration in upper 20–25 cm top soil layer was considered. TF values less than unity shows a low or inconsequential plant uptake of radionuclides from the soil, while values above unity give an indication of active radionuclide bioaccumulation.

13.3 Results and Discussion

Activity concentrations of primordial radionuclides in soil samples along with the corresponding radiation hazard indices are presented in Table 13.1.

Activity concentration of ^{238}U ranged from 8.39 ± 1.37 to 51.18 ± 6.42 Bq kg^{-1} with an average value of 40.36 ± 3.97 Bq kg^{-1}, while that of ^{232}Th ranged from 8.39 ± 0.50 to 21.68 ± 1.25 Bq kg^{-1} with a mean value of 14.71 ± 0.80 Bq kg^{-1}.

Table 13.1 Activity concentrations (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in soil samples

S. No	Sample ID	Activity concentrations (Bq kg^{-1})			
		^{238}U	^{232}Th	^{40}K	Ra_{eq}
1	SSS 01	14.26 ± 1.74	20.25 ± 1.20	383.75 ± 12.29	72.77
2	SSS 02	15.80 ± 2.26	13.69 ± 0.81	267.84 ± 14.07	56.00
3	SSS 03	70.55 ± 4.70	16.98 ± 0.53	436.93 ± 22.92	128.48
4	SSS 04	51.18 ± 6.42	17.61 ± 0.81	398.63 ± 16.20	107.06
5	SSS 05	32.50 ± 4.08	18.51 ± 1.10	395.79 ± 19.72	89.45
6	SSS 06	47.40 ± 5.88	9.89 ± 0.59	331.24 ± 17.36	87.05
7	SSS 07	20.54 ± 2.38	14.47 ± 0.63	408.06 ± 16.20	72.65
8	SSS 08	49.04 ± 6.15	11.73 ± 0.70	422.83 ± 22.20	98.37
9	SSS 09	48.22 ± 6.24	15.18 ± 0.91	355.90 ± 18.67	97.33
10	SSS 10	44.81 ± 4.41	21.69 ± 1.25	398.16 ± 5.10	106.49
11	SSS 11	bdl	9.05 ± 0.54	359.32 ± 8.47	–
12	SSS 12	88.73 ± 1.83	10.39 ± 0.50	360.00 ± 18.85	131.31
13	SSS 13	8.39 ± 1.27	16.79 ± 0.99	387.38 ± 20.26	62.23
14	SSS 14	bdl	14.62 ± 0.87	489.77 ± 15.28	–
15	SSS 15	33.24 ± 4.20	9.78 ± 0.58	388.86 ± 20.45	77.17
	Min	8.39 ± 1.27	8.39 ± 0.50	101.16 ± 5.10	56.00
	Max	51.18 ± 6.42	21.69 ± 1.25	436.93 ± 22.92	131.31
	Mean	40.36 ± 3.97	14.71 ± 0.80	385.63 ± 16.54	91.26
World average (UNSCEAR, 2000)		35	30	400	≤370

^{40}K activity values ranged from 101.16 ± 5.10 to 436.83 ± 22.92 Bq kg^{-1} with an average of 385.63 ± 16.54 Bq kg^{-1}. These values are within the world average values of 35, 30 and 400 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively [12]. Computed radium equivalent activity (Ra_{eq}) varied from 56.00 Bq kg^{-1} to 131.31 Bq kg^{-1} with a mean value of 91.26 Bq kg^{-1}. The natural distribution pattern of ^{238}U, ^{232}Th and ^{40}K in the soil samples is shown in Fig. 13.1.

Radiation hazard indices were computed using Eqs. (13.3)–(13.7) and the results are presented in Table 13.2. Calculated mean value of absorbed dose (D_R) at 1 m was 42.63 nGy h^{-1} with a corresponding annual effective dose (AEDE) of 0.05 mSv y^{-1}, while computed external and internal hazard indices were below unity (Table 13.1). Calculated excess lifetime cancer risk (ELCR) varied from 0.11 × 10^{-3} to 0.26 × 10^{-3} with a mean value of 0.18 × 10^{-3}. All computed radiation hazard indices were below their respective world average values of 370 Bq kg^{-1}, 58 nGy h^{-1}, 0.07 mSv y^{-1} and 0.18 × 10^{-3} documented in the UNSCEAR report [12].

Table 13.3 shows the specific activities of ^{238}U, ^{232}Th and ^{40}K in the commercial yam *(D. rotundata)* samples together with the corresponding hazard indices. Specific activities of ^{238}U, ^{232}Th and ^{40}K ranged from 2.88 ± 0.44 to 76.68 ± 9.73 Bq kg^{-1},

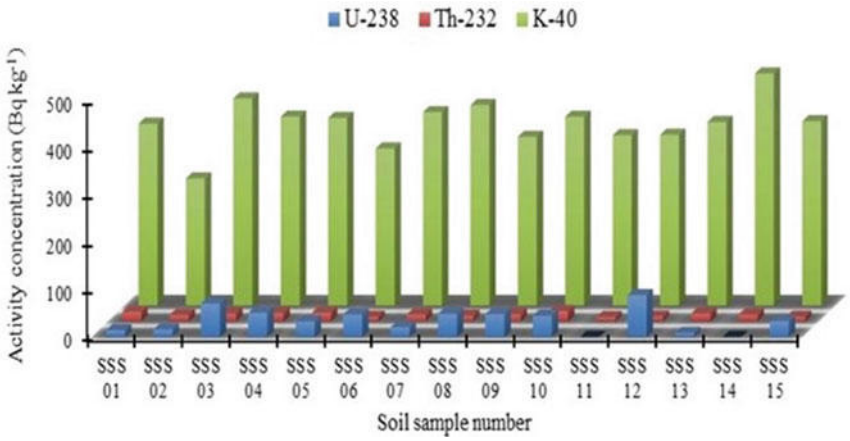

Fig. 13.1 Activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the soil samples

Table 13.2 Radiation hazard indices for the soil samples

S. No	Sample ID	D_R (nGy h^{-1})	AEDE (mSv y^{-1})	H_{ex}	H_{in}	ELCR ($\times 10^{-3}$)
1	SSS 01	34.82	0.04	0.20	0.24	0.15
2	SSS 02	26.74	0.03	0.15	0.19	0.11
3	SSS 03	61.07	0.07	0.35	0.54	0.26
4	SSS 04	50.90	0.06	0.29	0.43	0.22
5	SSS 05	42.70	0.05	0.24	0.33	0.18
6	SSS 06	41.69	0.05	0.24	0.36	0.18
7	SSS 07	35.25	0.04	0.20	0.25	0.15
8	SSS 08	47.37	0.06	0.27	0.40	0.20
9	SSS 09	46.29	0.06	0.26	0.39	0.20
10	SSS 10	50.41	0.06	0.29	0.41	0.21
11	SSS 11	–	–	–	–	–
12	SSS 12	62.28	0.08	0.35	0.59	0.26
13	SSS 13	30.17	0.04	0.17	0.19	0.13
14	SSS 14	–	–	–	–	–
15	SSS 15	37.48	0.05	0.21	0.30	0.16 ara>
	Min	26.74	0.03	0.15	0.19	0.11
	Max	62.28	0.08	0.35	0.59	0.26
	Mean	43.63	0.05	0.25	0.36	0.18
World average (UNSCEAR, 2000)		[60 (18-93)]	1.00	≤1	≤1	0.29

Table 13.3 Activity concentrations (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in yam samples

S. No	Sample ID	Activity concentrations (Bq kg^{-1})			
		^{238}U	^{232}Th	^{40}K	Ra_{eq}
1	DRD 01	11.77 ± 1.64	7.73 ± 0.46	438.31 ± 38.37	56.57
2	DRD 02	bdl	10.05 ± 0.78	499.31 ± 26.14	–
3	DRD 03	72.24 ± 8.49	14.06 ± 0.84	627.94 ± 32.77	140.70
4	DRD 04	33.24 ± 4.67	19.77 ± 1.30	530.22 ± 28.00	102.34
5	DRD 05	12.75 ± 1.74	14.31 ± 0.85	484.54 ± 30.41	70.52
6	DRD 06	37.19 ± 4.82	8.13 ± 0.49	460.56 ± 23.99	84.28
7	DRD 07	29.57 ± 2.93	15.43 ± 0.83	502.08 ± 28.91	90.30
8	DRD 08	25.92 ± 3.73	bdl	502.49 ± 26.35	–
9	DRD 09	2.88 ± 0.44	10.42 ± 0.63	435.56 ± 22.84	51.32
10	DRD 10	bdl	13.02 ± 0.78	312.50 ± 26.83	–
11	DRD 11	bdl	7.48 ± 0.45	408.86 ± 21.43	–
12	DRD 12	76.68 ± 9.73	9.69 ± 0.58	346.36 ± 20.73	117.21
13	DRD 13	bdl	bdl	446.36 ± 28.50	–
14	DRD 14	24.85 ± 3.28	9.88 ± 0.59	514.42 ± 26.85	78.59
15	DRD 15	15.14 ± 2.08	13.64 ± 0.81	494.88 ± 25.87	72.75
	Min	2.88 ± 0.44	7.48 ± 0.45	312.50 ± 20.73	51.32
	Max	76.68 ± 9.73	19.77 ± 1.30	627.94 ± 38.37	140.70
	Mean	31.11 ± 4.0	11.82 ± 0.72	466.96 ± 27.20	86.46

7.48 ± 0.45 to 19.77 ± 1.30 Bq kg^{-1} and 312.50 ± 20.73 to 627.94 ± 38.37 Bq kg^{-1} respectively, with their corresponding average values of 31.11 ± 4.0 Bq kg^{-1}, 11.82 ± 0.72 Bq kg^{-1} and 466.96 ± 27.20 Bq kg^{-1} in sequence. Calculated values for radium equivalent activity (Ra_{eq}) varied from 51.32 Bq kg^{-1} to 140.70 Bq kg^{-1}, with an average value of 86.46 Bq kg^{-1}. Computed averages for ^{238}U and ^{232}Th are within the international safety limits documented in UNSCEAR [12] report. Mean specific activity value for ^{40}K in yam samples is however slightly higher which may not pose any radiological threat since ^{40}K is an essential element needed for body development. Results of this study fall within the same range as that of similar studies in other parts of Nigeria and in Ghana [2, 3, 9, 25, 26]. Measured mean specific activities of ^{238}U, ^{232}Th and ^{40}K in this study were however found to be lower than those obtained for yam tubers in Jos, northcentral Nigeria, which were documented to be 684.5 ± 40.6 Bq kg^{-1} for ^{40}K, 85.5 ± 10.2 Bq kg^{-1} for ^{238}U and 89.8 ± 6.2 Bq kg^{-1} for ^{232}Th [5]. These enhanced radioactivity contents are due to continuous tin mining activities that have been going on in Jos, northcentral Nigeria for decades.

Results of the calculated radiation hazard indices for yam samples are presented in Table 13.4. Average values of 42.21 nGy h^{-1}, 0.05 mSv y^{-1} and 0.32 were recorded for the absorbed dose (D_R), annual effective dose (AEDE) and internal hazard index

Table 13.4 Radiation hazard indices for yam samples

S. No	Sample ID	D_R (nGy h^{-1})	AEDE (mSv y^{-1})	Hin ≤ 1	ELCR ($\times 10^{-3}$)
1	DRD 01	28.38	0.03	0.18	0.12
2	DRD 02	–	–	–	–
3	DRD 03	68.05	0.08	0.58	0.29
4	DRD 04	49.41	0.06	0.37	0.21
5	DRD 05	34.74	0.04	0.22	0.15
6	DRD 06	41.30	0.05	0.33	0.17
7	DRD 07	43.92	0.05	0.32	0.19
8	DRD 08	–	–	–	–
9	DRD 09	25.79	0.03	0.15	0.11
10	DRD 10	–	–	–	–
11	DRD 11	–	–	–	–
12	DRD 12	55.72	0.07	0.52	0.24
13	DRD 13	–	–	–	–
14	DRD 14	38.90	0.05	0.28	0.16
15	DRD 15	35.87	0.04	0.24	0.15
	Min	25.79	0.03	0.15	0.11
	Max	68.05	0.08	0.58	0.29
	Mean	42.21	0.05	0.32	0.18

(H_{in}) respectively. These values were found to be within the internationally acceptable standards as prescribed by the UNSCEAR [12]. The percentage contribution of primordial radioactive nuclides to the total absorbed dose is shown in Fig. 13.2. Computed excess lifetime cancer risk (ELCR) ranged between 0.11×10^{-3} and 0.29×10^{-3} with a mean of 0.18×10^{-3}. This result is lower than the safety limit of 0.29×10^{-3} documented by UNSCEAR [12] and 0.05 stipulated in the ICRP reports

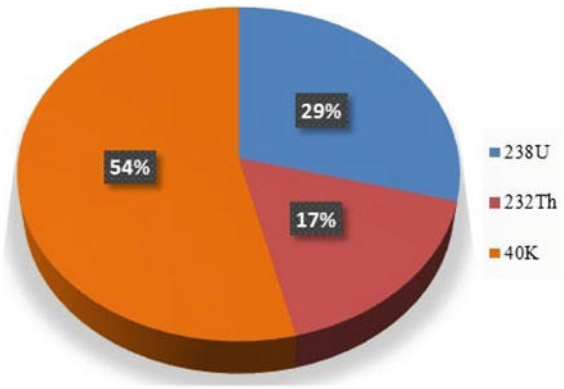

Fig. 13.2 Percentage contributions of ^{238}U, ^{232}Th and ^{40}K to total absorbed dose

for low-level radiations. This shows that the probability of cancer incidences due to consumption of Nigerian grown yam tubers is insignificant.

Soil-to-yam transfer factors (TF) for ^{238}U, ^{232}Th and ^{40}K for the commercial yam tubers were computed using Eq. (13.8) and the results are presented in Table 13.5. Root uptake has been identified as the principal process by which radionuclides can accumulate in plants. As seen in Table 13.5, TF for ^{238}U ranged between 0.06 and 1.44, with an average value of 0.70. TF for ^{232}Th varied from 0.38 to 1.39, with a mean value of 0.83, while TF for has the highest value of 1.86 and a mean of 1.23. Rate of radionuclide transfer from soil to yam shows a decreasing tr^{40}K end of ^{40}K (1.23) > ^{232}Th (0.83) > ^{238}U (0.70).

Mean TF values for ^{238}U, ^{232}Th and ^{40}K in this study compare favourably with those obtained in similar studies [3, 9, 27, 28]. Computed TFs in this study are below the recommended value of 2.7 for tubers [4]. Thus, the rate of radionuclides transfer and their subsequent accumulation in Nigerian yam tubers are moderate and do not constitute any immediate radiological incidence to the consumers.

Table 13.5 Soil-to-yam transfer factors (TF) for ^{238}U, ^{232}Th and ^{40}K in yam samples

S. No	Soil sample	Yam sample	^{238}U	^{232}Th	^{40}K
1	SSS 01	DRD 01	0.83	0.38	1.14
2	SSS 02	DRD 02	–	0.73	1.86
3	SSS 03	DRD 03	1.02	0.83	1.44
4	SSS 04	DRD 04	0.65	1.12	1.33
5	SSS 05	DRD 05	0.39	0.77	1.22
6	SSS 06	DRD 06	0.78	0.82	1.39
7	SSS 07	DRD 07	1.44	1.07	1.23
8	SSS 08	DRD 08	0.53	–	1.19
9	SSS 09	DRD 09	0.06	0.69	1.22
10	SSS 10	DRD 10	–	0.60	0.78
11	SSS 11	DRD 11	–	0.83	1.14
12	SSS 12	DRD 12	0.86	0.93	0.96
13	SSS 13	DRD 13	–	–	1.15
14	SSS 14	DRD 14	–	0.68	1.05
15	SSS 15	DRD 15	0.46	1.39	1.27
	Min		0.06	0.38	0.78
	Max		1.44	1.39	1.86
	Mean		0.70	0.83	1.23

13.4 Conclusion

Activity concentrations of ^{238}U, ^{232}Th and ^{40}K in commercially cultivated yam tubers and the corresponding cultivated soil samples were measured using gamma spectrometric technique which employs $3'' \times 3''$ NaI(Tl) gamma detector. Mean specific activities of ^{238}U, ^{232}Th and ^{40}K in yam tubers and soil samples are within their respective world average values presented in the United Nations Scientific Committee on the Effects of Atomic Radiation reports. Computed radiation hazard indices which are used in estimating any possible radiological health risk in the studied samples and the subsequent radiation dose associated with yam tuber consumption are below their permissible limits. Soil to plant transfer factor (TF) for the primordial radionuclides computed for the studied yam samples appears to be generally moderate. This indicates that activity concentrations of natural radionuclides in the Nigerian grown yam tubers do not pose any immediate radiological threat for public consumption and hence are fit for export to other nations from a radiological perspective. Continuous radiological monitoring of the food crop is however encouraged to check accumulation effects due to long-term consumption.

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