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ANNUAL EFFECTIVE DOSE ESTIMATION DUE TO THE NATURAL RADIOACTIVITY IN YAM TUBERS (*Dioscorea rotundata*) CULTIVATED IN NORTHCENTRAL NIGERIA

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Abstract: Yam tubers (*Dioscorea rotundata*) and soil from commercially cultivated farmland in northcentral Nigeria were collected and investigated for their natural radioactivity content using a 3” × 3” NaI(Tl) gamma detector. Average activities of ^{238}U, ^{232}Th and ^{40}K in the investigated farm soil were 38.13±3.76 Bq kg^{-1}, 15.06±0.99 Bq kg^{-1} and 381.80±15.50 Bq kg$^{-1,}$ respectively. The results agree with the world’s acceptable levels of safety. Activities measured in the yam tubers were in the range from BDL -76.68±9.73 Bq kg^{-1} for ^{238}U, BDL - 19.77±1.30 Bq kg^{-1} for ^{232}Th and 312.50±20.73 - 627.94±38.37 Bq kg^{-1} for ^{40}K, with average values of 29.23±4.0, 13.10±0.72 and 445.10±27.20 Bq kg$^{-1,}$ respectively. The total effective dose from radionuclide intake from yam ingestion fluctuated between 272.12 µSv y^{-1} and 935.97 µSv y^{-1}. Correlation analysis identified ^{238}U and ^{232}Th as the leading contributors to the total effective dose from ingesting yam tubers cultivated in northcentral Nigeria.

Keywords: *Natural radioactivity, yam tubers, NaI(Tl) detector, committed effective dose, northcentral Nigeria*

1. Introduction

The soil-plant-man ingestion route is a significant environmental pathway for human exposure to radiation. Radiological contamination of the human food chain can occur by radionuclide absorption through plant roots and uninterrupted intake of contaminated farm products, water and critter. Contamination can also occur when radionuclides are directly deposited on plant leaves (Gregory & Agbalagba, 2014; IAEA, 2010). Applying fertilisers for bountiful crop yield could also contaminate the food chain. According to Omoniyi et al. (2013), factors such as general agricultural practices, climatic conditions, soil characteristics, plant types and the physicochemical nature of the radioisotopes affect radionuclide uptake by the plant roots and subsequent deposition in the consumable plant parts. Naturally occurring radionuclides, 228Th and 238U, contribute to the radiation dose incurred from ingesting plants, animals, soil and water (Jwanbot et al., 2012). Ingested radionuclides from contaminated plants tend to enhance the total radiation dose deposited in various organs of the human body, posing radiological health challenge after a long period of exposure (Adesiji & Ademola, 2019; N. Jibiri et al., 2007). Therefore, it is important to maintain routine radiological investigations of agricultural products meant for human consumption to ensure their radiological safety and compliance with the ALARA principle.

Yam (Dioscorea rotundata) is an essential food crop that dominates the population diet in Nigeria. It is primarily cultivated in the northcentral part of Nigeria. Its capacity to be processed into different powder forms for human consumption and animal feeds has made it widespread among the Nigerian population. The Nigerian government has been giving considerable attention recently to the agricultural sector to diversify the national economy. The government aims to focus on yam production, processing and exportation for massive foreign exchange earnings. Hence, the need to comply with international safety protocols, especially from the radiation protection perspective regarding food crop export.

2. Materials and Methods

2.1 Sample Collection and Preparation

Northcentral Nigeria has been known as one of the regions with high potential for yam (*Dioscorea rotundata*) cultivation and production. The region does not just cultivate yam tubers for local consumption but also for exportation to boost the Nigerian economy. Eighteen (18) samples (YM 01 – YM 18) of cultivated yam tubers *(D. rotundata)* from a commercially cultivated yam farm were randomly collected for analysis. Also collected for

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radiological analysis were the corresponding farm soil samples (SS 01 – SS 18), which were screened for all types of contamination at the collection site. Each collected yam and soil sample was carefully loaded into the sample bags and correctly designated for proper identification. The samples were then conveyed to the laboratory and further prepared for radiological analysis.

At the laboratory, yam samples were thoroughly cleaned with distilled water and dried under the sun for about 200 minutes to ensure the elimination of all surface moisture. Dried yam tubers were then peeled using a sharp kitchen knife. Portions meant for human consumption were cut into smaller sizes, rewashed with clean water, and sun-dried for 72 hours to remove all moisture from the samples. The samples were thoroughly powdered after drying and homogenized through a 2-mm sieve. Soil samples were also air-dried, pulverized, sieved and homogenized. Soil samples of 371.9±0.2 g each and yam samples of 180.8±0.1 g each were then packed into tightly closed designated containers and kept for about 32 days to ensure that long-lived parent radionuclides would reach radiological equilibrium with their decayed daughters (Asaduzzaman et al., 2014; UNSCEAR, 2000).

2.2 Sample Analysis

All the samples were analysed for their natural radioactivity by a 3″ × 3″ NaI(Tl) gamma-ray detector manufactured by Scintillation Technologies USA. A 6-cm thick lead house was used to shield the detector from any interference from external radiation. To effectively cancel out any spectral interference by unauthorized frequencies, the internal parts of the detector were coated with copper sheets. Gamma spectra from the detector were acquired and analysed using the ACCUSPEC computer program in the multichannel analyzer (MCA) attached to the detector. Standard calibration isotope sources (^{137}Cs and ^{60}Co) with an energy range of 200 keV-2.810 MeV were employed for energy and efficiency calibration of the detector before analysis. The surrounding radiation background was then determined by measuring an empty sample container with dimensions comparable to samples for 36000 seconds. Similarly, each sample (yam and farm soil) was measured for 36000 seconds. The activity concentration ^{214}Bi measured based on its γ-ray peak (1.760 MeV) was used to estimate ^{238}U in all the samples. Meanwhile, the ^{208}Tl activity concentration measured from its γ-ray peak (2.614 MeV) was used to evaluate ^{232}Th. The activity concentration of ^{40}K in all the samples was assessed based on the single characteristic gamma line measured at 1.460 MeV. The analysis was performed at Ladoke Akintola University of Science and Technology (LAUTECH), Ogbomosho, Nigeria.

The relative activities of ^{238}U, ^{232}Th and ^{40}K were calculated using the established formula (Khandaker *et al.*, 2012; Kolo *et al.*, 2015; Kolo *et al.*, 2020):

$$A(Bq\ kg^{-1}) = \frac{C}{\varepsilon_\gamma \times I_\gamma \times W} \quad (1)$$

where A is the activity concentrations of radionuclides in the samples measured in Bq kg^{-1}, C is the net count rate measured as counts/sec, I_γ is the intensity of gamma-ray, ε_γ (E) is the detector photo-peak efficiency (%) and W is the weight of sample in kg.

Absorbed dose rate (D_R) in the air, which shows the degree of radiation risk for public exposure, was computed from the specific activities of ^{238}U, ^{232}Th and ^{40}K in the farm soils. D_R was computed using the relation formula (Ravisankar *et al.*, 2014; UNSCEAR, 2000):

$$D_R(nGy\ h^{-1}) = pA_U + qA_{Th} + rA_K \quad (2)$$

where p is per unit dose rate of ^{238}U activity given for 4.27 × 10^{-10} Gy h^{-1}/Bq kg^{-1}, q is per unit dose rate of ^{232}Th activity given for 6.62 × 10^{-10} Gy h^{-1}/Bq kg$^{-1,}$ and r is per unit dose rate of ^{40}K given for 0.43 × 10^{-10} Gy h^{-1}/Bq kg^{-1}. $A_{U,}$ $A_{Th,\ and}$ A_K express the activities of ^{238}U, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The dose rate in the air was converted to the effective dose, which represents the radiation vulnerability of an individual. This conversion was done using two conversion factors: (i) 0.7 Sv Gy$^{-1,}$ which transforms Gy to Sv, to measure the biological effects of any given radiation dose to inflict damage in the human body tissue; (ii) the outdoor occupancy factor. Adejuwon (2002) reported that a typical Nigerian farmer spends 10 hours outdoors daily on average. Thus, an occupancy factor of 0.4 was adopted in this study for the computation of the effective dose rate.

2.3 Committed Effective Dose Rate from Ingesting Yam Tubers

The committed effective dose is a single parameter summarising the radiation dose of different radionuclides from various radioactive sources. The total dose of individual radionuclides residing in the organs of the human body gives a measure of radiological health incidences connected with ingesting the radioisotopes (Jibiri *et al.*, 2007). Radiation dose from ingestion is a product of specific activities (Bq kg^{-1}) in the ingested food and the mass of the food intake over a given period (kg/d or kg/y). Committed effective dose from ingestion can thus be computed by applying an appropriate transformation factor (Sv bq^{-1}). Ingested dose from the consumption of yam tubers was calculated using the following formula (Jibiri *et al.*, 2007; Till & Moore, 1988):

$$H_{T,r} = \left(U^{Bi}A_r^{Bi} + U^{Pf}A_r^{Pf} + U^{Mi}A_r^{Mi} + \cdots\right)g_{T,r} \quad (3)$$

In summary, Eq (3) is written as

$$H_{T,r} = \sum\left(U^i A_r^i\right)g_{T,r} \quad (4)$$

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Where i indicates the food group, U^i is the rate of intake (Bq y^{-1}), A_r^i represents activity concentration of radionuclide r (Bq kg^{-1}) and $g_{T,r}$ is the dose constant for intake of radionuclide (r) in Sv Bq^{-1}. ICRP (1994, 1996) and RIFE (2005) give the g value of each radionuclide as 4.8 × 10^{-8} Sv Bq^{-1} (^{238}U), 2.3 × 10^{-7} Sv Bq^{-1} (^{232}Th) and 5.9 × 10^{-9} Sv Bq^{-1} (^{40}K). The annual ingestion rate of yam tubers in Nigeria is 75.15 kg y^{-1}, according to FOS (2006).

3. Results and Discussion

Activities of ^{238}U, ^{232}Th and ^{40}K in the cultivated farm soils and their computed total effective doses are presented in Table 1.

Table 1. Activities of ^{238}U, ^{232}Th, and ^{40}K in the cultivated farm soil and corresponding effective dose rates.

S. no	Sample ID	Activity concentrations (Bq kg^{-1})			Effective dose rate (µSv h^{-1})
		^{238}U	^{232}Th	^{40}K	
1	SS 01	14.26±1.74	20.25±1.20	383.75±12.29	0.010
2	SS 02	15.80±2.26	13.69±0.81	267.84±14.07	0.008
3	SS 03	70.55±4.70	16.98±0.53	436.93±22.92	0.017
4	SS 04	51.18±6.42	17.61±0.81	398.63±16.20	0.014
5	SS 05	32.50±4.08	18.51±1.10	395.79±19.72	0.012
6	SS 06	23.01±1.32	20.10±1.90	389.67±9.23	0.011
7	SS 07	47.40±5.88	9.89±0.59	331.24±17.36	0.011
8	SS 08	20.54±2.38	14.47±0.63	408.06±16.20	0.010
9	SS 09	49.04±6.15	11.73±0.70	422.83±22.20	0.013
10	SS 10	48.22±6.24	15.18±0.91	355.90±18.67	0.013
11	SS 11	44.81±4.41	21.69±1.25	398.16±5.10	0.014
12	SS 12	BDL	9.05±0.54	359.32±8.47	0.009
13	SS 13	88.73±1.83	10.39±0.50	360.00±18.85	0.017
14	SS 14	32.23±3.40	17.14±1.71	375.21±10.53	0.012
15	SS 15	8.39±1.27	16.79±0.99	387.38±20.26	0.009
16	SS 16	BDL	14.62±0.87	489.77±15.28	0.012
17	SS 17	33.24±4.20	9.78±0.58	388.86±20.45	0.010
18	SS 18	30.12±3.91	13.23±2.13	323.14±11.23	0.010
	Min	8.39±1.27	9.05±0.54	267.84±14.07	0.008
	Max	88.73±1.83	21.69±1.25	489.77±15.28	0.017
	Mean	38.13±3.76	15.06±0.99	381.80±15.50	

BDL, below detection unit

Activity concentration of ^{238}U fluctuated between 8.39±1.27 Bq kg^{-1} and 88.73±1.83 Bq kg$^{-1,}$ as seen in Table 1. Specific activities of ^{232}Th and ^{40}K ranged from 9.05±0.54 to 21.69±1.25 Bq kg^{-1} with an average of 15.06±0.99 Bq kg^{-1} and from 267.84±14.07 to 489.77±15.28 Bq kg^{-1} with a mean of 381.80±15.50 Bq kg^{-1}, respectively. These values are within the world's precautionary limits for safety, documented in the UNSCEAR (2000) report. Figure 1 shows ^{238}U, ^{232}Th and ^{40}K distribution in the cultivated soil expressed in %. Furthermore, the computed effective gamma dose rate varied from 0.008 to 0.017 µSv h^{-1}, which is lower than the global mean of 0.055 µSv h^{-1}, documented by the UNSCEAR (2000).

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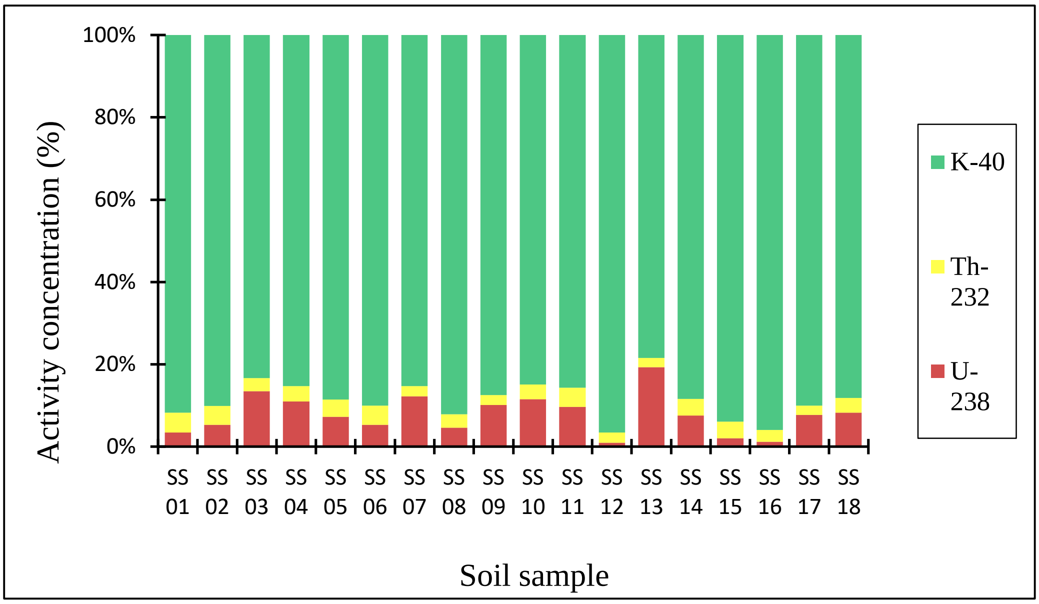

Figure 1. Percentage spread natural radionuclides in the cultivated farm soil.

Activities of ^{238}U, ^{232}Th and ^{40}K in the cultivated yam tubers *(D. rotundata)* are summarised in Table 2. Table 2 also shows the computed committed effective dose (CEDE) from the consumption of the cultivated yam tubers. Specific activities of ^{238}U in the cultivated yam tubers varied from BDL to 76.68±9.73 Bq kg^{-1}, while that of ^{232}Th was from BDL to 19.77±1.30 Bq kg^{-1}. The activity concentration values for ^{40}K ranged from 312.50±20.73 to 627.94±38.37 Bq kg^{-1}, with a mean value of 445.10±27.20 Bq kg^{-1}. Computed effective dose from radionuclides uptake from consuming cultivated yam tubers, shown in Table 2, ranged from 272.12 µSv y^{-1} to 935.97 µSv y^{-1}, with an average of 529.24 µSv y^{-1}. The calculated average is lower than the global safety threshold of 1.1 mSv y^{-1} (IARC, 2000) and natural exposure values of 2000 µSv y^{-1} reported by Jibiri *et al.* (2007). The discrepancies could be due to the various food processing and preparation methods. Nevertheless, the result agrees with the previously reported findings (Jibiri & Eke, 2021) for a study in the Niger Delta of Nigeria.

Table 2. Activities of ^{238}U, ^{232}Th and ^{40}K with the respective committed effective dose from consuming yam tubers.

S. no	Sample ID	Activity concentrations (Bq kg^{-1})			CEDE (µSv y^{-1})
		^{238}U	^{232}Th	^{40}K	
1	YM 01	11.77±1.64	7.73±0.46	438.31±38.37	370.41
2	YM 02	BDL	10.05±0.78	499.31±26.14	395.10
3	YM 03	72.24±8.49	14.06±0.84	627.94±32.77	782.02
4	YM 04	33.24±4.67	19.77±1.30	530.22±28.00	696.71
5	YM 05	12.75±1.74	14.31±0.85	484.54±30.41	508.17
6	YM 06	28.21±2.45	17.43±1.97	338.69±18.64	553.20
7	YM 07	37.19±4.82	8.13±0.49	460.56±23.99	478.88
8	YM 08	29.57±2.93	15.43±0.83	502.08±28.91	595.98
9	YM 09	25.92±3.73	BDL	502.49±26.35	316.30
10	YM 10	2.88±0.44	10.42±0.63	435.56±22.84	383.61
11	YM 11	BDL	13.02±0.78	312.50±26.83	363.60
12	YM 12	BDL	7.48±0.45	408.86±21.43	310.57
13	YM 13	15.66±5.41	22.04±4.23	370.03±22.10	601.50
14	YM 14	76.68±9.73	9.69±0.58	346.36±20.73	597.66
15	YM 15	BDL	BDL	446.36±28.50	BDL
16	YM 16	24.85±3.28	9.88±0.59	514.42±26.85	488.50

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17	YM 17	15.14±2.08	13.64±0.81	494.88±25.87	509.80
18	YM 18	23.09±6.20	16.55±4.27	298.72±18.98	501.80
	Min	BDL	BDL	312.50±20.73	272.12
	Max	76.68±9.73	19.77±1.30	627.94±38.37	935.97
	Mean	29.23±4.0	13.10±0.72	445.10±27.20	529.24

BDL, below detection limit

Table 3 compares the results of this investigation with other findings from related investigations within Nigeria. The variations in these findings could be due to the use of chemical and organic fertilisers for bountiful crop yield by commercial farmers.

Table 3. Activities of ^{238}U, ^{232}Th and ^{40}K in cultivated yam tubers from different parts of Nigeria expressed as Bq kg^{-1}

Location	^{238}U	^{232}Th	^{40}K	Reference
Oguta, Niger-Delta	23.75 ±5.69	30.99 ±9.51	189.99 ±59.14	Jibiri & Eke (2021)
Plateau State	2.32 ± 0.62	3.24 ± 0.36	22.12 ± 2.34	Jwanbot *et al.* (2012)
Ondo State	4.67	3.07	81.87	Ibitola *et al.* (2018)
Osun State	1.72± 0.10	2.24 ± 0.21	37.84 ± 2.40	Nwankpa (2017)
Onne, Rivers State	6.3±1.8	8.4±2.6	227. ±27.3	Gregory & Agbalagba (2014)
Ogun State	9.60± 0.49	ND	490.67 ±43.35	Jibiri & Abiodun (2012)
Minna, North Central	29.23 ±4.0	13.10 ±0.72	445.10 ±27.20	Present study

Natural relationships and suggested interdependency likely to occur between radiation parameters in the cultivated yam tubers were assessed based on Pearson's correlation using a Statistical software package, Statistical Program for Social Science (SPSS 22.0). The computed correlation metrics are shown in Table 4.

Table 4. Correlation metrics between radiation contents of the yam samples

Variables	^{238}U	^{232}Th	^{40}K	CEDE
^{238}U	1.00			
^{232}Th	0.17	1.00		
^{40}K	0.23	-0.15	1.00	
CEDE	0.68	0.76	0.24	1.00

Table 4 shows a strong positive correlation between ^{238}U (r = 0.68) and ^{232}Th (r = 0.76) and the respective CEDE. Table 4 also shows a weak correlation (r = 0.24) between ^{40}K and CEDE. These findings suggest that ^{238}U and ^{232}Th are the main contributors to the total effective dose from ingesting yam tubers cultivated in the northcentral Nigeria.

4. Conclusion

This paper presents the radiological data of yam tubers grown commercially in the Northcentral of Nigeria. A 3" × 3" NaI(Tl) gamma-ray detector determined the primordial radionuclide composition of the yam tubers. The equivalent committed effective dose due to radionuclides incorporation into the human body from consuming the cultivated yam tubers was also computed. The average activity of ^{238}U was 29.23±4.0 Bq kg^{-1}; ^{232}Th recorded an average activity of 13.10±0.72 Bq kg^{-1}; for 40K was 445.10±27.20 Bq kg^{-1}. The results of this investigation agree with the findings from other related investigations in some regions of Nigeria. Although correlation studies showed that ^{238}U and ^{232}Th are the significant contributors to total ingestion dose, computed ingestion dose from consumption of the yam tubers was proved relatively low, resulting in significant radiation incidence among the consumers. Therefore, cultivated yam tubers from northcentral Nigeria are radiologically fit and safe for local consumption and export. However, it is recommended that commercially grown and cultivated food crops be checked and monitored continually to mitigate radiation-induced health incidences arising from continuous consumption and ensure strict compliance with the ALARA safety protocol.

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