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Dose and Health Risk Assessment due to Natural Radioactivity in Root and Tuber Crops from Selected Local Government Areas in Ekiti State, Southwestern Nigeria

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Abstract: Among the several ways by which man is exposed to radiation, the transfer of radionuclides from soil to crops consumed by humans is one of the prevalent pathways. Assessment of natural radioactivity in root and tubers crops consumed in selected local government area in Ekiti State, South-western Nigeria has been carried out. The specific activities of ^{40}K, ^{238}U, ^{232}Th were determined using a 76 mm by 76 mm lead-shielded Sodium Iodide Detector doped with Thallium (NaI(Tl)) located at the Center for Energy, Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. To assess the effect of consumption of these food crops, health impact parameters such as the Annual Effective Dose (AED) due to ingestion and Excess Lifetime Cancer Risks (ELCR) were determined. The activity concentration of radionuclide in the samples investigated ranged from 128.85 ± 10.22 to 398.84 ± 31.23 with a mean value of 275.98 ± 21.47 Bq kg^{-1} for ^{40}K, from 6.67 ± 0.18 to 12.24 ± 0.27 with an average of 9.47 ± 0.20 Bq kg^{-1} for ^{238}U and from 7.26 ± 0.13 to 12.23 ± 0.21 Bq kg^{-1} for ^{232}Th with 10.43 ± 0.19 Bq kg^{-1} as the mean value. The estimated AED varied from 0.05 to 0.93 mSv yr^{-1} with a mean value of 0.60 mSv yr^{-1}. Values for ELCR ranged from 2 x 10^{-7} to 3.3 x 10^{-6} with 2.1 x 10^{-6} as the average value. The radioactivity levels, AED and ELCR were all within the limit set by UNSCEAR (2000). Consumption of the root and tuber crops cultivated in the study area, therefore, poses no serious risk to the locals. However, regular radiological monitoring of the food crops cultivated in the area is recommended.

Keywords: Natural radioactivity, Gamma Spectrometry, Health impacts, food, Nigeria

1 Introduction

Human exposure to ionizing radiation is as a result of naturally occurring radioactive materials (NORM) in our immediate environment. These radioactive materials contains differing concentrations of ^{40}K isotopes, ^{238}U and ^{232}Th together with their progenies [1-3]. The degree of exposure of man to ionizing radiation beyond natural background levels could lead to damaging effect which could be somatic or genetic and consequently leading to death [4-6]. Human food, water and soil used for construction of buildings are composed of these natural radionuclides. Effectively monitoring these radionuclides in food consumed therefore calls for serious attention and should constitute a significant aspect of human and environmental protection [7].

Root and tuber crops comprising of cassava, yams and potatoes indicate plants whose edible parts are stored in subversive tuber, corm or roots. These crops are the most prevalent food crops directly consumed in Africa. In comparison, their production per unit land usually exceeds those of several other crops because of their capability of been cultivated in various agro ecologies. They possess certain features enabling them to produce sufficiently well in dry or semi-fertile lands where other crops otherwise fails [8-10]. The root and tuber crops occupy an important position in the feeding pattern of South-western Nigerians particularly among the locals in the study area. Yam is often boiled, pounded into chunky paste and eaten usually with vegetable soup. Cassava is also a staple food made into several composites dry or wet and eaten alone or with soup. Discussions regarding natural radioactivity in food crops have dominated research in recent years. Natural radioactivity in the selected food crops are of great concern because studies have posited that tuber and root crops

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acquire high water content from the soil consequently accumulating soluble radionuclides as a result of their direct contact with the ground [11]. This study therefore aims to thoroughly investigate and evaluate the concentration of natural radionuclides in roots and tuber crops in selected local government areas in Ekiti State, South-western Nigeria.

2 Experimental Sections

2.1 Study Area

The study area lies approximately between latitude 7°33′65″N and 7°54′14″N and longitude 4°22′64″E and 5°36′98″E. It is reported to have a population of about 2,737,186 people [12] It is underlain by rocks having step sided out crops and is mainly an upland zone rising over 250 meters above the sea level with hills taking a greater portion of the land mass [13] The geology of the study area is dominated by migmatite, granite gneiss, biotite granites and quartzite [14] The climate of the area is mainly tropical with two distinct seasons, rainy and dry alternating yearly. The former from April – October and the later beginning in November and ending in March [12] The area of study is illustrated in figure 1.

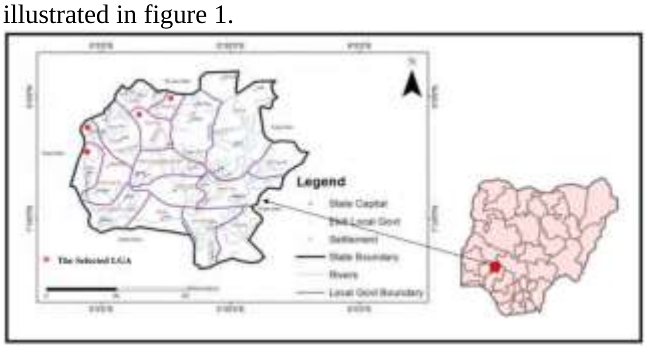

Fig. 1: Map of Ekiti State showing the selected Local Government Areas.

2.2 *Sample Collection and Preparation*

Samples comprising of tuber and root crops were collected based on the understanding that they constitute a high percentage of the diet of the locals. A total of eleven (11) root and tuber crops were collected directly from farmlands within four local government areas located in the north-eastern part of the state where most of the food crops are cultivated.. At the collection points, samples were discretely and carefully placed in pre-labelled polythene bags to avoid mix-up. The samples were air dried for a few a days and then oven dried at a temperature of about 105°C to constant weight. Pulverization followed thereafter the samples were sieve in a 2mm mesh sieve for homogeneity. The end products were sealed in air tight pre-washed containers for a minimum of 28 days for secular equilibrium to take place. Table 1 presents a description of the samples explored.

Table 1: Description of samples.

Code	LGA	Farm Location	Crop type	Description	Botanical Names
T1	Ekiti West	Okemesi 1	Tuber	Yam	*Dioscorea spp*
T2	Ekiti West	Okemesi 2	Tuber	Yam	*Dioscorea spp*
T3	Ekiti West	Okemesi 3	Tuber	Yam	*Dioscorea spp*
T4	Ilejemeje	Iye	Tuber	Yam	*Dioscorea spp*
T5	Efon-Alaaye	Itawure1	Tuber	Yam	*Dioscorea spp*
T6	Efon-Alaaye	Itawure2	Tuber	Yam	*Dioscorea spp*
R1	Efon-Alaaye	Efon-Alaaye	Roots	Cassava	*Manihot esculentum*
R2	Ilejemeje	Ewu1	Roots	Cassava	*Manihot esculentum*
R3	Ilejemeje	Ewu1	Roots	Cassava	*Manihot esculentum*
R4	Ido-Osi	Ido1	Roots	Cocoyam	*Colocosia esculentum*
R5	Ido-Osi	Ido2	Roots	Cocoyam	*Colocosia esculentum*

2.3 Radioactivity Measurement

Determination of the activity concentration of natural radionuclide in the samples were carried out using a calibrated 76 mm by 76 mm NaI(Tl) scintillate detector (Bicron Corp Model 3M/3) situated at the Centre for Energy Research and Development (CERD) Obafemi Awolowo University, Ile-Ife. The detector was shielded from background radiation by a 5cm thick lead block. A preamplifier (Bicon Corp Model PA-14), an Analogue to Digital converter (ADC) (Canberra Model 8075), an Amplifier (Canberra Model 2022) and a Multi-channel Analyzer (MCA) card slotted into a desktop computer were all coupled with the detector. The Canberra S100 multi-channel analyzer (MCA) software helps to display the output on the desktop. For the detector calibrations, standard procedures as detailed in [5] were followed using standard sample with reference number IAEA-375 for radionuclides and trace elements from International Atomic Energy Agency (IAEA), Vienna, Austria was used. The procedures followed were repeated regularly at intervals whenever there was a shift in energy. The peak corresponding to 1460 keV for ^{40}K; 1120.30 keV for ^{214}Bi; and 911 keV for ^{228}Ac were used to measure activity concentration of ^{40}K; ^{238}U and ^{232}Th, respectively. The system was preset to 25,200 seconds counting time. The activity concentrations for a particular radionuclide in the measured samples were evaluated using the following equation [15]

$$C_{sm} = \frac{A_{sm} - A_0}{P_\gamma m_{sm} t\varepsilon} \quad (1)$$

Where the activity concentration of radionuclide in the sample is depicted by C_{sm} , A_{sm} represents the area covered by the spectrum, A_0 is the area of the background, P_γ is the gamma yield, m_{sm} is the mass of individual sample, t is the counting time, while ε is the detector's efficiency. The lower limit of detection at 95% degree of confidence was estimated using the expression below [16]

$$\text{LLD} = \frac{N_{min}}{\varepsilon P_\gamma t} \quad (2)$$

Where N_{min} represents the minimum net area of the spectrum measured

$$N_{min} = 4.66\,(S_b)^{1/2} \quad (3)$$

Where S_b is the estimated standard error of the net count due to Compton background. On introduction of the food samples, the Minimum Detectable Activity Concentration (MDA) was calculated using the following formular.

$$\text{MDA} = \frac{4.66\,(S_b)^{1/2}}{\varepsilon P_\gamma W t} \quad (4)$$

Where W is the mass of the sample (kg).

2.4 Health Impact Assessment

The health impact of the natural radioactivity in the samples were assessed through the following parameters;

2.4.1 Annual Effective Dose due to ingestion of root and tuber crops

The Annual effective dose due to ingestion (AED) was determined as follows;

$$\text{AED}\ (\text{Sv yr}^{-1}) = \text{C}\ (\text{Bq kg}^{-1}) \times \text{M}\ (\text{kg yr}^{-1}) \times \text{DCF}\ (\text{Sv Bq}^{-1}) \quad (5)$$

Where C is the activity concentration of radionuclide, M is the consumption rate per year (Table 2), and DCF is the standard dose conversion factor which is equal to 0.28 μSv Bq^{-1} for ^{226}Ra, 0.23 μSv Bq^{-1} for ^{232}Th and 0.0062 μSv Bq^{-1} for ^{40}K for the persons who live over 17 years [17,18,19]

2.4.2 Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risk (ELCR) was calculated using the following equation

$$\text{ELCR} = \text{AED} \times \text{DL} \times \text{RF} \quad (6)$$

Where AED is the annual effective dose equivalent due to ingestion, DL is the duration of life (70 years) and risk factor (RF) of 0.05 Sv^{-1} which is fatal cancer risk per sievert.

Table 2: Food consumption rates (Source: [20]).

Food Type	Consumption rate (Kg^{-1})
Cassava	124.20
Yams	100.40
Other root crops	8.00

3 Results and Discussion

3.1 Radioactivity Levels in Root Crops

The specific activity of radionuclides detected in the crops ± σ are presented in Table 3 and portrayed in Figure 2. The radionuclides detected and quantified came from the naturally occurring ^{238}U, ^{232}Th decay series as well as the non-series ^{40}K. In the root crops the activity levels of ^{238}U was in the range 6.67 ± 0.18 – 12.24 ± 0.27 both from cassava, with a mean value of 9.77 ± 0.21 Bq kg^{-1} with the lowest and highest values obtained from Ilejemeje and Efon-Alaaye respectively. That of ^{238}Th ranged from 9.49 ± 0.16 (cocoyam) to 11.46 ± 0.23 (cassava) with 10.40 ± 0.196 Bq kg^{-1} as the average value. The lowest and highest values were recorded at Ido-Osi and Ilejemeje respectively. 289.41 ± 22.86 Bq kg^{-1} (cocoyam) obtained at Ido-osi and 398.84 ± 31.23 Bq kg^{-1}(Cassava) from Ilejemeje were the minimum and maximum value obtained for ^{40}K, the mean value was 323 ± 25.19 Bq kg^{-1}. It is depicted in the result that lower values were obtained from cocoyam for estimated radionuclide concentrations. This corroborates the report from similar studies carried out on cocoyams and cassava [22,11,23]. On close appraisal, the activity of the three nuclides appeared to be lower at Ido-osi.

3.2 Radioactivity Levels in Tubers

Similarly, in tuber crops the specific activity of ^{238}U ranged from 8.68 ± 0.18 (Ekiti-West) to 10.81 ± 0.20 (Efon-Alaaye) with an average of 9.23 ± 0.19 Bq kg^{-1}. ^{232}Th was in the range of 7.26 ± 0.13 to 12.23 ± 0.21 with an average value of 10.45 ± 0.19 Bq kg^{-1}, with minimum and maximum values both from Ekiti-West. ^{40}K had a maximum and minimum value of 356.31 ± 28.37 (Ilejemeje) and 128.85 ± 18.36 (Ekiti-West) respectively, with a mean value of 236.02 ± 20.77 Bq kg^{-1}. Averagely lower values seems to be recorded at Ekiti-West. The high values obtained for ^{40}K in the samples depicts its primary contribution to radiation levels in the food crops compared to the other two

Table 3: Mean Specific activity and health impact Parameters.

Sampl e code	Specific activity			AED ($mSv\ y^{-1}$)	ELCR (x 10^{-6})
	^{40}K	^{238}U	^{232}Th		
T1	259.16 ± 20.00	8.68 ±0.18	12.23 ± 0.21	0.69	2.4
T2	144.34 ± 11.50	8.68 ± 0.18	9.83 ± 0.17	0.56	2.0
T3	128.85 ± 10.22	8.90 ± 0.18	7.26 ± 0.13	0.50	1.7

T4	356.31 ± 28.37	9.29 ± 0.23	10.88 ± 0.23	0.73	2.6
T5	193.75 ± 14.92	9.00 ± 0.18	10.86 ± 0.18	0.62	2.2
T6	333.68 ± 25.15	10.81 ± 0.20	11.63 ± 0.19	0.78	2.7
Mean (Tubers)	236.02 ± 18.36	9.23 ± 0.19	10.45 ± 0.19	0.65	2.3
R1	292.31 ± 23.40	6.67 ± 0.18	11.46 ± 0.23	0.78	2.7
R2	398.84 ± 31.23	8.89 ± 0.21	10.33 ± 0.21	0.91	3.2
R3	295.41 ± 22.49	11.99 ± 0.21	10.01 ±0.17	0.93	3.3
R4	343.72 ± 25.98	9.04 ± 0.18	9.49 ± 0.16	0.05	0.2
R5	289.41 ± 22.86	12.24 ± 0.27	10.71 ± 0.21	0.06	0.2
Mean (Roots)	323.94 ± 25.19	9.77 ± 0.21	10.40 ± 0.20	0.55	1.9
Over all mean	275.98 ± 21.47	9.47 ± 0.20	10.43 ± 0.19	0.60	2.1
Limit [21]	410	28	28	1 (ICRP, 2007)	0.2 x 10^{-3}

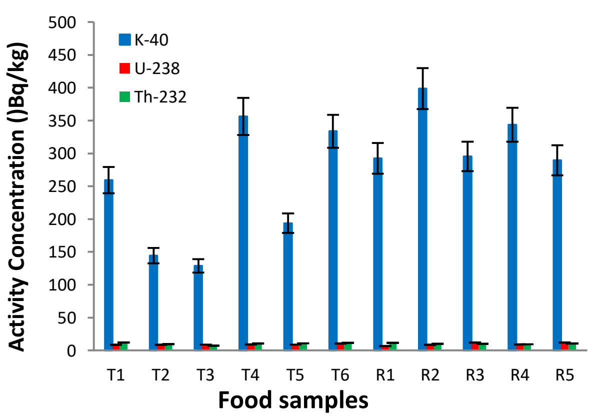

Fig.2: Activity concentration of radionuclides in food samples.

Radionuclides. This validates the report that potassium is an important element to crops, plants however do not possess the capacity to differentiate isotopes of elements hence ^{40}K is preferred to ^{232}Th and ^{238}U [7]. The abundance of ^{40}K is usually of limited interest because it is homeostatically controlled in human cells [24,23]. This makes ^{238}U and ^{232}Th of particular interest. Correlating their activity concentrations in the food samples using Pearson's correlation in statistical analysis, a result showing a weak insignificant negative relationship between ^{238}U and ^{232}Th ($r = -0.024$, $p > 0.001$) was obtained (Figure 3), portraying the independence of the activity of one on the other. Interestingly, in the root and tuber crops, mean specific activity of ^{232}Th exceeded that of ^{238}U. This could be an indication of the poor migration characteristics of ^{238}U. Table 4 presents a comparison of values obtained for the radioactivity levels of the radionuclides in this study with reports from similar studies within and beyond Nigeria.

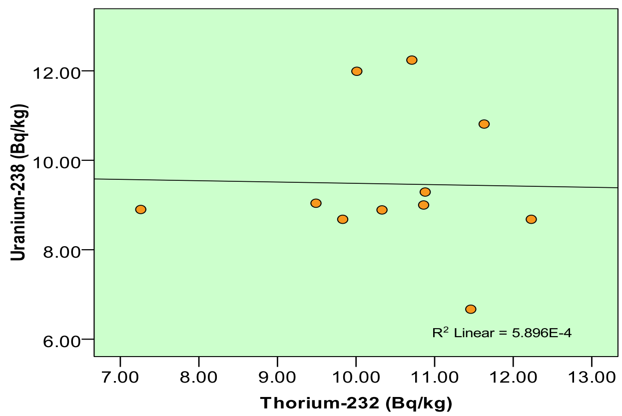

Fig.3: Correlation between ^{238}U and ^{232}Th in the food samples.

3.3 Health Impact Assessment

It is insufficient to assess the effects of natural radioactivity in food crops through measured activity levels alone. There is the need to explore health impact parameters such as Annual Effective Dose (AED) due to ingestion of contaminated food crops and Excess Lifetime Cancer Risks (ELCR). The generated values for the health impact parameters are presented in Table 3. The values obtained for the mean AED due to the ingestion of tuber and root crops were 0.65 and 0.60 mSv yr^{-1} respectively. Average ELCR was estimated as 2.3 x 10^{-6} and 2.1 x 10^{-6} for the crops respectively. Elevated values were obtained in tuber crops compared to the root crops. This can be attributed to increased consumption rate of tuber crops, particularly yams compared to cassava and cocoyam. The AED and the ELCR both had the lowest and highest values at Ido-Osi and Ekiti-West respectively. Generally, the values obtained for both crop types fall within the standard limit recommended for both the AED and the ELCR. [21]. A comparison of the values obtained for the AED with the recommended limit is illustrated in figure 4.

Table 4: Comparison of mean activity in root and tubers with similar studies world-wide.

Location	Food types	Specific Activity (BqKg-1)			References
		238U	232Th	40K	
Delta State	Yam	17.78 ± 2.82	16.60 ± 4.67	202.75 ± 8.75	[22]
Osun State	Yam	0.375 ± 0.013	0.410 ± 0.046	40.583 ± 4.384	[7]
Niger Delta	Yam Cassava coco yam	15.75 ± 4.53	10.90 ± 3.72	229.35 ± 27.19	[11]
Delta	Cassava	8.43 ± 2.6	11.37 ± 2.9	211.81 ± 10.6	[25]
Ghana	Cassava	15.54 ± 1.01	21.97 ± 1.64	477.10 ± 7.47	[24]
India	Tapioca	BDL	107 ±24.1	181 ± 14.3	[26]
Indonesia	Cassava	3.586	16.920	0.872	[27]
Ekiti, Nigeria	Yam Cassava Coco yam	9.47 ± 0.20	10.43 ± 0.19	275.98 ± 21.47	Present study

4 Conclusions

In this article, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K have been exhaustively estimated and explored in order to assess the risk due to consumption of root and tuber crops in the study area. The study has revealed that ^{40}K contributed largely to the overall activity in the food crops. Also, the mean concentration of Thorium exceeded Uranium due to the latter's poor migration characteristics. The values obtained for the Annual Effective Dose (AED) and Excess Life-time Cancer Risks (ELCR) due to ingestion of the food crops were lower than the safe recommended limits and therefore pose no severe or serious risk to consumers. However there is the to continuously monitor the radioactivity content of root and tuber crops in the area since they are reportedly highly consumed in order to avoid cumulative radiological risks associated with consumption over a long period of time.

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