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ASSESSMENT OF RADIONUCLIDES IN SOME NIGERIAN MADE CEREALS AND TEA PRODUCTS

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ABSTRACT

This study investigated the presence of the radionuclides ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in some cereals and tea products commonly available in Nigerian markets. Fifteen cereal samples and ten tea samples were purchased from different markets in Lagos, Nigeria. Gamma-ray spectrometric analyses of the samples were done using a High Purity Germanium (HPGe) detector to obtain the activity concentrations of the radionuclides with ^{137}Cs being below the detection limit in all the samples analyzed. The mean activity concentrations (in Bqkg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in the cereal samples were (0.839 ± 0.713), (1.153 ± 1.084) and (22.514 ± 8.897) respectively; while the values for the tea samples were (1.145 ± 0.765), (0.94 ± 0.601) and (19.212 ± 9.533) respectively. The associated hazard indices for the cereals ranged from 0.0065 to 0.0368 while that for the tea products varied from 0.0044 to 0.0292. These values are well below the world recommended limit of 1.0. The calculated annual effective doses due to the ingestion of the investigated samples ranged from 0.068 mSvy^{-1} (for age groups from 1 y) to 0.189 mSvy^{-1} (for age group 17 y). For the tea samples, the highest value was found in the age group 12 – 17 y, while the lowest was found in the age group 1 – 2 y. These values are below the allowable level of 1 mSv per annum for members of the general public as recommended by the International Commission on Radiological Protection. This indicates that the consumption of these cereals and teas do not pose as health hazards to both children and adults in the populace.

Keywords: Radionuclides, gamma-ray spectrometric analyses, Activity concentrations, Hazard indices, Annual effective dose.

INTRODUCTION

Humans are exposed to naturally occurring quantities of radiation every day. Exposure to this Naturally Occurring Radioactive Materials (NORM) occurs through the air we breathed in, the food consumed, the soil, the water consumed, and even within the human body (Ademola, 2008; Avwiri *et al.*, 2011) therefore, monitoring of the concentrations of radionuclides in the environment and in man is of great importance. The consumption of food is one of the most important routes by which natural and artificial radionuclides get into the human body. It is therefore important to evaluate the levels of radionuclides in different food samples (Meli et al., 2013). Cereals and tea tees have become important components of the Nigerian diet, so it is of particular concern to estimate the possible radiological hazards that may be incurred through their consumption.

Generally, there are two sources of environmental radionuclides, naturally produced (mainly from the ^{238}U and ^{232}Th series) and artificially produced sources. ^{238}U, ^{232}Th and ^{40}K are three long-lived naturally occurring radionuclides present in the earth crust. Man-made radionuclides produced by human activities also contribute to the environmental radioactivity and one of these important radionuclides of environmental concern is ^{137}Cs. ^{137}Cs occurs in the environment as a result of human activities such as fallout from atmospheric nuclear tests carried out in the late 1950's and early 1960's (Hacker B. C., 1994), Chernobyl nuclear accident, sea dumping of nuclear waste and low level effluents released from routine operations of nuclear power plants and fuel reprocessing plants (UNSCEAR, 2000). Ionizing radiation is hazardous to health, especially the charged particles and the high energy photons (Turner, 1995).

Ingestion and inhalation are the main pathways through which natural radionuclides enter into the human body. Ingested radionuclides could be concentrated in certain parts of the body for example chemical uranium is toxicity primarily affects the kidney, causing damage to the proximal tubule. Furthermore, this metal has been identified as a potential reproductive toxicant (Linares *et al.*, 2006). ^{232}Th causes effects in lungs, liver and skeleton tissues while the effects of ^{40}K occur in muscles. Depositions of large quantities of these radionuclides in particular organs will affect the health condition of humans such as weakening the immune system, induce various types of diseases, and finally increasing the mortality rate (Tawalbeh *et al.*, 2012). The environmental radionuclides present the most risk to human health, so it is important to understand the transport, fate and effects of radionuclides moving through drinks and foods, such as cereals, teas.

Cereals and teas are vital in the diet of Nigerians and the presence of natural radionuclides in them has radiological implications not only on the foods, but also on the populace consuming these food sources (Fortunati *et al.,* 2004). The deleterious radiological health hazards posed by human activities (especially in the production of energy, research, medical applications of nuclear facilities and oil and gas extraction and production) have attracted great concern and tremendous interest over the years in the field of radiation protection (Arogunjo *et al.,* 2004; Alaamer, 2008; Al-Hamarneh and Awadallah, 2009; Alzubaidi et al., 2016). Contamination of the food chain occurs as a result of direct deposition of these radionuclides on plants leaves, fruits, tubers, and via root uptake from contaminated soil or water. Considerable efforts are being made by many authors in many parts of the world to measure the activities of radionuclides in the food chain and the estimated soil-plant transfer of radionuclides (Velasco *et al.*, 2004; Alharbi and El-Taher, 2014; Haque and Ferdous, 2017).

In this study a total of fifteen (15) cereal and ten (10) tea samples available in markets located in Lagos, Nigeria were analyzed to obtain the activity concentrations of the naturally occurring gamma-emitting radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in the beverage samples. An estimate of the effective dose due to the ingestion of the cereals and teas was also obtained for possible health risks evaluation for the population using age ranges.

MATERIALS AND METHODS

Samples Collection and Preparation

In this study a total of fifteen cereal and ten tea samples available in six major markets located in Lagos, Nigeria (Figure 1). Were obtained Prior to measurement, each sample went through pre-treatment by blending into powder form to achieve a homogeneous state. Each of the samples was put into 1-litre Marinelli beakers as that of the measuring standard for the detector used. The beakers of the same dimension were closed by screw caps and sealed with tape. The sample-filled containers were then left for a minimum of 4 weeks to allow for secular equilibrium between the ^{238}U (^{226}Ra) and ^{232}Th (^{228}Ra) and their respective progenies prior to measurements (Kabir et. al, 2009).

Radioactivity Measurements

The activity concentrations of the cereals and tea samples were determined using a computerized gamma-ray spectrometry system consisting of an n-type High Purity Germanium (HPGe) detector, a Lead shield, a preamplifier, a linear amplifier, a high-voltage power supply, multichannel analyzer system and a monitor. The relative efficiency of the detector system was 25%, and resolution of 1.8 keV at 1.33MeV of ^{60}Co. A software program called MAESTRO- 32 was used to accumulate and analyze the data manually using a spreadsheet to calculate the radioactivity concentrations in the samples.

Prior to the measurements, the energy and efficiency calibrations of the detector were done to enable both qualitative and quantitative analyses of the samples; using a mixed radionuclides calibration standard homogenously distributed (in the form of solid water, serial number NW 146) with an approximate volume 1000 mL and density 1.0 g cm^{-3} in a 1.0 L Marinelli beaker. The standard contains radionuclides with known energies ^{241}Am (59.54 keV), ^{109}Cd (88.03 keV), ^{57}Co (122.06 keV), ^{139}Ce (165.86 keV), ^{203}Hg (279.20 keV), ^{113}Sn (391.69 keV), ^{85}Sr (514.01 keV), ^{137}Cs (661.66 keV), ^{60}Co (1173.2 keV and 1332.5 keV) and ^{88}Y (898.04 keV and 1836.1 keV).

Figure1: Map of Lagos showing Markets Locations from which Samples were obtained

A counting time of 86,400 seconds (24 hours) was used to acquire spectral data for each sample. The activity concentrations of the ^{226}Ra and ^{232}Th were determined using gamma-ray emissions of ^{214}Pb at 351.9 keV (35.8%) and ^{214}Bi at 609.3 keV (44.8%) for ^{226}Ra, and for the ^{232}Th-series, the emissions of ^{228}Ac at 911 keV (26.6%), ^{212}Pb at 238.6 keV (43.3%) and ^{208}Tl at 583 keV (30.1%) were used. The ^{40}K activity concentration was determined directly from its emission line at 1460.8 keV (10.7%). The gamma-ray emission spectrum of ^{137}Cs was obtained at 661.66 keV.

From the integral counts obtained under the gamma-energy peaks of interest, and using the measured efficiency of the detector, the activity concentration A is calculated using the equation (Ebaid, 2010):

$$A = \frac{C}{P_{\gamma}(E)\varepsilon(E).M_{s}} \tag{1}$$

Where A is in Bqkg-1; C the net gamma counting rate in counts /second (cps); $\varepsilon(E)$ the efficiency of the detector at an energy E (in keV); P_{γ} the absolute transition probability of gamma decay; and M_s the mass of the sample (in kg).

RESULTS AND DISCUSSION

Activity Concentrations of Radionuclides

Using Equation (1), the radioactivity concentration was obtained for each of the 25 samples. For the cereal samples, the results of the activity concentrations for the natural radionuclides ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs are presented in Table 1; while the values for the tea samples are given in Table 2.

The minimum detectable activity (MDA) derived from background measurements were approximately 0.11 Bqkg^{-1}for ^{226}Ra, 0.10 Bqkg^{-1} for ^{232}Th and 0.15 Bqkg^{-1} for ^{40}K. Any activity concentration values below these detection limits have been taken, in this work, to be below the minimum detectable limit (MDL). The values of the activity concentrations of ^{226}Ra were above the minimum detectable activity (MDA), in all the cereal samples. The maximum value was 2.95 Bqkg^{-1} (Sample 4), the minimum value detected was 1.0 Bqkg^{-1} (Sample 9) and a mean value of (0.839±0.713) Bqkg^{-1}. For ^{232}Th, we have a maximum value of 4.60 Bqkg^{-1} (Sample 4), a minimum value was 0.23 Bqkg^{-1} (Sample 9), with a mean value of (1.153±1.084) Bqkg^{-1}. The values of the activity concentrations for ^{40}K were found to be much higher than those of ^{226}Ra and ^{232}Th in all the analyzed samples. The values ranged between 10.54 Bqkg^{-1} (Sample 10) and 36.78 Bqkg^{-1} (Sample 8) with a mean value of (22.514±8.897) Bqkg^{-1}. The values for ^{137}Cs were below detectable limit in all the samples. The inability to detect ^{137}Cs in the samples does not however imply its absence in the samples. It is understood that background level and system MDA could not conceive minor photopeaks. Figure 2 gives an illustration of the relative contribution to dose due to each of the radionuclides indicating a percentage contribution of 3.4%, 4.7% and 91.9% for ^{226}Ra, ^{232}Th and ^{40}K respectively for the cereal samples.

Table 1: Activity Concentrations of Radionuclides in Cereal Samples (Bqkg-1)

S/No	Basic Ingredient	Sample codes	^{232}Th	^{226}Ra	^{40}K	^{137}Cs
1	Rice, Maize, Barley	Sample 1	1.14	1.32	19.17	BDL
2	Maize	Sample 2	2.05	1.09	30.96	BDL
3	Maize	Sample 3	1.79	1.24	11.70	BDL
4	Maize	Sample 4	4.62	2.95	14.49	BDL
5	Millet	Sample 5	1.06	1.21	21.82	BDL
6	Maize	Sample 6	1.18	0.98	27.71	BDL
7	Maize	Sample 7	0.54	0.41	17.74	BDL
8	Oats	Sample 8	0.38	0.28	36.78	BDL
9	Maize	Sample 9	0.23	0.10	34.64	BDL
10	Maize	Sample 10	0.38	0.72	10.54	BDL
11	Maize	Sample 11	0.56	0.29	25.93	BDL
12	Rice	Sample 12	0.52	0.28	14.43	BDL
13	Maize	Sample 13	0.41	0.30	36.04	BDL
14	Oats	Sample 14	1.79	1.24	11.70	BDL
15	Maize	Sample 15	0.64	0.18	24.06	BDL
		Mean ± S.D.	1.153±1.084	0.839±0.713	22.514±8.897	

S.D = Standard Deviation

Table 2: Activity Concentrations of Radionuclides in Tea samples (Bqkg-1).

S/N	Sample codes	^{232}Th	^{226}Ra	^{40}K	^{137}Cs
1	Sample 16	0.33	0.26	15.03	BDL
2	Sample 17	1.96	1.21	14.74	BDL
3	Sample 18	0.83	1.31	9.76	BDL
4	Sample 19	0.51	1.88	30.53	BDL
5	Sample 20	0.41	0.3	6.04	BDL
6	Sample 21	2.69	1.94	40.22	BDL
7	Sample 22	1.76	0.98	23.2	BDL
8	Sample 23	0.54	0.36	14.4	BDL
9	Sample 24	0.8	0.43	19.5	BDL
10	Sample 25	1.62	0.73	18.7	BDL
	Mean ± SD	1.145 ± 0.765	0.94 ± 0.601	19.212 ± 9.533	

The results given in Table 2 for the tea samples indicate that for ^{226}Ra, the minimum value obtained was 0.26 $Bqkg^{-1}$ (Sample 16), a maximum value of 1.94 $Bqkg^{-1}$ (Sample 21), with an average value of (0.94 ± 0.601) $Bqkg^{-1}$. For ^{232}Th, the minimum value was 0.33 $Bqkg^{-1}$ (Sample 16), the maximum value was 2.69 $Bqkg^{-1}$ (Sample 21), while the mean value was (1.145 ± 0.765) $Bqkg^{-1}$. Again, the activity concentrations of ^{40}K were obtained to be above the minimum detectable activity (MDA) in all the tea samples. The values ranged from 6.04 $Bqkg^{-1}$ (Sample 20) to 40.22 $Bqkg^{-1}$ (Sample 21) with a mean value of (19.212 ± 9.533) $Bqkg^{-1}$. The implication of a very high deposition of large quantities of radionuclides in particular organs is that they have high risk of weakening the immune system, thereby increasing the mortality rate of such an individual (Tawalbeh *et al*., 2012). Moreover, a very high concentration of ^{40}K in the body may affect the muscle. The values of ^{137}Cs in the tea samples were below the minimum detectable activity. Again, the percentage contribution of each of the natural radionuclides in the tea samples is illustrated in Figure 3.

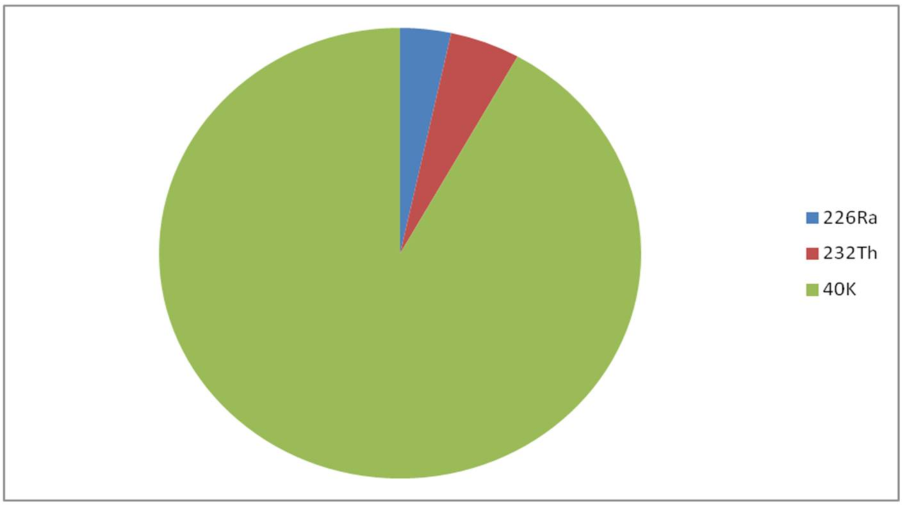

Figure 2: Relative contributions to dose of ^{226}Ra, ^{232}Th and ^{40}K in the activity concentrations of the cereal samples.

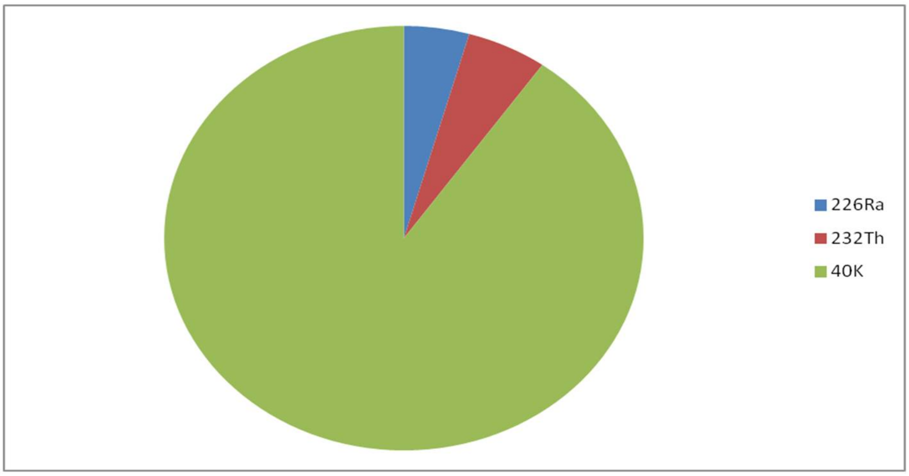

Figure 3: Relative activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the Tea Samples.

Calculation of Radiological Parameters

Annual Effective Dose

The effective dose **E** (in Sieverts per year) due to the intake of a radionuclide with the ingested material is calculated using the expression (Ababneh *et. al*, 2009):

$$E = CA_iD_i \quad (2)$$

where C (kg/yr) = mean annual consumption of foodstuff; A_i (Bq/kg) = activity concentration of radionuclide i in the ingested material; D_i (Sv/Bq) = dose coefficients for radionuclide i.

Thus the total annual effective dose E_t is calculated as

$$E_t = \sum CA_iD_i \quad (3)$$

Since both dose conversion factors and annual intakes are age dependent, the values for the annual effective dose; and the total annual effective dose for the different age groups were obtained using values for dose coefficients D for each radionuclide; and mean annual consumption C of foodstuff (Table 3).

Using the activity concentration values given in Table 1, the associated annual effective dose that an average individual receives in one year was evaluated for the different age groups. The results are presented in Table 4 while Table 5 gives the total annual effective dose ($mSvy^{-1}$) for different age groups as a result of the consumption of the different cereal products. The variations in the total annual effective doses; and the mean values are given in Table 6.

The values of the annual effective dose for the cereals studied are well within the permissible limit of $1mSvy^{-1}$ (ICRP, 1990) for members of the public.

Table 3: Values of the Ingestion Dose Coefficients and Assumed Mean Annual Consumption for each radionuclide according to age groups (ICRP, 2012; Shaban and Rolf, 2009).

Age Group (Years)	Dose coefficients D for Radionuclides (in $SvBq^{-1}$) ^{226}Ra	^{232}Th	^{40}K	Mean annual consumption C of foodstuff (in $kgyr^{-1}$)
<1	4.70×10^{-06}	4.60×10^{-06}	6.20×10^{-08}	12
>1 to 2	9.60×10^{-07}	4.50×10^{-07}	4.20×10^{-08}	30
>2 to 7	6.20×10^{-07}	3.50×10^{-07}	2.10×10^{-08}	80
>7 to 12	8.00×10^{-07}	2.90×10^{-07}	1.30×10^{-08}	95
>12 to 17	1.50×10^{-06}	2.50×10^{-07}	7.60×10^{-09}	110
>17	2.80×10^{-07}	2.30×10^{-07}	6.20×10^{-09}	110

Table 4: Annual effective dose ($mSvy^{-1}$) due to ingestion of different cereal samples.

Cereals Products	Radionuclides	Age/y <1	>1 - 2	>2 - 7	>7 - 12	>12 - 17	>17
Sample 1	^{232}Th	0.0629	0.0154	0.0319	0.0314	0.0314	0.0288
	^{226}Ra	0.0744	0.038	0.0655	0.1003	0.2178	0.0407
	^{40}K	0.0143	0.0242	0.0322	0.0237	0.016	0.0131

Sample 2	^{232}Th	0.1132	0.0277	0.0574	0.0565	0.0564	0.0519
	^{226}Ra	0.0615	0.0314	0.0541	0.0828	0.1799	0.0336
	^{40}K	0.0230	0.0390	0.052	0.0382	0.0259	0.0211
Sample 3	^{232}Th	0.0988	0.0242	0.0501	0.0493	0.0492	0.0453
	^{226}Ra	0.0699	0.0357	0.0615	0.0942	0.2046	0.0382
	^{40}K	0.0087	0.0147	0.0197	0.0144	0.0098	0.0080
Sample 4	^{232}Th	0.2550	0.0624	0.1294	0.1273	0.1271	0.1169
	^{226}Ra	0.1664	0.085	0.1463	0.2242	0.4868	0.0909
	^{40}K	0.0108	0.0183	0.0243	0.0179	0.0121	0.0099
Sample 5	^{232}Th	0.0585	0.0143	0.0297	0.0292	0.0292	0.0268
	^{226}Ra	0.0684	0.0348	0.0600	0.092o	0.1997	0.0373
	^{40}K	0.0162	0.0275	0.0367	0.0269	0.0182	0.0149
Sample 6	^{232}Th	0.0651	0.0159	0.033	0.0325	0.0325	0.0299
	^{226}Ra	0.0553	0.0282	0.0486	0.0745	0.1617	0.0302
	^{40}K	0.0206	0.0349	0.0466	0.0342	0.0232	0.0189
Sample 7	^{232}Th	0.0298	0.0073	0.0151	0.0149	0.0149	0.0137
	^{226}Ra	0.0231	0.0118	0.0203	0.0312	0.0677	0.0126
	^{40}K	0.0132	0.0224	0.0298	0.0219	0.0148	0.0121
Sample 8	^{232}Th	0.021	0.0051	0.0106	0.0105	0.0105	0.0096
	^{226}Ra	0.0158	0.0081	0.0139	0.0213	0.0462	0.0086
	^{40}K	0.0274	0.0463	0.0618	0.0454	0.0307	0.0251
Sample 9	^{232}Th	0.0127	0.0031	0.0064	0.0063	0.0063	0.0058
	^{226}Ra	0.0056	0.0029	0.005	0.0076	0.0165	0.0031
	^{40}K	0.0258	0.0436	0.0582	0.0428	0.029	0.0236
Sample 10	^{232}Th	0.021	0.0051	0.0106	0.0105	0.0105	0.0096
	^{226}Ra	0.0406	0.0207	0.0357	0.0547	0.1188	0.0222
	^{40}K	0.0078	0.0133	0.0177	0.013	0.0088	0.0071
Sample 11	^{232}Th	0.0309	0.0076	0.0157	0.0154	0.0154	0.0142
	^{226}Ra	0.0164	0.0084	0.0144	0.022	0.0479	0.0089
	^{40}K	0.0193	0.0327	0.0436	0.032	0.0217	0.0177

Sample 12	^{232}Th	0.0287	0.007	0.0146	0.0143	0.0143	0.0132
	^{226}Ra	0.0158	0.0081	0.0139	0.0213	0.0462	0.0086
	^{40}K	0.9107	0.0182	0.0242	0.0178	0.0121	0.0984
Sample 13	^{232}Th	0.0226	0.0055	0.0115	0.0113	0.0113	0.0104
	^{226}Ra	0.0169	0.0086	0.0149	0.0228	0.0495	0.0924
	^{40}K	0.0268	0.0454	0.0605	0.0445	0.0301	0.0246
Sample 14	^{232}Th	0.0988	0.0242	0.0501	0.0493	0.0492	0.0453
	^{226}Ra	0.0699	0.0357	0.0615	0.0942	0.2046	0.0382
	^{40}K	0.0087	0.0147	0.0197	0.0144	0.0098	0.008
Sample 15	^{232}Th	0.0353	0.0086	0.0179	0.0176	0.0176	0.0162
	^{226}Ra	0.0102	0.0052	0.0089	0.0137	0.0297	0.0055
	^{40}K	0.0179	0.0303	0.0404	0.0297	0.0201	0.0164

Table 5: Total annual effective dose (mSvy^{-1}) with age groups (year) for different cereal samples

Cereal Products	Age/y <1	>1-2	>2-7	>7-12	>12-17	>17
Sample 1	0.1516	0.0776	0.1296	0.1554	0.2652	0.0826
Sample 2	0.1977	0.0981	0.1635	0.1776	0.2621	0.1066
Sample 3	0.1774	0.0746	0.1313	0.1580	0.2636	0.0915
Sample 4	0.4322	0.1656	0.3000	0.3694	0.6259	0.2176
Sample 5	0.1430	0.0767	0.1263	0.1481	0.2470	0.0790
Sample 6	0.1410	0.0791	0.1282	0.1412	0.2173	0.0789
Sample 7	0.0661	0.0415	0.0653	0.0679	0.0973	0.0384
Sample 8	0.0641	0.0595	0.0863	0.0772	0.0874	0.0433
Sample 9	0.0441	0.0496	0.0696	0.0567	0.0518	0.0325
Sample 10	0.0694	0.0391	0.0641	0.0782	0.1381	0.0390
Sample 11	0.0666	0.0486	0.0736	0.0695	0.0849	0.0408
Sample 12	0.0552	0.0333	0.0527	0.0534	0.0726	0.0316
Sample 13	0.0664	0.0596	0.0869	0.0786	0.0909	0.0443
Sample 14	0.1774	0.0746	0.1313	0.1580	0.2636	0.0915
Sample 15	0.0634	0.0441	0.0673	0.0610	0.0674	0.0381
Mean±S.D.	0.1277±0.10	0.0681±0.03	0.1117±0.62	0.1233±0.08	0.1890±0.15	0.0704±0.05

S.D = Standard Deviation

Table 6: Range and Mean values of Total Annual Effective Dose

S/No.	Age group (y)	Dose Range (mSvy-1)	Mean Values (mSvy-1)
1.	>1	0.044 – 0.432	0.128
2.	>1–2y	0.333 – 0.166	0.068
3.	>2–7y	0.053 – 0.164	0.112
4.	>7–12y	0.054 – 0.369	0.123
5.	>12–17y	0.052 – 0.626	0.189
6.	> 17 y	0.032 – 0.218	0.071

Internal Hazard Index

The internal hazard index is used to estimate the level of internal exposure hazard associated with the natural radionuclides in food samples. The hazard index (HI) is calculated from the equation (Tawalbeh *et al.* 2012):

$$HI = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (4)$$

Where A_{Ra} , A_{Th} and A_K in Bq/kg are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively. The value must be less than unity for radiation hazard to be negligible.

Table 7 gives the values of the internal hazard indices for the cereal samples which ranged from 0.0065 to 0.0368 with a mean value of (0.0140 ± 0.008). The highest value of the internal hazard index is seen to be less than unity. The values of the internal hazard indices for the tea samples are given in Table 8. The values ranged between 0.0044 and 0.0292 with a mean value of (0.0135 ± 0.007). The highest value of internal hazard index (in sample 20) is also less than unity

Table 7: Internal Hazard Indices of Cereal Samples

S/N	Cereal Products	Internal Hazard index
1.	Sample 1	0.0155
2.	Sample 2	0.0202
3.	Sample 3	0.0160
4.	Sample 4	0.0368
5.	Sample 5	0.0152
6.	Sample 6	0.0156
7.	Sample 7	0.0080
8.	Sample 8	0.0106
9.	Sample 9	0.0086
10.	Sample 10	0.0076
11.	Sample 11	0.0091
12.	Sample 12	0.0065
13.	Sample 13	0.0107
14.	Sample 14	0.0160
15.	Sample 15	0.0141
	Mean±S.D.	0.0140 ± 0.008

Table 8: Internal Hazard indices of tea samples

S/N	Tea sample code	Internal Hazard Index
1.	Sample 16	0.0058
2.	Sample 17	0.0172
3.	Sample 18	0.0123
4.	Sample 19	0.0185
5.	Sample 20	0.0292
6.	Sample 21	0.0044
7.	Sample 22	0.0169
8.	Sample 23	0.0070
9.	Sample 24	0.0095
10.	Sample 25	0.0141
	Mean±S.D.	0.0135±0.0071

S.D = Standard Deviation

CONCLUSION

In this study, the activity concentrations of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were obtained in the samples of cereal and tea products. In the cereal samples, the highest activity concentrations of ^{226}Ra and ^{232}Th were found in Sample 4 with values of 2.95 $Bqkg^{-1}$ and 4.60 $Bqkg^{-1}$ respectively and for ^{40}K to be 36.78 $Bqkg^{-1}$ in Sample 8. The annual effective dose from the consumption of ^{226}Ra, ^{232}Th, and ^{40}K was calculated for the selected age groups based on ICRP (Shaban and Rolf, 2009) recommended annual cereal consumption rate for the age groups. All the results obtained for the total annual effective doses in this study were below the annual effective dose limit of $1mSvy^{-1}$ for the general public. The entire hazard indices evaluated were all below unity which implies an insignificant health burden on the population as a result of the consumption of the cereals.

For the tea samples, the highest concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were found in sample 20 to be $1.94Bqkg^{-1}$, $1.145Bqkg^{-1}$ and $40.22Bqkg^{-1}$ and the mean concentration was 1.145, 0.94 and 19.212 $Bqkg^{-1}$ respectively. Also all the hazard indices evaluated were below unity which implies that the tea samples also pose no health hazard for consumers. We take note that ^{137}Cs was found to be below detection limit for all the samples.

Based on the results of all the parameters estimated, the highest effective dose for the cereals was found in the age group 12-17years and the lowest was in the age group 1-2years. The annual effective dose values were below the limit of $1mSvy^{-1}$ for the general public as recommended by International Commission on Radiological Protection (ICRP) and 0.25-0.4 $mSvy^{-1}$ (The portion of the background dose resulting from ingestion of natural radionuclides in food) as recommended by International Atomic Energy Agency (IAEA, 1989). The activity concentrations of ^{226}Ra and ^{40}K found in the investigated cereals and tea samples are lower in magnitude while the activity concentrations of ^{232}Th obtained in the present study (tea and cereal samples) were found to be of the same order of magnitude as most of those reported from other parts of the world as illustrated in Table 9.

The annual effective doses and hazard indices obtained in this study do not present any radiological concern for consumers of cereals and tea. However, when the results obtained are compared with the UNSCEAR reference values, it can be concluded that the values for the activity concentrations of ^{40}K in the cereal samples are much higher. Again, in order to have a more robust baseline data, there is need to carry out investigations on other types of cereals available in other parts of the country. Alpha and beta emitting radionuclides also need to be studied in different foodstuffs.

Table 9: Comparison of activity concentrations (in $Bqkg^{-1}$) of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in cereal and tea samples investigated in this study with those reported in other places/countries.

Country	Sample	^{226}Ra	^{232}Th	^{40}K	Reference
Iran	Maize	0.81±0.03	0.85±0.3	101.52±1.29	Changizi et al., 2013
Yemen	Sorghum	2.61	1.63	147.54	El-Gamal et al., 2019
Odisha, India	Cereal	0.8 ± 0.1	1.7 ± 0.2	190 ± 3.2	Lenka et al., 2013
Vizag, India	Milk	1.78 ± 0.67	1.11 ± 1.19	8.78 ± 11.55	Patra et al., 2014
Nigeria	Cereal	0.84 ± 0.74	1.15 ± 1.12	22.51 ± 9.21	Avwiri & Alao, 2013
Nigeria	Cereal	-	6.78	130	Arogunjo et al., 2004
Egypt	Tea	3.1 ± 0.7	3.4 ± 1.2	623 ± 25	Harb S., 2007
UK	Cereal	0.0 – 0.9	0.0 – 0.6	38 -100	Alrafae et al., 2012
Iraq	Wheat flour	6.603± 3.7	1.95± 1.33	133.1±67.04	Abojassim et al., 2014
Tanzania	Maize	13.23± 0.1	4.08± 0.01	48.7± 0.11	MIwile et al., 2007
Nigeria	Cereal	0.84±0.713	1.153±1.08	22.52 ± 8.9	Present work
Nigeria	Tea	0.94±0.63	1.15±0.81	19.2 ± 10.05	Present work
Global Average	Maize	40	40	580	UNSCEAR, 2000

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