Natural Radionuclides in Commonly Consumed Food Items in Enugu State, Nigeria

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Abstract

Food is any substance that provides nutritional support for the body. It is usually of plant or animal origin. For human consumption, food's biological purity is always considered but radionuclide contamination is also possible. The objectives of this study was to assess the concentrations of natural radionuclides (^{238}U, ^{40}K, and ^{232}Th) in selected food items commonly consumed in Enugu State, Nigeria, and their radiological implications. A prospective cross-sectional survey of thirteen food samples from markets in Enugu State was adopted. Study lasted from March to June, 2017. Samples were processed within 24hours of collection. The IAEA (1989) Technical series 295, No 95 recommendation was adopted. The average ^{40}K, ^{226}Ra and ^{232}Th concentrations were 208.8828 ± 4.4244 Bq/Kg, 31.4486 ± 4.7706 Bq/Kg and 55.9818 ± 2.6958 Bq/Kg respectively. The ^{40}K and ^{232}Th concentrations were highest in vegetables and lowest in local tomatoes and local meat. The ^{226}Ra concentration was highest in foreign meat and lowest in local rice. The radium equivalent (Ra_{eq}) ranged from 77.9886Bq/kg (local rice) to 168.3839 Bq/kg(foreign meat) with average of 127.5829Bq/kg. The internal hazard index, H_{in} ranged from 0.211(local rice) to 0.462(foreign meat). The highest aggregate average annual effective doses (AAAED) from the radionuclides were: yam(15.3295µSv/y), local tomatoes(15.2627µSv/y) and foreign meat(14.6705µSv/y). The ^{40}K, ^{226}Ra and ^{232}Th were higher in foreign foods but the (AAAED) was higher in local foods, perhaps because of greater intakes of local foods. Food in Enugu State is safe since Ra_{eq} and H_{in} were within the safety limits.

Key words: Effective dose; Food items; Hazard index. Natural radionuclides concentrations; Radium equivalent.

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Introduction

Food is any substance consumed to provide nutritional support for the body. It is usually of plant or animal origin and contains essential nutrients such as carbohydrates, Proteins, vitamins, fats, minerals. When considering the suitability of food for human consumption, attention is often focused on the biological purity in terms of contamination by micro-organisms. Hardly has the possibility of contamination by radioactive elements been considered. Evidence however, showed that food is contaminated by radioactive elements and the ingestion of these radionuclides through food intake accounts for a substantial part of average radiation doses to various organs of the body[1, 2] and the concentration of the naturally occurring radionuclides in foodstuffs vary in direct relationship to their levels in soil[1] The most important radionuclides associated with internal radiation exposure (due to ingestion of contaminated water and food) and the contamination of the environment, are ^{134}Cs, ^{137}Cs, ^{137m}Ba, ^{131}I, ^{89}Sr, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{241}Am, ^{242}Cm and tritium[3] Others are Uranium (^{238}U) Thorium (^{232}Th) and Potassium-40 (^{40}K) [4, 5,6.] Potassum-40 is present in many common foods including red meats, white potatoes, banana, lima beans, Brazil nuts and other products very frequently consumed[7] Foods may be contaminated as a result of deposition of radionuclides on food crops or on pasture. Radionuclides may be transported into grains through the plant growth process[8] Meat contamination is mainly as a result of animal grazing and consumption of contaminated drinking water.

Knowledge of the radionuclide contamination, concentration in the diet and the characterization of their current background activity in the diet is important for better identification of future contamination incidents and possible long-term trends for mitigating against reaching levels that can pose significant health risk[9]These radionuclides enter food via the use of artificial fertilizer as a result of the need for increased productivity. These fertilizers are known to contain elements such as nitrogen, phosphorus and potassium[10, 11]. Ingested radionuclides could be concentrated in certain parts of the body. For examples. ^{238}U accumulate in human lungs and kidney, ^{232}Th in lungs, liver and skeletal tissues and ^{40}K in muscles[12]. Depositions of large quantities of these radionuclides in particular organs will affect the health condition of the individual. Researches showed that more than 70% of the total annual radioactive dose received by humans originates from natural sources of ionizing radiation of which 54% was due to the inhalation and the ingestion of natural radioactive gas radon ^{222}Rn and its decay products[13]. UNSCEAR report showed that the total exposure per person resulting from ingestion of terrestrial radioisotopes was 0.29 mSv (0.17 mSv from ^{40}K and 0.12mSv from thorium and uranium series) while exposure due to inhalations of terrestrial radioisotopes account for 0.01 mSv[14].Ingested radionuclides are absorbed into the blood[15] and accumulate in specific tissues that they may damage. Of the absorbed uranium, 66% is rapidly eliminated via urine, while the rest is distributed and stored; 12-25% in the kidney, 10-15% in bone and [the rest in] soft tissue[16]. Natural uranium induces chemical toxicity, especially nephrotoxicity, whereas radium and radon are thought to induce solely radiotoxicity[16].

Studies showed the average activity concentrations of ^{232}Th, ^{238}U, 40K and ^{137}Cs in farm soil as 72.4 ± 9.8, 51.1 ± 8.3, 229.3 ± 14.7 and 312.9 ± 11.5 Bq kg^{-1} respectively and the mean transfer factors of ^{232}Th, ^{238}U, 40K and ^{137}Cs, from soil to vegetables and fruit as 0.57, 0.32, 2.12 and 0.04, respectively with the average activity concentrations of ^{232}Th, ^{238}U, ^{40}K and ^{137}Cs in food samples as 8.2 ± 1.8, 17.3 ± 3.3, 465.8 ± 11.8 and 20.9 ± 3.8 Bq kg^{-1} respectively[17]. The internal effective dose to individuals and excess lifetime cancer risk from the consumption of food ranged from 11.7 to 53.6 μSv y^{-1} and 0.05×10^{-3} to 0.24×10^{-3}, respectively while the annual external gamma effective dose and excess lifetime cancer risk in the farms due to soil radioactivity ranged from 94.1 to 139.8 μSvy^{-1} and 0.43×10^{-3} to 0.64×10^{-3}, respectively[17].

This study assessed the radionuclides in foreign and locally produced food items commonly consumed in Enugu State, Nigeria, their concentrations and the radiological impact.

Materials And Methods

A Prospective cross-sectional survey research design was adopted. Thirteen (13) food samples obtained from markets in Enugu Metropolis: New market, Ogbete Main Market, and Shoprite shopping mall were studied. Food items studied include: (1) Foreign rice(Royal thai-from Thailand) (2)Local Rice , (3)Foreign tomato(ochre-from China), (4) Local tomato, (5) Foreign meat(beef- fromChina) (6) Local meat, (7) Foreign fish(sardine-from China), (8)Local fish, (9) Beans, (10) Yam, (11) Vegetable, (12) Garri, (13) groundnut.The meat, fish and tomato were all canned ones. The information about their origin was from the labels on the packaging for each of them.

The food samples were processed at the Centre for Energy, Research and Training (CERT), Ahmadu Bello University, Zaria, Kaduna State, Nigeria. These samples were prepared following the IAEA Technical Report series 295 No 95 procedure[3] and processing was carried out within 24hours of collection. As soon as samples were obtained, they were washed to remove adhering soils (where applicable for solid foods) and labeled accordingly. The inedible parts of the food samples were discarded. The edible samples were then air dried and then oven dried, pulverized and sieved until they become 500um homogeny powder. The powdered samples were kept in sealed tight container with geometry of 6.5 × 6.5cm designed to fit into the Sodium Iodide, NaI (TI) detector counting chamber. The containers were weighed, washed in 0.1M hydrochloric acid, rinsed in distilled water and dried (to avoid contamination by radioactive particles), packaged and properly labeled and sealed with candle wax, masking tape and Vaseline to avoid falling off of some radioisotope progeny. The sealed samples were reweighed, to get the net weights and then left for 28 days to allow short-lived radionuclides (^{238}U and ^{232}Th) to attain secular equilibrium after which each sample was subjected to gamma spectrometric analysis using a 76x76mm NaI (Tl**)** detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1kilovolt external source. The detector was enclosed in a 6cm lead shield with cadmium and copper sheets to minimize the effects of background and scattered radiations. Maestrodata acquisition softwareby Canberra Nuclear Products was used. Each sample was measured for 29000 seconds. The peak area of each energy in the spectrum was used to compute the activity concentrations in each sample using the equation:

$$\mathbf{C\,(Bq.kg^{-1})} = \frac{\mathbf{C_n}}{C_{fk}}$$ Where

C = activity concentration of the radionuclides in the sample (in $BqKg^{-1}$)

$\mathbf{C_n}$ = count rate (counts per second, cps)

C_{fk}= Calibration factor of the detecting system.(C_{fk} = 0.000643 for K-40; 0.000863 for Ra-226 and 0.000877 for Th-232)

The detector crystal has the capacity of distinguishing the gamma rays energies likely to be encountered in the measurement of the samples. Energy and efficiency calibrations was carried out using standard source from IAEA 375 whose energies and activities are known.

Each sample was counted for 29000 seconds and the data acquired automatically by SAMPO 90 software which searches for the peak, evaluates the peak position in the energy spectrum, identifies the radionuclides by means of a radionuclide library and calculates the net peak areas after subtracting the background count.

Internal Hazard Index

Hazard index was used to estimate the level of gamma radiation hazard associated with the natural radionuclides in food samples. The internal hazard index was calculated from the equation[18]:

$$Hin = A_k/4810 + A_{Ra}/370 + A_{Th}/259 \leq 1$$

Where: A_k = activity concentration of potassium-40; A_{Ra} = activity concentration of Radium-226; and A_{Th} = activity concentration of Thorium-232.

Radium Equivalent Index

The radium equivalent activity (Ra_{eq}) is used to describe the gamma output from different mixtures of the radionuclides- ^{226}Ra, ^{232}Th and ^{40}K in a material[19]. The radium equivalent (Bq/kg) for each food sample was calculated using the UNSCEAR formular[20]:

$$R_{aeq} = A_{ra} + 1.43A_{Th} + 0.0077A_K$$

Where: A_{ra}, A_{Th} and A_k(Bq/kg) are the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

Daily Intake of Radionuclides

The Daily Intake of radionuclides(^{226}Ra, ^{232}Th and ^{40}K) by individuals due to consumption of foodstuff was estimated by the formular:

$$Dint = \frac{A_c + A_{ig}}{Y_d}$$

Where: Dint = the daily intake of radionuclides (Bqd^{-1}) by individuals; Ac = the activity concentration of radionuclides ($BqKg^{-1}$); Aig= the Per Capita per year consumption of a particular food; Yd = the days in the year[21].

Annual Effective Dose

The annual effective dose to an individual due to an intake of ^{226}Ra, ^{232}Tth and ^{40}K radionuclides from food consumption were obtained by the formula[22]:

$$E_{eff} = A_c \, X \, A_{ig} \, X \, D_d$$

Where: Eff = the annual effective dose (μSvy^{-1}) to an individual owing to an ingestion of radionuclides; Ac = the average activity concentration of radionuclides ($BqKg^{-1}$); A_{ig} = the annual intake of a particular food Per Capita consumption; andDd = the ingestion dose conversion factor for the radionuclides of interest:- ($2.8x10^{-7}$ $SvBq^{-1}$ for ^{226}Ra, $2.3x10^{-7}SvBq^{-1}$ for ^{232}Th and $6.2x10^{-9}$ $SvBq^{-1}$ for ^{40}K)..

Results

The major radionuclides in food items commonly consumed in Enugu State are Potassium-40 (^{40}K), Radium-226 (^{226}Ra) and Thorium-232 (^{232}Th) in various concentrations.

From Table I, the average concentration of ^{40}K, ^{226}Ra and ^{232}Th in carbohydrate foods ranged from 97.6028-239.1806Bq/kg, 7.2728 - 48.8273Bq/kg and 40.3413 -64.5950Bq/kg for ^{40}K, ^{226}Ra and ^{232}Th respectively. The ^{40}K concentration is highestin each food item and higher in foreign rice than in local rice.

From Table II, it can be seen that the activity concentration of each of the radionuclides is highest in vegetables and that for each food item the concentration of K-40 is highest. For the tomatoes, the concentration of the radionuclides is more in the foreign than the local one.

From Table III the K-40 concentration is seen to be the highest in each food item and the concentration of each of the radionuclides is more in the foreign than the local ones.

From Table IV it can be seen that the radium equivalent (Raeq) ranged from 71.8748Bq/kg(for local rice) to 154.2021 Bq/kg(for vegetable)with average of 113Bq/kg, and the internal hazard index (H_{in}) ranged from 0.211 (for local rice) to 0.456 (for vegetable) with average of 0.308. The Ra_{eq} and the H_{in}were high for vegetable *(SpinaciauOleracea)*, foreign meat, foreign fish, garri, groundnut, beans,

Table I. Mean Radionuclide Concentrations in carbohydrate foods

Food Samples	K-40 (cps)	K-40 (Bq/kg)	Ra-226 (cps)	Ra-226 (Bq/kg)	Th-232 (cps)	Th-232 (Bq/kg)
Foreign rice	0.1538 ± 0.0077	239.1806 ± 11.9590	0.0145 ±0.0008	16.7819± 0.9190	0.0529±0.0014	60.3153 ± 1.6121
Local rice	0.0628 ± 0.0047	97.6028 ± 7.3470	0.0063± 0.0058	7.2728 ±6.7128	0.0391±0.0028	44.5877 ± 3.1455
Garri	0.1769 ± 0.0012	275.1649 ± 1.8770	0.0421± 0.0044	48.8273± 5.1544	0.0570± 0.0024	64.5950 ± 2.9523
Yams	0.1422. ± 0.0009	221.2125 ± 1.4480	0.0245± 0.0047	28.3694± 5.4341	0.0354± 0.0027	40.3413 ± 3.1062

Table II Mean Radionuclide Concentrations in fruits and vegetables

Food Samples	K-40 (cps)	K-40 (Bq/kg)	Ra-226 (cps)	Ra-226 (Bq/kg)	Th-232 (cps)	Th-232 (Bq/kg)
Foreign tomatoes	0.0997 ± 0.0034	155.0920 ± 5.3628	0.0131± 0.0036	15.1836 ±4.1955	0.0549± 0.0012	62.5565 ± 1.4155
Local tomatoes	0.1878 ± 0.0021	70. 0822 ± 5.2168	0.0112 ±0.0027	7.2251 ± 3.4129	0.0381 ±0.0050	61.0247 ± 1.5291
Veg etables *(SpinaciauOleracea)*	0.2929 ± 0.0023	315. 4931 ± 3.6467	0.0416± 0.0070	48.1480 ±8.0713	0.0636± 0.0008	72.4649 ± 0.9437

Table III. Mean Radionuclide Concentrations in protein and leguminous foods

Food Samples	K-40 (cps)	K-40 (Bq/kg)	Ra-226 (cps)	Ra-226 (Bq/kg)	Th-232 (cps)	Th-232 (Bq/kg)
Foreign meat	0.1882 ± 0.0010	292.7549 ± 1.5552	0.0772± 0.0050	89.5033± 5.8337	0.0346± 0.0036	39. 3976 ± 4.0892
Local meat	0.1738 ± 0.0060	148. 9847 ± 1. 0647	0.0543± 0.0010	42.5194± 6.0148	0.0158± 0.0013	31. 2729 ± 3.5184
Foreign fish	0.1943 ± 0.0027	302.2470 ± 4.1830	0.0178± 0.0049	20.6577± 5.6739	0.0583±0.00 16	66.4491 ± 1.7694
Local fish	0.1202 ± 0.0042	129.0770 ± 3.6518	0.0153± 0.0016	9.3453 ± 1.0459	0.0329± 0.0011	63.5329 ± 3.1041
Beans	0.1859 ± 0.0072	289. 0545 ± 11.1546	0.0264± 0.0041	30.6469± 4.7549	0.0567± 0.0028	64. 6797 ± 3.1455
Groundnuts	0.1150 ± 0.0004	178. 9028 ± 0.6972	0.0388± 0.0037	44.9115± 4.2354	0.0493± 0.0016	56.1868 ± 1.8087

Tab le IV Radium equivalent+ and internal hazard index* obtained from the studied food samples.

Food samples	Raeq (Bq/Kg)	H_{in}
Foreign Rice	104.8744	0.328
Local Rice	71.8748	0.211
Garri	143.3169	0.439
Yam	87.7608	0.278
Foreign Tomatoes	105.8336	0.315
Local Tomatoes	95.0301	0.269
Vegetable (SpinaciaOleracea)	154.2021	0.456
Foreign Meat	148.0961	0.462
Local Meat	88.3868	0.267
Foreign Fish	118.6072	0.375
Local Fish·	101.1911	0.297
Beans	125.3621	0.393
Groundnut	126.6362	0.375

+ Calculation based on Yasir et al (2013)'s formula *Calculation based on Tufarl et al (2000)'s formula

foreign tomatoes and foreign rice. The average annual effective dose AAED from the radionuclides, K-40, Ra-226 and Th-232was 3.462µSv/yr.

From Table V the aggregate annual effective dose(AAAED) from the radionuclides arising from consumption of the food items is highest for yam (15.3295 µSv/y), followed by local tomatoes (15.2627µSv/y) and foreign meat(14.6705µSv/y). The highest average annual effective dose from the consumption of the food items is from Thorium-232

Table V. Daily Intake[+] of radionuclides and Annual Effective Dose[*] for the studied food samples

	Radionuclides					
	^{40}K		^{226}Ra		^{232}Th	
Food samples	Daily Intake (Bq/d)	Effective dose(μSv/y)	Daily Intake(Bq/d)	Effective dose(μSv/y)	Daily Intake(Bq/d)	Effective dose(μSv/y)
Foreign rice	16.3	2.4172	1.1	5.1688	4.1	5.6877 (13.2736)
Local rice	6.6	3.9939	0.5	1.0182	3.0	4.2046(9.2177)
Garri	72.8	1.2420	12.9	1.7636	17.2	2.5554 (5.5609)
Yam	46.7	6.4050	5.9	1.0378	8.5	7.8867 (153295)
Foreign tomato	4.6	4.4351	0.5	2.1257	1.9	2.7337 (10.1030)
Local tomato	2.0	8.6902	0.2	4.0461	1.8	2.5264 (15.2627)
Vegetable (Spinacia Oleracea)	0.2	3.9121	0.1	1.3481	0.1	1.6667 (6.9270)
Foreign meat	6.9	1.2524	2.1	5.2628	0.9	8.1553 (14.6705)
Local meat	3.5	3.2310	1.0	1.1905	0.7	5.0349 (9.4564)
Foreign fish	9.1	1.7053	0.6	3.4705	0.2	3.0567 (8.2327)

(4.1061μSv/y).

Discussion

The major radionuclides found in food items consumed in Enugu state are ^{40}K, ^{226}Ra and ^{232}Th with mean concentrations: 208.8828±4.4244 Bq/kg, for ^{40}K, 31.4486±4.7706 Bq/kg, for ^{226}Ra and 55.9818±2.6958 Bq/kg, for ^{232}Th. The concentration of ^{40}K was highest in all the samples of food items. The concentration of each of the radionuclides was higher in the foreign food.

The finding of the three radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in food items with ^{40}K concentration being the highest in each food item agrees with the findings of researchers in Nigeria[23,24] and in Tehran, Iran[25] but disagreed with the work of[26,] and[27] who found the same ^{40}K, ^{226}Ra and ^{232}Th as in this study but in very small concentrations.

The finding of higher concentrations of these radionuclides in protein foods should be of concern and needs more investigations because of the importance of these proteins foods for human health and well being while the radiations from the radionuclides are undesirable.

Jibiri et al found the radionuclides in yam[24] as this study while Awudu et al[5] found them in higher concentrations in all the food items studied with the maximum concentrations of ^{40}K and ^{232}Th in cassava. Their maximum concentrations in this study was in garri. The variation may be due to soil type and fertilization method[24]

In terms of radiological risk, the radium equivalent, Ra_{eq}(Bq/kg) and the internal hazard (H_{in}) found in the study were all within the UNSCEAR recommended safe limit. The values of the Ra_{eq} ranged from 77.986Bq/kg (in local rice) to 168. 3839Bq/kg (in foreign meat) while the values of H_{in} ranged from 0.221 (in local rice) to 0.462 (in foreign meat).

Although within the UNSCEAR recommended safe limits, the higher Ra_{eq} and H_{in} in foreign food items suggests that Nigerians should go more for local food items. The higher AAAED from local foods may be because of their higher intake. For radiation safety there is need to reduce their annual intake.

Summary and Conclusion

The major radionuclides in food items consumed in Enugu State are ^{40}K, ^{226}Ra and ^{232}Th with ^{40}K being highest in all the food items studied. The Ra_{eq} and H_{in} and the annual effective doses for these radionuclides were all within the recommended safe limits(Hin $\leq$1, Raeq, $\leq$370Bq/kg and average annual effective dose, AAED, $\leq$ 1mSv/yr). Radiations resulting from radionuclides in food in Enugu State are within the recommended safe limits. So the food consumed in Enugu State is radiologically safe.

Limitation of The Study

The number of food samples studied for each class of food was quite small compared to food items in that class. This may affect making generalization with the results. The results from this study therefore, create awareness and the need to investigate larger samples in each class of food.

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