ASSESSMENT OF NATURAL RADIOACTIVITY IN POTATO AND THE HEALTH RISK ASSOCIATED WITH ITS CONSUMPTION IN ENUGU, NIGERIA

Fredrick Oghenebrorie Ugbede[1] and Anita Franklin Akpolile[2]

[1]Department of Physics with Electronics, Evangel University Akaeze, Ebonyi State, Nigeria.
[2]Department of Physics, Faculty of Science, Delta State University, Abraka, Nigeria.
*Corresponding author. E-mail: ugbedefred@evangeluniversity.edu.ng. Tel: +2348064148555.

Accepted 28th May, 2020

The determination of the specific activity of radioactivity in food stuffs is an important tool in the evaluation of human internal radiation exposure through ingestion. In this regard, the activity of natural radionuclides ^{40}K, ^{238}U and ^{232}Th in potato samples from different markets in Enugu town were determined by means of gamma spectrometry using NaI(TI) detector. The activity concentrations of ^{40}K ranged from 327.65±17.49 – 725.30±38.66 Bq.kg^{-1} with mean value 526.39±135.98 Bq.kg^{-1}, those of ^{238}U ranged from BDL – 13.94±1.73 Bq.kg^{-1} with mean of 8.55±4.67 Bq.kg^{-1} and those of ^{232}Th ranged from BDL – 3.38±0.20 Bq.kg^{-1} with mean value of 1.14±1.11 Bq.kg^{-1}. The average daily intake of ^{40}K, ^{238}U and ^{232}Th were found to be 20.70, 0.34 and 0.04 Bq.d^{-1} respectively. The mean annual effective doses to age groups 2–7 yr, 7–12 yr, 12–17 yr and >17 yr were estimated to be 0.240, 0.201, 0.246 and 0.085 mSv.y^{-1} respectively. These values indicate that individuals within the age group 12–17 yr in Enugu are at higher radiation risk from potato consumption.

Key words*:* Natural radionuclides, potatoes, effective dose, Enugu.

INTRODUCTION

Contamination of food crops with radioactive nuclides and toxic heavy metals at certain concentration poses serious adverse health effects. The uptake of radionuclides by plants from farmlands along with other micronutrients and their subsequent relocation to human body through ingestion is one major pathway of human internal exposure. Radionuclides belonging to ^{238}U and ^{232}Th series as well as ^{40}K are the major naturally occurring radionuclides (NORMs) which are present in agricultural soils. Their ingestion through food intake accounts for a significant part of the total radiation doses to organs of the human body (McDonald et al., 1999; Fernandez et al., 2004; Hernandez et al., 2004). When elevated levels of these radionuclides accumulate within the human body, the organs will be subjected to continuous exposure from the emitted photons and radiation, creating radiation damage, biochemical and morphological changes (Asaduzzaman et al., 2015a; Akhter et al., 2007). According to UNSCEAR (2000), an average radiation dose of 0.29 mSvy^{-1} is received worldwide via ingestion of natural radionuclides of ^{238}U and ^{232}Th series as well as ^{40}K during habitual consumption of food and water.

Sweet potato (*Ipomoea batatas, L*) is an important tropical root crop. It supplies the necessary daily requirements of various substances including macro and micro elements (Mahamud et al., 2015). Besides carbohydrates, potato is a rich source of protein, lipid, calcium and carotene (Anyaegbunam and Nto, 2011). The high nutritional and culinary values of sweet potato make it a staple food in the diet of most people in Nigeria. Like every other food crops, the health safety, integrity and sanity of sweet potatoes consumed need to be assessed due to uptake of unprecedented levels of chemical and radioactive contaminants present in agricultural soils where they were grown. Its frequent consumption among Enugu residents makes it a choice of this study to assess the natural radionuclides content of sweet potatoes sold in Enugu markets and to evaluate the possible health risk associated with their consumption. A survey by us revealed that sweet potato sold in Enugu markets are imported from nearby villages like Owo, Ameachi Idodo, Nkalagu, Ezillo and neighbouring states like Benue. Radioactive nuclides present in the soil where they are grown are taken up by the plant through root uptakes. They successively find their way into the human internal body system when consumed. Studies regarding natural radioactivity and heavy metals surveys of foods of this nature are designed to evaluate food safety and also assess the health risk effects associated with radioactive and chemical contaminants in food. International organizations such as World Health Organization (WHO) and European Food Safety Authority (EFSA) have incorporated risk analysis as a useful methodology to strengthen food safety systems and reduce diseases linked to food consumption (European Commission 2000, 2002; FAO/WHO 2006, 2009). To evaluate food safety therefore, exposure needs to be assessed and compared with health safety limits or toxicological endpoint values (Marín et al., 2017).

MATERIALS AND METHODS

Samples collection and preparation

Sweet potato samples were bought from seven major markets in Enugu town. The markets are Afia Abakpa market, Old Artisan market, Orie Emene market, Garriki market, New Havan market, New market and Ogbete market. In each market, potato samples were purchased from three sellers and were mixed together to give a representative and composite sample of that market and thus that area. Samples from each market were labeled appropriately in order to avoid any mix-up as well as cross contamination. The potatoes were transported to the laboratory, washed with distilled water, peeled to remove the back cover, rinsed with distilled water and were sliced into chips using stainless kitchen knife and grater, which were initially washed and rinsed with distilled water. Sliced potato chips were spread on aluminium foil and sun dried for four days in open space under normal atmospheric conditions. The potato chips were then oven dried (DHG – 9030) at 75°C for 12 h until constant weight was achieved. The dried potato chips were grinded to fine powder using Binatone electronic blender (Model: BRG-451). Then, 200 g of each sample was measured into cylindrical plastic containers of uniform size using an electronic weighing balance (G&G electronic scale: JJ500) and sealed for four weeks before gamma spectrometric analysis, in order to allow for attainment of secular equilibrium between parent and daughter nuclides.

Gamma-ray spectrometry and activity measurements:

Storing and gamma spectrometric analysis of the samples was carried out at the environmental research laboratory of National Institute of Radiation Protection and research (NIRPR), University of Ibadan, Ibadan. The activities of natural radionuclides in the samples were analyzed using 7.6 cm × 7.6 cm NaI(Tl) detector (Model 802 series) by Canberra Inc. The detector has a resolution of about 8% at 0.662 MeV, which is capable of distinguishing the gamma ray energies of the radionuclides of interest in this study. The interference of background radiation was reduced with the use of 15 mm lead shield, which reduced the background by a factor of about 95%. The output of the detector was connected to a Canberra series 10 plus Multichannel Analyzer (MCA) with computer-based MAESTRO (ORTEC) program used for data acquisition and analysis of the gamma spectra. Prior to sample analysis, energy and efficiency calibrations of the gamma-counting system, using standard IAEA sources, were performed for various energies of interest in the selected sample geometry following the procedures described in IAEA (1989). The background count was determined by counting an empty container having same geometry as the one containing the samples and subtracted from the gross count. Each sample including the background was counted for 36000 s to obtain the gamma spectrum with good statistics. The activity of ^{238}U, ^{232}Th, and ^{40}K were determined using the gamma ray photo peaks corresponding to energy of 1120.3 keV (^{214}Bi), 911.21 keV (^{228}Ac) and 1460.82 keV (^{40}K) respectively. The activity concentrations of the radionuclides were thus calculated using the total net counts under the selected photo-peaks, the measured photopeak efficiency, gamma intensity and weight of the samples using the following expression (Akinloye and Olomo, 2000; Jibiri et al., 2007).

$$C\ (B.kg^{-1}) = \frac{C_n}{\varepsilon P_\gamma M_s} \quad (1)$$

Where, C is the activity concentrations of radinuclides in the sample, C_n is the total net count rate under each photopeak, P_γ is the absolute transition probability of the specific gamma energy, ε is the efficiency of the detector for the specific gamma energy and M_s is the mass of the sample in kilogram (kg).

Estimation of Radium equivalent activity (Ra_{eq})

Since ^{40}K, ^{238}U and ^{232}Th are not equally distributed in a sample, the radium equivalent activity, Ra_{eq} is used in radiological study as a single activity concentration of ^{40}K, ^{238}U and ^{232}Th radionuclides present in a sample. The assumption is based on the fact that 4810 Bq/kg of ^{40}K, 370 Bq/kg of ^{238}U and 259 Bq/kg of ^{232}Th produce the same gamma dose effect (UNSCEAR, 2000). The Ra_{eq} was estimated using equation 2 (UNSCEAR, 2000; Avwiri and Agbalagba, 2013; Akpolile and Ugbede, 2019).

$$Ra_{eq} = A_u + 1.43A_{Th} + 0.077A_k \quad (2)$$

Where A_u, A_{Th} and A_k stand for the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

Estimation of daily intake of radionuclides and annual effective dose

To ascertain the actual gamma radiation dose arising from ^{40}K, ^{238}U and ^{232}Th due to potato consumption among Enugu residence, the daily intake (D_{int}) of radionuclides and annual effective dose (AED) were estimated using equations 3 and 4 respectively (Jibiri et al., 2007; Khandaker et al., 2013; Ibikunle et al., 2017; Nahar et al., 2018) by assuming an annual potato consumption rate of 14.35 per kg per person (Federal Office of statistics, 2006; Jibiri et al., 2007).

$$D_{int} = \frac{A_c \times A_{ig}}{Y_d} \quad (3)$$

$$AED = \sum_i (A_c^i \times D_{cf}^i) A_{ig} \quad (4)$$

Where A_c is the activity concentration of concerned radionuclide, A_{ig} is the per capital annual consumption rate of potato and Y_d is the total number of days (365 days) in a year. A_c^i and D_{cf} signify the activity and dose conversion factor ($SvBq^{-1}$) of ith radionuclide respectively. Since the dose conversion factor is age dependent, the AED was calculated for four age groups (2–7 yrs, 7–12 yrs, 12–17 yrs and >17 yrs). The dose conversion factors for the age groups are shown in Table 1 (ICRP, 1996).

Table 1. Radionuclides dose conversion factor.

Radionuclide	Dose conversion factor ($Sv.Bq^{-1}$) per age group			
	2–7 yrs	7–12 yrs	12–17 yrs	>17 yrs
^{238}U	6.2×10^{-7}	8.0×10^{-7}	1.5×10^{-6}	2.8×10^{-7}
^{232}Th	3.5×10^{-7}	2.9×10^{-7}	2.5×10^{-7}	2.3×10^{-7}
^{40}K	2.1×10^{-8}	1.3×10^{-8}	7.6×10^{-9}	6.2×10^{-9}

RESULTS AND DISCUSSION

Activity concentrations of radionuclides

Table 2 presents the activity concentrations of ^{40}K, ^{238}U and ^{232}Th (together with their uncertainty) obtained from the gamma spectrometric analysis and the estimated radium equivalent activity in the potato samples collected from each location.

The activity concentrations of potatoes from the Enugu markets ranged from 327.65±17.49 Bq/kg in Emene to 725.30±38.66 Bq/kg in Ogbete for ^{40}K, BDL in Emene; to 13.94±1.73 Bq/kg in

Table 2. Activity concentrations of natural radionuclides in sweet potatoes from Enugu markets.

S/N	Sample code	Activity concentration (Bq/kg)			Raeq (Bq/kg)
		^{40}K	^{238}U	^{232}Th	
1	Abakpa	477.46±25.57	12.38±1.50	1.06±0.06	50.66
2	Artisan	431.73±22.99	13.94±1.73	0.58±0.03	48.01
3	Emene	327.65±17.49	BDL	0.84±0.05	26.43
4	Garriki	482.24±23.52	8.37±1.16	0.47±0.20	46.17
5	New haven	642.41±34.54	6.15±0.78	1.65±0.10	57.98
6	New market	597.94±32.08	7.75±0.99	3.38±0.20	58.62
7	Ogbete	725.30±38.66	11.28±1.41	BDL	67.13
Mean		**526.39±51.40**	**8.55±1.76**	**1.14±0.42**	**50.72±4.89**

BDL: Below Detection Limit.

Artisan market for ^{238}U and BDL in Ogbete; to 3.38±0.20 Bq/kg in New market for ^{232}Th. The mean activity was estimated to be 526.39±51.40, 8.55±1.76 and 1.14±0.42 Bq/kg for ^{40}K, ^{238}U and ^{232}Th respectively. It is observed that ^{40}K was detected in all the potatoes analysed and exhibited the highest activity concentrations in all the sample locations as shown in Figure 1.

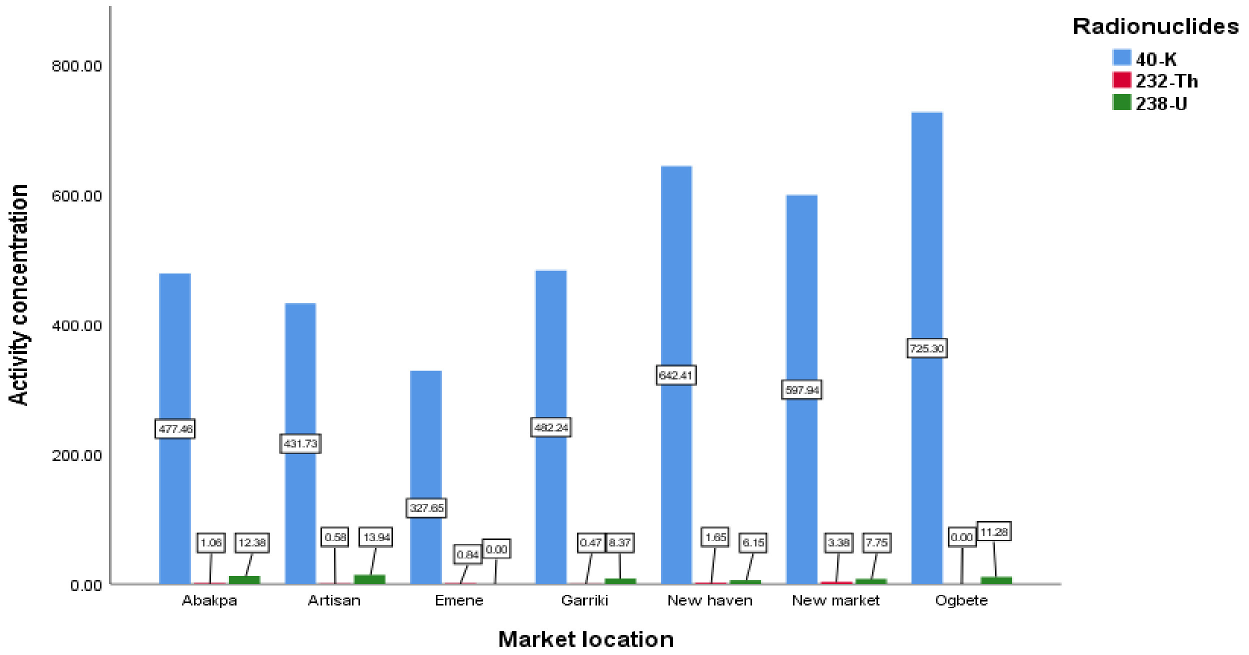

Figure 1. Activity concentrations of radionuclides in potatoes.

This may be due to the incessant use of potassium rich phosphate fertilizers by farmers to improve soil fertility and in turn crop yields and also the natural abundance of potassium in soil (Nahar et al., 2018). Potassium-40 is a vital mineral for plant growth and its natural abundance is just 0.012% (Asaffar et al., 2015), hence the need for enrichment. Also, the activity levels of ^{238}U were observed to be higher than those of ^{232}Th in all the locations except for samples collected at Emene market, where the activity was below detection limit of the gamma spectrometric detector. This observation clearly indicates the fact that ^{238}U and its series nuclide ^{226}Ra are more soluble in soil water than ^{232}Th and its series nuclides (Nahar et al., 2018). Thus, the potato plants absorb more of ^{238}U than ^{232}Th within the same rooting zone. The slight variations observed in the radionuclides activity with respect to sample and location can in whole be attributed to two factors. The first factor is the non-uniform distribution of radionuclides in soil which shows geological and geophysical dependent. The second factor is the transfer ability of the plant to transfer and trans-locate radionuclides alongside essential nutrients from the soil through the rooting system, to stem and to edible parts of the plant. This transfer ability is however dependent on the plant species, geographical and geological characterizations of farm soil; physical, chemical and microbial properties of the soil, type of fertilizer and other agrochemicals applied, cultivation practices, etc. (Jibiri et al., 2007; Karunakara et al., 2013; Asaduzzaman et al., 2015b; Nahar et al., 2018). The uniformity of the radionuclides activity levels is depicted by the single quantity, radium equivalent activity, Ra_{eq}. The values of Ra_{eq} range from 26.43 to 67.13 Bq/kg. The average value was found to be 50.72±4.89 Bq/kg. These values are well below the reference value of 370 Bq/kg (UNSCEAR, 2000).

Generally, the result obtained in this study depicts the ability of potato plants to uptake and transport radionuclides from the soil by the root system. It also shows that ^{40}K is the most radionuclide contaminant present in the farm soil where the potato plants were grown. This result is in line with similar studies reported in literature for different food crops (Akhter et al., 2007; Jibiri et al., 2007; Asaffar et al., 2015; Nahar et al., 2018), but contrast with the findings of Asaduzzaman et al. (2015b) and Darko et al. (2015), where ^{232}Th activity was reported to be higher than that of ^{238}U and its series nuclide ^{226}Ra in rice (Malaysia) and tuber crops (Ghana) respectively.

Daily intake of radionuclides and annual effective dose

The D_{int} and AED of respective radionuclide present in any foodstuff depend on the concentration level of the radionuclide and the annual consumption rate of such food. The estimated D_{int} through potato diet (Table 3) varies from 0.00 to 0.13 Bq.d^{-1}, 0.00 to 0.55 Bq.d^{-1} and 12.88 to 28.55 Bq.d^{-1} for ^{232}Th, ^{238}U and ^{40}K respectively. The mean values are 0.04, 0.34 and 20.70 Bq.d^{-1} for ^{232}Th, ^{238}U and ^{40}K respectively. The highest daily intake was observed in ^{40}K. This is due to its wide distribution and high concentration in the potato tubers as compared to other radionuclides. Although, potassium is an essential element for the human body system, its high concentration in diets may result to continuous gamma irradiation of the internal body organs. This in turn may create changes in some physiological and biochemical processes of the body cells, partial or total radiation damage of some organs and genetic effects.

The estimated mean annual effective doses (AED) to age groups 2–7 yr, 7–12 yr, 12–17 yr and >17 yr are 0.240 mSv.y^{-1} (0.103 – 0.319 mSv.y^{-1}), 0.201 mSv.y^{-1} (0.065 – 0.265 mSv.y^{-1}) 0.246 mSv.y^{-1} (0.039 – 0.349 mSv.y^{-1}) and 0.085 mSv.y^{-1} (0.032 – 0.110 mSv.y^{-1}) respectively. The mean AED for the age groups are below world average value of 0.29 mSv.y^{-1} (UNSCEAR, 2000). Hence at this present rate of consumption, no significant threat to the public is observed. However, the values for the group, 12–

Table 3. Daily intake of radionuclides and annual effective dose due to potato diet.

S/N	Sample code	Daily intake of radionuclides (Bq d^{-1})			Annual effective dose (mSv y^{-1})			
		^{40}K	^{238}U	^{232}Th	2–7 yr	7–12 yr	12–17 yr	>17 yr
1	Abakpa	18.77	0.49	0.04	0.259	0.236	0.322	0.096
2	Artisan	16.97	0.55	0.02	0.257	0.243	0.349	0.096
3	Emene	12.88	0.00	0.03	0.103	0.065	0.039	0.032
4	Garriki	18.96	0.33	0.02	0.222	0.188	0.234	0.078
5	New haven	25.26	0.24	0.06	0.257	0.197	0.208	0.087
6	New market	23.51	0.30	0.13	0.266	0.215	0.244	0.095
7	Ogbete	28.55	0.44	0.00	0.319	0.265	0.322	0.110
Mean		**20.70**	**0.34**	**0.04**	**0.240**	**0.201**	**0.246**	**0.085**

17 years, at Abakpa, Artisan and Ogbete showed elevated effective doses above the world average. This indicates that individuals within this age group are at higher radiation risk and more susceptible to radiation hazard from potato diet. As a result, further consumption of potato by this group of individuals in these locations should be minimized in order to reduce radionuclides accumulation in the human body system and as well reduce the radiation hazards to “as low as reasonable achievable” (ALARA) framework.

Conclusion

Sweet potatoes sold in different markets in Enugu town have been assessed for natural radioactivity content. The assessment has thus far provided baseline information on the radionuclides activity and internal effective doses to the residents of Enugu urban which may arise due to potatoes consumption. The distribution and concentrations of the radionuclides in the studied potatoes samples have been observed to be non uniform with ^{40}K displaying the highest concentration. The daily intake of radionuclides was also observed to be highest in ^{40}K. This may be due to the use of phosphate rich fertilizer in the farmlands where they were grown. Generally, the annual effective doses due to potato diet, at this present rate, pose no significant threat to the public. However, with increase in consumption rate, the radionuclide intake and effective dose may likely increase.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Akhter, P., Rahman, K., Orfi, S. D., and Ahmad N. (2007). Radiological impact of dietary intakes of naturally occurring radionuclides on Pakistani adults. *Food and Chemical Toxicology*. 45: 272–277.

Akinloye, M. K., and Olomo, J. B. (2000). The measurement of the natural radioactivity in some tubers cultivated in farmlands within the Obafemi Awolowo University Ile-Ife, Nigeria. *Nigerian Journal of Physics*. 12: 60–63.

Akpolile, F. A. and Ugbede, F. O. (2019). Natural radioactivity study and radiological risk assessment in surface water and sediments from Tuomo River in Burutu, Delta State Nigeria. *Journal of Nigerian Association of Mathematical Physics (J. NAMP)*. 50: 267–274.

Alsaffar, M. S., Jaafar, M. S., Kabir, N. A. and Ahmad, N. (2015). Distribution of ^{226}Ra, ^{232}Th, and ^{40}K in rice plant components and physico-chemical effects of soil on their transportation to grains. *Journal of Radiation Research and Applied Sciences*. 8: 300–310.

Anyaegbunam, H. N. and Nto, P. O. (2011). Assessment of the Performance of Sweet Potato Marketing System in South East Agro Ecological Zone, Nigeria. *American Journal of Experimental Agriculture*. 1(4): 477–485.

Asaduzzaman, K., Khandaker, M. U., Amin, Y. M. and Mahat, R. (2015). Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular Malaysia for the estimation of ingestion dose to man. *Annals of Nuclear Energy*. 76: 85–93.

Asaduzzaman, K., Khandaker, M. U., Amin, Y. M., Zainuddin, Z., Farook, M. S. and Bradley, D. A. (2015). Measurement of radioactivity and heavy metal levels in edible vegetables and their impact on Kuala Selangor communities of Peninsular Malaysia. *Radiation Protection Dosimetry*. 167(1-3): 165–170 doi:10.1093/rpd/ncv237.

Avwiri G.O. and Agbalagba E. O. (2013). Assessment of natural radioactivity, associated radiological health hazards indices and soil-to-crop transfer factors in cultivated area around a fertilizer factory in Onne, Nigeria. *Environmental Earth Science*. 71(4): 1541-1549.

Darko, G., Faanu, A., Akoto, O., Acheampong, A., Goode, E. J. and Gyamfi, O. (2015). Distribution of natural and artificial radioactivity in soils, water and tuber crops. *Environmental Monitoring and*

Assessment. 187: 339. DOI 10.1007/s10661-015-4580-9.

European Commission, E.U. (2000). White Paper on Food Safety. In: COM (1999) 719 final. Brussels: European Commission.

European Commission, E.U. (2002). Regulation (EC) Nº 178/2002 of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. Off J Eur Comm. L31: 1–23.

FAO/WHO. (2006). Food Safety Risk Analysis. A guide for national food safety authorities. FAO. Food and Nutrition paper 87. Available at: http://www.who.int/foodsafety/publications/micro/riskana lysis06.pdf (Last accessed on 21th July, 2019).

FAO/WHO. (2009). Principles and Methods for the Risk Assessment of Chemicals in Food. Environmental Health Criteria. 240. In: IPCS (International Program on Chemical Safety). Chapter 6. Dietary exposure assessment of chemicals in food. Geneva: WHO.

Federal Office of Statistics of Nigeria (2006). Compilation of FOS/FOA annual consumption data/food balance sheet of Nigeria. A publication of Federal Office of Statistics (FOS), Nigeria (now Nigerian Bureau of Statistics, NBS).

Fernandez, G., Rodriquez, I. M., Castro, G. V., Carrazana, G., Martizez, R. N. (2004). Radiological surveillance of foods and drinking water in the Cuban Republic. Proceedings of the 11th Conference of the International Radiation Protection Association (IRPA), Madrid, Spain, May 23–28.

Hernandez, F., Hernandez-Armas, J., Catalan, A., Fernandez-Aldecoa, J. C., Landeras, M. I. (2004) Activity concentrations and mean effective dose of foodstuffs on the Island of Tenerife, Spain. *Radiation Protection Dosimetry*. 111: 205-210.

IAEA (1989). International Atomic Energy Agency: Measurement of radiation in Food and the Environment. A Guidebook. Technical Report Series (1989) No. 295.

Ibikunle, S. B., Arogunjo, A. M., Ajayi, O. S. and Olaleye, O. O. (2017). Risk assessment of natural radioactivity in surface water and sediments from waterfall site, Osun State, Nigeria. *Human and Ecological Risk Assessment: An International Journal*. 23(8): 1978-1988.

ICRP (1996). International Commission on Radiological Protection: Age-dependent doses to members of the public from intake of radionuclides: Part 5, compilation of ingestion and inhalation dose coefficients. ICRP Publication 72 (1996). Oxford, United Kingdom: Pergamon Press.

Jibiri, N. N., Farai, I. P. and Alausa, S. K. (2007). Estimation of annual effective dose due to natural radioactive elements in Ingestions of foodstuffs in tin mining area of Jos-Plateau, Nigeria *Journal of Environmental Radioactivity* 94: 31–40.

Khandaker, M. U., Wahib, N., Amin, Y. M. and Bradley, D. A. (2013). Committed effective dose from naturally occurring radionuclides in shellfish. *Radiation Physics and Chemistry*. 88: 1–6.

Mahamud, M. A., Chowdhury, M. A. H., Rahim, M. A. and Mohiuddin, K. M. (2015). Mineral nutrient contents of some potato accessions of USA and Bangladesh. *Journal of Bangladesh Agriculture University*. 13(2): 207–214.

Marín, S., Pardo, O., Báguena, R., Font, G. and Yusà, V. (2017). Dietary exposure to trace elements and health risk assessment in the region of Valencia, Spain: a total diet study. Food Additives & Contaminants: Part A. 34(2):228–240. http://dx.doi.org/10.1080/19440049.2016.1268273.

McDonald, P., Jackson, D., Leonard, D. R. P. and McKay, K. (1999). An assessment of ^{210}Pb and ^{210}Po terrestrial foodstuffs from regions of potential technological enhancement in England and Wales. *Journal of Environmental Radioactivity*. 43: 15-29.

Nahar, A., Asaduzzaman, K., Islam, M. M., Rahman, Md. M. and Begum, M. (2018). Assessment of natural radioactivity in rice and their associated population dose estimation. *Radiation Effects and Defects in Solids*. 173(11-12): 1105-1114. https://doi.org/10.1080/10420150.2018.1542696.

UNSCEAR (2000). United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. Report to the United Nations General Assembly.