E-ISSN: 1115 – 831X P-ISSN: 3027-2963
MPRI-JAVS | INTERNATIONAL JOURNAL OF AGRICULTURAL AND VETERINARY SCIENCE
VOL. 13 NO. 1 - JULY, 2026

ASSESSMENT OF RADIOACTIVITY AND CONCOMITANT DOSE IN VEGETABLES GROWN IN KUDAN, KADUNA STATE, NIGERIA

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DOI: https://doi.org/10.70382/mejavs.v13i1.045

Abstract

The natural radioactivity level in soil can be elevated by human activities especially technological advancement and nuclear technology proliferation. Therefore, it is important to assess the concentration of radioactive materials in vegetables due to the transfer of radionuclides in the chain soil-plant-human via ingestion. Using NaI detector, the present study was undertaken to measure the concentration of ^{226}Ra, ^{228}Ra and ^{40}K in more prominent vegetables (Tomatoes, cabbage and lettuce) grown in Kaduna, Nigeria. For ^{226}Ra, ^{228}Ra and ^{40}K, the mean activity concentrations (Bq/kg) were 73.5, 33.2 and 90.4 respectively in tomatoes, 78, 23.6 and 129.2 in cabbage and 82.4, 30.8 and 188.6 in lettuce. Overall, the measured data were found to be below the average value of 82Bq/kg and 310Bq/kg for 228Ra and 40K respectively, while for 226Ra the values were above the average value of 67Bq/kg prescribed by the United

Keywords:
Radioactivity, Effective dose, Cancer risk, Hazard indices Vegetables, Kudan.

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Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The annual effective dose, radium equivalent and internal hazard index were all below the permissible limit of 1mSv/y, 370Bq/kg and 1 respectively as recommended by UNSCEAR. The lifetime cancer risk from consumption of the studied food was also assessed and found to be below the International Commission On Radiological Protection cancer risk factor of 4.5×10^{-3} based on additional annual dose limit of 1mSv for the general public. Therefore, consumption of the vegetables does not pose any substantial threat to the public.

Introduction

Human beings are continuously exposed to ionizing radiation that stem from both natural and man-made sources (UNSCEAR, 2000). The main constituents of natural radiation are cosmic rays and gamma ray emitters in soil (U^{238}, Th^{232} and K^{40}). The concentration of radionuclides in soil is primarily related to its origin. However, human activities can strongly modify their concentration in the environment (Abdul, 2017). The various inputs are most essentially in line with population growth, rapid urbanization and associated developments in support of modern life, mining, milling, oil and gas extraction, agriculture and medical facilities include, all contributing to enhanced radioactivity in the environment (Yarima et al., 2020). Consequently, the uptake of radioactivity by plants increases.

Surveys in various regions have demonstrated enhanced levels of NORMs in plants at varying concentrations (Yarima et al., 2020; Karunaka et al., 2013). Human exposure to radionuclides via ingestion is typically associated with radionuclide content in soil, with uptake of nutrients and minerals by plants, chemical properties of the soil and consumption rates of a particular foodstuff (Yarima et al., 2020; Karunaka et al., 2013). Taking note of the various influences it is considered important to analyze the presence of radioactive material in vegetables, providing insight into potential effects on humans. Moreover, such analysis provides data on natural radioactivity in crops, providing basis for dose estimation (Yarima et al., 2020; UNSCEAR, 2000).

A general literature survey has shown natural radioactivity studies of Nigerian grown foodstuffs/crops to be highly limited, particularly in comparison with other parts of the world (Yarima et al., 2020; Arogunjo et al., 2009). Hence, the United Nations Scientific committee on Atomic Radiation reference values poorly represent data on food produced in most African countries (UNSCEAR, 2000). While previous studies of natural radioactivity in key Nigerian foodstuffs exist, these have typically originated from mining areas only (Yarima et al., 2020; Arogunjo et al., 2009). Most locations in Nigeria are reported to contain natural resources that could enhance the degree of radionuclides in such an

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environment. Even if they are present in the same area, soils with different geological characteristics contain different amounts of radionuclides. Therefore, the uptake of radionuclides by crops also changes, leading to different radiation dose rates in the population (Chetty and Ilori, 2024). The present study aim to overcome this deficit of data. The study area is one of the major contributors to the production of a very large number of vegetables in north-western Nigeria. To the best of our knowledge, no assessment of radioactivity has been made concerning the vegetables identified. Therefore, the present study sought to analyze the concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in vegetables using NaI detector. The annual effective dose, hazard indices and excessive life time cancer risk were also estimated.

Sample collection and preparation

The vegetable samples were randomly collected from various farms; Hunkuyi, Doka, Kudan and Tashan Kade all situated in Kudan local government of Kaduna State, Nigeria. The vegetables selected for the study have been extensively cultivated in the study area. They include Tomatoes, Cabbage and Lettuce. A total of 9 farms were selected at different locations within the study area collecting three samples at each location in order to fully represent the vegetable samples in the study area. Approximately, 5-7 Kg of each sample from each location was collected in a well-labelled polythene bag to avoid cross contamination of the samples, then brought to the center for energy research and training Zaria for preparation and analysis. The samples were air dried under room temperature and then pulverized into powder and passed through a standard mesh(2mm) to achieve homogeneity (Darko, et al., 2015; Chetty and Ilori, 2024). The samples were filled into 25g plastic containers which were sealed to prevent escape of air bone Radon from the samples. The samples were then weighed and kept for 28 days before measurement in order to attain secular equilibrium between the parent ^{222}Rn (^{226}Ra) and ^{220}Rn (^{228}Ra) and their short-lived progeny (Bello, 2020).

Measurement of samples

The radioactivity measurements for the studied samples were performed using a sodium iodide detector (Na (Tl)). The detector has a 6cm thick lead shield, cadmium lined assembly with copper sheets for detection of background radiation. The detector has a pulse resolving time of about 0.25s, an incorporated preamplifier and 1kV external source which enable its use for high counting rates. The detector has a computer based multichannel analyzer, a Maestro program from ORTEC for the analysis of gamma spectra. Efficiency calibration of the detector was thus performed using the standard sources, and the geometry of the counting samples was the same as that of the standard samples. The spectral energy used for the gamma spectrometric analysis were 2614.5 keV, 1764 keV and

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1460 keV, for ^{238}U, ^{232}Th and ^{40}K respectively using isotopes^{208}Tl, ^{214}Bi, ^{40}K for ^{238}U, ^{232}Th and ^{40}K respectively. Each sample was counted for 30000 seconds in the outlined detector geometry in order to reduce the influence of background radiation from radioactive contaminants within the shielding material of detector. The activity concentration was obtained using the equation below (Abdul, 2017; Jibiri, et al., 2005).

$$C(Bq/kg) = KC_n \text{(Bq/kg)=KC_n} \quad (1)$$

Where K= $\frac{1}{\varepsilon P_y M_s}$, C_n is the count rate under the corresponding peak, $\boldsymbol{\varepsilon}$ is the detector efficiency at the specific $\boldsymbol{\gamma}$-ray energy, P_y is the absolute transition probability of the specific $\boldsymbol{\gamma}$-ray and M_s is the mass of the sample.

Annual effective dose due to ingestion of samples

The annual effective dose (AED_{ing}) from ingestion of NORMs through plant samples were estimated using equation (2) as provided by (Yarima et al., 2020; UNSCEAR, 2000).

$$AED_{ing} = A_R IR_{ing} \boldsymbol{\Sigma DCF_{ing}} \quad \textbf{(2)}$$

where A_r is the mean activity concentration of radionuclides in a sample; IR_{ing} is the plant consumption rate per year with the value of 200kg/year (DEA, 2010); DCF_{ing} is the effective dose coefficient in Sv/Bq for the ingestion of ^{226}Radium, ^{232}Th and ^{40}K with values of $4.5e^{-8}$, $2.3e^{-7}$ and $6.2e^{-9}$ respectively (ICRP, 2012).

Radium equivalent

The radium equivalent (Ra_{eq}) describes the gamma output from different mixtures of the natural radionuclides in a material and it was calculated using (3). It has a maximum permissible value of 370 Bq/kg which corresponds to an effective dose of 1mSv for the general public (Yarima et al., 2020; UNSCEAR, 2000).

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_k \quad (3)$$

Internal hazard index

This is a hazard that may arise as a result of ingestion of radioactive material. It helps to assess the risk associated with radioactive contamination.

$$H_{in} \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (4)$$

Where C_{Ra}, C_{Th} and C_K are the activity concentration in Bq/kg of radium, thorium and potassium, respectively as obtained from the analyzed samples. The maximum

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permissible limit of the internal hazard index should be less than 1, which corresponds to the permissible limit of radium equivalent activity 370 Bq/kg (Bello, 2020).

Excessive lifetime cancer risk

Long time exposure to radiation could have some risk of causing cancer. The excessive life time cancer risk is the probability of an individual developing cancer over a lifetime considering a specified exposure level. The ELCR was estimated using the equation below (Taskin et al.,2009).

$$ELCR = AED \times RF \times 10^{-3} \quad (5)$$

Where AED is the annual effective dose, DL is the average lifetime and 55 years was adopted as in (Yarima et al., 2020;), RF is the risk factor 0.05 Sv^{-1}.

Result and discussion

The activity concentrations for ^{226}Ra (parent ^{238}U), ^{228}Ra (parent ^{232}Th) and ^{40}K radionuclides were assessed in tomatoes, cabbage and lettuce (Table1). The activity concentration (Bq/kg) of tomatoes collected from Kudan show mean values of 73.5±3.8 for ^{226}Ra, 33.2±3.1 for ^{228}Ra and 90.4±3.9 for ^{40}K. In cabbage samples collected from Hunkuyi, these were found to have mean values of 78±3.8, 23.6±1.3 and 129.2±3 for ^{226}Ra, ^{228}Ra and ^{40}K respectively. For lettuce collected from Likoro, mean concentration were 30.8±4.9, 30.8±2.2 and 188.6±4.5 for ^{226}Ra, ^{228}Ra and ^{40}K respectively. The analyzed radionuclides in different vegetable samples show an overall order of ^{40}K > ^{226}Ra >^{228}Ra. That ^{226}Ra has values greater than ^{228}Ra can be attributed to the fact that the parent radionuclide ^{238}U is more mobile than thorium (Yarima et al., 2020; Martinez-Aguirre et al., 1995). The concentration of ^{40}K surpassed that of both ^{228}Ra and ^{226}Ra as expected because it is the most abundant radioactive element and it is also used by local farmers as part of NPK fertilizer. It could also be due to the fact that potassium is a micro nutrient and plants could not differentiate the stable from unstable isotopes for uptake (Yarima et al., 2020). While judicious use of NPK fertilizer has been seen to be made by local farmers in promoting crop growth, it has not been to the extent of excessive elevation of radionuclides in the crops (Karunaka et al., 2013; pietrzak- Flis et al., 2001). It can also be observed from table 1 that the activity concentration of the studied radionuclides in all of the vegetable samples were found to be lower than recommended limit by UNSCEAR with the exception of ^{226}Ra in samples collected from Kudan and Hunkuyi. This is potentially as a result of emerging developments around the towns with large-scale structural development occurring there. However, in general, the concentration of NORMs follows a heterogenous distribution pattern in various places in the world due to the variations in local geology (Yarima et al., 2020).

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The annual effective dose (mean value) due to the measured radionuclides received by the populace via consumption of tomatoes, cabbage and lettuce obtained in Kudan, Hunkuyi and Likoro were found to be 0.0031mSv/y, 0.0036mSv/y and 0.9947mSv/y respectively (Table 1). All the values obtained were below the recommended limit of 1mSv/y by UNSCEAR as highlighted in table 1.

The radium equivalent and internal hazard index estimated in the study were all below the recommended limit 370 Bq/kg for radium equivalent and threshold of 1 for the internal hazard index. These implies that consumption these vegetables or plants may not pose any significant radiological hazard.

The calculated values of ELCR were also shown in table 1. The mean values of ELCR for the studied radionuclides were found to be 8.53×10^{-6}, 9.99×10^{-6} and 1.32×10^{-5} for tomatoes, cabbage and lettuce respectively. The risk values calculated are within the USEPA acceptable limit of 1×10^{6} - 1×10^{-4}. The values also compared reasonably with the ICRP cancer risk factor of 4.5×10^{-3} (Eckerman et al., 2013) base on an annual above background dose limit of 1mSv for general public, and an annual mortality probability of 10-5 equating to 1 in 100,000 (Yarima et al., 2020; ICRP, 1991).

Table 1.0: Activity concentrations of 226Ra, 228Ra and 40K in the studied vegetable and estimation annual effective dose, radium equivalent, internal hazard index and excessive lifetime cancer risk via their consumption.

Vegetable	Sample code	Activity Concentration (Bq/kg)			AED	Ra_{eq}	H_{in}	ELCR
		^{226}Ra	^{232}Th	^{40}K	(mSv/y)	Bq/kg		
Tomato	Kdn-1	75.8±4.9	20.8±2.7	75.7±5.2	0.0027	111.37	0.50	7.46E-06
(Kudan)	Kdn-2	46.9±3.1	49.4±3.4	66±3.0	0.0026	122.62	0.45	7.03E-06
	Kdn-3	97.9±3.4	29.5±3.2	129.4±3.7	0.0040	150.04	0.67	1.11E-05
	Mean	**73.5±3.8**	**33.2±3.1**	**90.4±3.9**	**0.0031**	**128.02**	**0.54**	**8.53E-06**
Cabbage	Hnk-1	93.2±4.9	20.4±1.3	140.6±3.6	0.0040	133.19	0.61	1.10E-05
(Hunkuyi)	Hnk-2	85.2±3.2	20.4±1.3	94.8±3.8	0.0032	121.67	0.56	8.67E-06
	Hnk-3	55.7±3.3	29.9±1.2	152.1±1.7	0.0037	110.16	0.45	1.03E-05
	Mean	**78±3.8**	**23.6±1.3**	**129.2 ±3**	**0.0036**	**121.67**	**0.54**	**9.99E-06**
Lettuce	Lk-1	80.9±5.4	20.4±2.5	84.7±3.2	0.0029	116.59	0.53	8.05E-06
(Likoro)	Lk-2	83.9±4.4	47.5±1.5	188.1±2.6	0.0151	166.30	0.68	4.15E-05
	Lk-3	82.5±4.9	24.5±2.5	293±7.7	0.0062	140.09	0.60	1.73E-05
	Mean	**82.4±4.9**	**30.8±2.2**	**188.6±4.5**	**0.0047**	**140.99**	**0.60**	**1.31E-05**
UNSCEAR (2000)		67	82	310	1	370	1	-

Conclusion

This study measured the activity concentration of radionuclides (228Ra, 226Ra and 40K) in vegetable samples collected from Kudan local government area of Kaduna State using NaI detector. The annual effective dose, hazard indices and excessive life time cancer risk

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were also estimated. The activity concentrations of 228Ra and 40K in all the samples were all below the average limit of 82Bq/kg and 319Bq/kg respectively, while concentrations of 226Ra were above the average limit of 67Bq/kg as proposed by UNSCEAR. The annual effective dose, radium equivalent, internal hazard index and excessive lifetime cancer risk values were all below the recommended limit by UNSCEAR. Therefore, consumption of vegetables from the study area may not pose any significant carcinogenic and non-carcinogenic risk. However, measures should be taken to periodically monitor the levels of natural radionuclides in various vegetables and crops from different locations in Nigeria. Also, Radiation survey and monitoring should be integrated into agricultural extension services in order to promote environmental friendly farming practices

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