Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/090109

Measurement of Radionuclide Concentrations in Chicken Feeds, Meat and Bones from Commercial Suppliers in Kampala, Uganda

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Received: 14 Sept. 2023, Revised: 12 Nov. 2023, Accepted: 27 Dec. 2023.
Published online: 4 Jan. 2024.

Abstract: Organic and inorganic feeds that enhance faster growth in chicken are on high demand by suppliers of chicken meat in and around Kampala. Competition in chicken business, however, raises concerns on the quality of chicken feeds and meat, as well as risk of cancer and other biological effects of radiation to consumers of chicken products. This study focused on determining the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in chicken feeds, meat and bones supplied in Kampala. Equal broiler and kroiler samples of feeds, meat and bones were collected and analyzed using γ-spectrometry method. Kroiler samples show higher activity concentrations than broiler samples. All samples have safe activity concentration levels of ^{226}Ra. Only broiler feeds have activity concentrations of ^{232}Th below the world limit, and both broiler and kroiler meat have activity concentrations of ^{40}K above the world limit of 400 Bq kg^{-1}. The heightened activity concentration levels of ^{232}Th and ^{40}K require regular radionuclide check-ups in chicken feeds and products. Radiological risk parameters need to be determined in order to check the health risks to consumers of chicken products in Kampala.

Keywords: Radioactivity, Spectroscopy, Food Chain.

1 Introduction

Cancer is a major global cause of mortality [1, 2]. It has been predicted that cases of cancer will increase by 73% in developing countries and 29% in the developed world by 2020 [3], and by 2030, the world will have 21 million new cases of cancer per year - with 75% of them expected to be in developing countries [4].

About 30% of world cancers originate from diet and as developing countries become urbanized, patterns of cancer tend to shift towards those of developed countries [5]. Thus, dietary changes in lifestyle can make the percentage to rise or fall. In Kampala, an overall increase in cancer risk was noted as driven largely by urbanization and dietary lifestyles [6]. Uganda has more than 60,000 cases of cancer per year and this could rise to 80, 000 in the next five years [7].

The earth is continuously exposed to radiation, mainly from natural and anthropogenic sources, as radioactivity is widely spread in the earth's environment [8, 9]. Natural radioactivity from uranium (^{238}U), thorium (^{232}Th); their progeny, and potassium (^{40}K) exposes humans to cancer and biological effects of radiation [10]. Naturally occurring radioactive materials (NORMs) emit high energy γ-rays that can be measured using a gamma ray spectrometer [11].

Chicken feeds are made from a composite of organic ingredients and inorganic ingredients [12], or technologically enhanced naturally occurring radioactive materials (TENORMs) that have the potential of elevating radionuclide content in the chicken feeds, meat and bones [13]. The use of fertilizers and agro-chemicals during farming enhances uptake of radionuclides by plants, and this becomes a pathway of radiation exposure to plants, chicken feeds, and chicken products [13, 14, 15].

Organic ingredients carry NORM content in them, and phosphate fertilizers and other inorganic ingredients contain TENORM [16, 17]. The NORM and TENORM contents expose chicken to radionuclides. Besides, the presence of NORM in the environment with activity concentrations higher than the radiological reference levels assigned by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is hazardous to living organisms [18].

One of the objectives of Uganda National Animal Feeds Policy is to ensure quality animal feeds and protect end users from contaminated feeds [19]. Therefore,

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measurement of radionuclides in foods is important in monitoring, quantifying and assessing radiological risks [20]. In Uganda, Kampala has multiple chicken/feeds suppliers and dealers. Hence, this study focused on the common chicken feeds, meat and bones from suppliers in Kampala.

2 Materials and Methods

The study used NaI(Tl) detector for sample analysis, and marinelli beakers, plastic bags, microwave oven, for sample preparation, respectively.

2 *2.1 Sample Preparation*

A total of 36 samples of chicken feeds, meat and bones were obtained from different farms and feed suppliers in and around Kampala. The suppliers were purposively sampled as they were known for experience and high supply to farmers and outlet dealers. The feed samples, each measuring 1 kg, had 6 broilers' and 6 kroilers', respectively. The same were true for meat and bone samples.

Fresh meat samples were obtained from chicken slaughtered, de-feathered, and washed with water. For bone samples, fresh chicken meat pieces were boiled for 1 hour at 100 ^oC to separate the bones from meat. Each sample of feeds, meat and bones was then put in plastic bags, labeled, double packed, inserted in a box, and transported to the laboratory for further processing [21].

Each sample of chicken feeds was oven dried at 30 ^oC for 5 hours, meat at 105 ^oC for 24 hours, and bones at 250 ^oC for 40 minutes, respectively [20, 22]. After cooling, each sample was crushed, grinded into powder, and sieved through a 2 mm mesh. Each powdered sample was then weighed, packed and sealed in plastic marinelli beaker, then labeled and stored for at least 30 days in order to allow ^{238}U (^{226}Ra) and ^{232}Th (^{228}Ra) attain secular equilibrium with their progeny [23]. The sealing of the samples was to prevent radon, that is, ${}^{222}_{86}Rn$ and ${}^{220}_{86}Rn$, from escaping [24].

Prior to sample analysis, energy calibration of NaI(Tl) detector was done using ^{137}Cs standard source run for 2 hours, as recommended by IAEA [25]. Monoenergetic γ-line of ^{137}Cs at 662 keV was chosen to generate an energy calibration spectrum and perform a linear fit of energy-channel data. Hence, the energies of the γ-ray emissions from the spectra of the radionuclides contained in the sample were easy to identify [26]. The energy calibration converts channel numbers to gamma-ray energies [27]. Efficiency calibration of NaI(Tl) detector was done using ^{137}Cs and ^{60}Co standard sources run for 2 hours to a generate γ-ray spectra. The energy resolution of 8.2% was determined by measuring ^{137}Cs in the detector for 2 hours and obtaining a spectrum at 662 keV. The detector efficiency was 0.0255.

2.2 Sample Analysis

Background counts were measured by analyzing empty beakers in the NaI(Tl) detector for a period of 7200 seconds using Maestro-32 analysis software. For the same timing, the counts were measured for the beaker with the samples. The actual sample counts were obtained by deducting the background counts. Since ^{238}U and ^{232}Th are alpha particle emitters, their activities cannot be directly determined from the gamma ray spectrometer. Thus, the energy peaks of ^{214}Pb, ^{208}Tl, and ^{228}Ac (which are gamma ray emitters) were used. These have distinct peaks due to the low energy of NaI (Tl) detector [23]. Table 1 shows the regions of interest and peak energies considered for the assessment of activity levels of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

Table 1. Gamma-line energy peaks considered for the determination of activities of ^{226}Ra, ^{232}Th, and ^{40}K.

Region	Peak Energy (keV)	Daughter Nuclide	Parent Nuclide
I	352	^{214}Pb	^{238}U (^{226}Ra)
II	511	^{208}Tl	^{232}Th
II	911	^{228}Ac	^{232}Th
IV	1460	-	^{40}K

2.3 Determination of Activity Concentration (C)

The specific activity concentrations of the radionuclides were calculated based on the measured efficiency of the detector and the net count rates over a period of 2 hours using Equation (1) [18];

$$C = \frac{N}{tB\epsilon M}, \tag{1}$$

where C is the activity concentration of the radionuclide in Bq kg^{-1}, N is the net peak area of the radionuclide of interest, B is the branching ratio (%), M is the mass of the sample (kg), and ϵ is the energy efficiency of the detector. The error (δ) associated with the determination of the activity concentration was calculated using Equation (2) [28];

$$\delta = \frac{\sqrt{N}}{tB\epsilon M}. \tag{2}$$

3 Results and Discussion

Table 2 shows the average activity concentrations of the radionuclides measured from the samples. The box and whisker plots for activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for broiler and kroiler samples are shown in Figures 1-3, respectively. Broiler feeds and bones had higher average activity concentration of ^{226}Ra than in kroilers. However, kroiler meat had higher activity levels of

^{226}Ra than broiler meat.

Table 2. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for Broiler and Kroiler samples.

Sample		Activity Concentration (Bq kg^{-1})		
		^{226}Ra	^{232}Th	^{40}K
Feeds	Broiler	4.4±0.30	28.6±0.95	378.7±5.40
	Kroiler	4.1±0.29	33.9±1.06	362.6±5.31
Meat	Broiler	5.4±0.33	33.0±1.02	327.9±4.93
	Kroiler	7.2±0.47	47.4±1.46	457.4±6.94
Bones	Broiler	6.4±0.41	32.4±1.07	413.2±6.28
	Kroiler	3.2±0.22	29.6±1.01	391.0±5.99

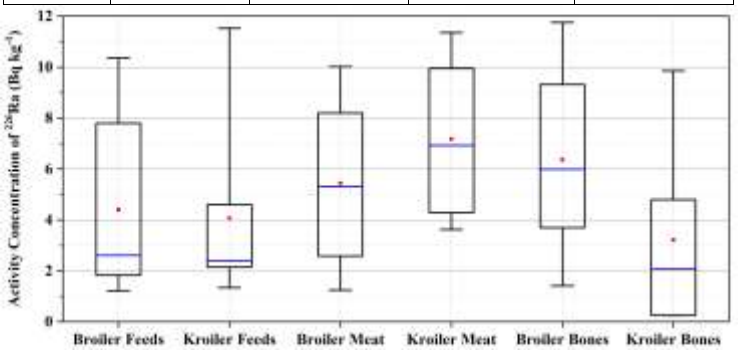

Fig. 1. Box and whisker plots for activity concentrations of ^{226}Ra for broilers and kroilers.

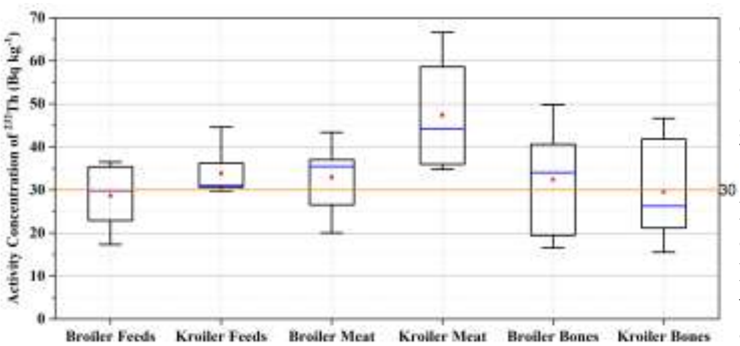

Fig.2. Box and whisker plots for activity concentrations of ^{232}Th for broilers and kroilers.

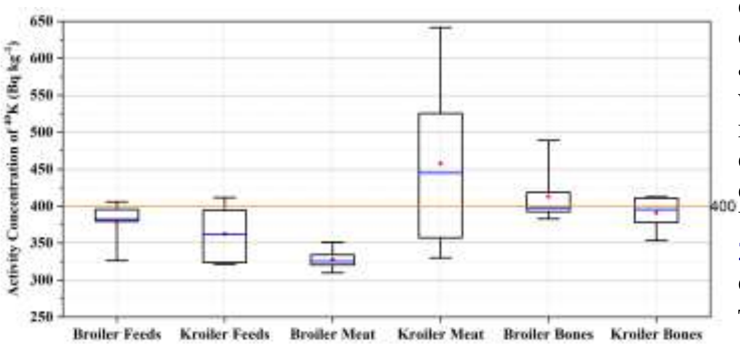

Fig.3. Box and whisker plots for activity concentrations of ^{40}K for broilers and kroilers.

Meat and bones had higher activity levels of ^{226}Ra compared to feeds. This may be due to radionuclides from ingestion of water and other inorganic additives. The average ^{226}Ra activity concentrations were below the world average of 35 Bq kg^{-1} [18]. The chemical behaviour of ^{226}Ra is similar to that of calcium, allowing it to replace calcium in carbonate minerals. Therefore, ^{226}Ra can easily be taken up by plants that are also used to make chicken feed ingredients [29].

The activities of ^{232}Th were above the world average of 30 Bq kg^{-1} [18], with exception of broiler feeds and kroiler bones. Kroiler meat had the highest activity concentration of 47.4 Bq kg^{-1}. Broiler bones had higher activity concentration compared to kroiler bones, while kroiler feeds had high activity concentration compared to broiler feeds. Generally, meat samples had highest activity concentrations, followed by bones and feeds. One would expect more ^{232}Th-uptake by plants (and later in feeds). However, ^{232}Th has low solubility compared to ^{238}U and ^{226}Ra [30, 31]. Therefore, ^{232}Th has less trouble in water. Plant uptake of radionuclides depends more on their concentrations in solutions than on their total concentrations in the soils [30]. Thus, high concentration of ^{232}Th in feeds may be due to the industrial processes of making feeds and other anthropogenic activities [18, 32]. Thorium intake by ingestion and inhalation is mainly deposited on bone surfaces and retained for long periods, and metabolic modeling assumes that 70% of the body content of thorium is retained in the skeleton [18]. This could explain the high activity concentration levels of ^{232}Th in the samples.

Both kroiler meat and broiler bones had activity concentrations of ^{40}K that above the world average of 400 Bq kg^{-1} [18], although Kroiler bones nearly reached the world average value. Broiler meat had the least activity concentration values. High activity levels may accrue from anthropogenic activities; use of phosphate fertilizers, waste disposal, agricultural practices, mining, among others. Soils from Western and Eastern Uganda, where chicken feed ingredients are mainly cultivated, have high activity levels [33, 34]. Soil's mineral is made up of weathered rock, and mineral fragments, where ^{40}K is a major element, and it is absorbed by plants and passed onto the chicken via the food chain. Higher concentrations of ^{40}K have been reported in water, rocks and soils in Uganda, where chicken feed ingredients are cultivated [34, 21, 35]. This could contribute to the high activities of ^{40}K obtained in this study.

To compare the radionuclide abundances in the samples, the activity concentration ratios were calculated. Table 3 shows the average activity concentration ratios. Figures 4 and 5 show the associated graphs. It can be said that ^{40}K-bearing minerals dominated all the samples, followed by ^{232}Th-bearing minerals and ^{226}Ra-bearing minerals, respectively. These indicate the abundance of potassium in the earth's crust and in the soils, where the chicken feed ingredients were grown. Broiler and kroiler feeds had almost equal abundance of ^{40}K-bearing minerals with respect to ^{226}Ra. Broiler meat and bones roughly equal abundance of ^{40}K-bearing minerals with respect to ^{226}Ra. The abundance of ^{40}K-bearing minerals with respect to ^{232}Th was averagely the same in all the samples.

Table 3. Activity concentration ratios for Broilers and Kroilers.

Sample		Concentration Ratio	
		^{40}K/^{226}Ra	^{40}K/^{232}Th
Feeds	Broiler	151.5	14.0
	Kroiler	143.6	10.9
Meat	Broiler	103.0	10.6
	Kroiler	75.6	9.8
Bones	Broiler	101.3	14.9
	Kroiler	614.8	15.2

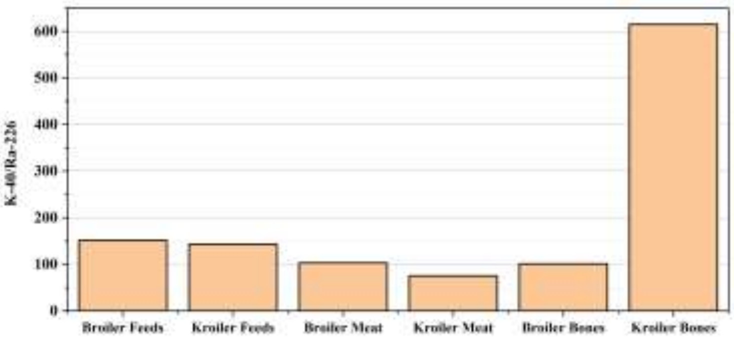

Fig.4. Activity concentration ratios of ^{40}K/^{226}Ra for broilers and kroilers.

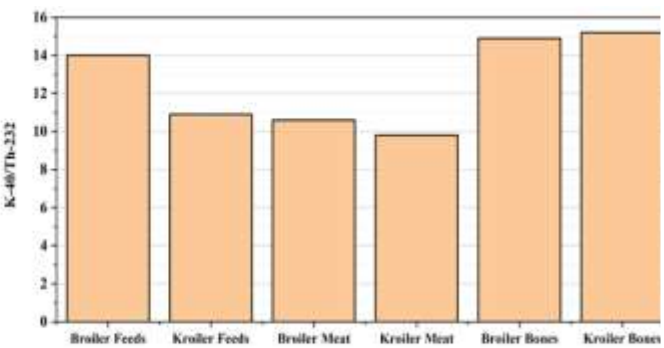

Fig.5. Activity concentration ratios of 40K/232Th for broilers and kroilers.

Figures 6 and 7 show the correlation plots used to measure the direction and intensity of relationship between chicken feeds and chicken products (meat and bones), with respect to ^{226}Ra. Strong positive correlations of r ~ 0.85 (R^2 ~ 0.72) and r ~ 0.94 (R^2 ~ 0.89) were obtained, which mean that the activities of chicken feeds and chicken products (meat and bones) for ^{226}Ra were nearly clustered around the trend lines. Similar results were also obtained for ^{232}Th and ^{40}K, respectively, as summarized in Table 4.

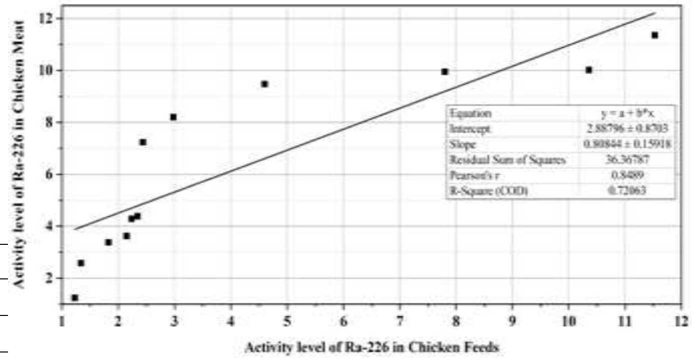

Fig. 6. Relationship between chicken feeds and meat for 226Ra.

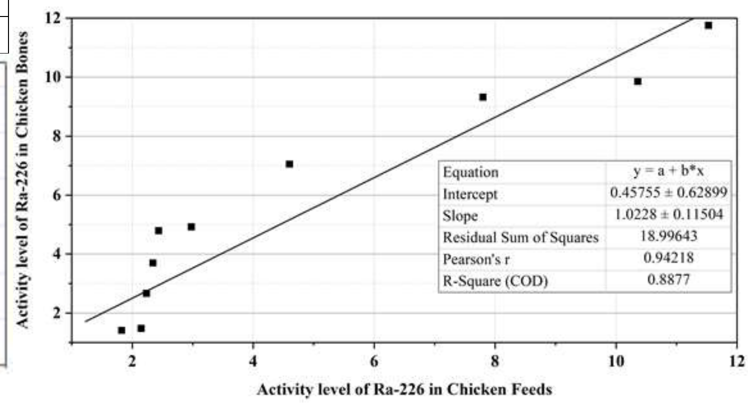

Fig.7. Relationship between chicken feeds and bones for ^{226}Ra.

4 Conclusions

Natural radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K have been measured in chicken feeds, meat and bone samples from suppliers in Kampala. All samples had activity concentrations of ^{226}Ra below the world average limit, making them safe for human consumption, ceteris paribus. Broiler feeds also had safe activity concentration levels of ^{232}Th, otherwise the activity levels of ^{232}Th in other samples were above the world average of 30 Bq kg^{-1}. Similarly, the activity levels of ^{40}K (save for broiler bones and kroiler meat) were above the world average of 400 Bq kg^{-1}, showing some level of unsafety for consumption of chicken.

Acknowledgment

The authors are grateful to the anonymous suppliers of chicken and chicken feed samples used in this study. Similarly, data analysis was carried out at the Department of Physics, Busitema University.

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