Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in common maize meal consumed in Namibia and their potential radiation hazards

Onjefu, S.A.[1]*, Kafidi N.N.[1], Kamunda C.[2], Uloko P.I.[3], Hitila M.[1], Ejembi E[1] and Kennedy J.[1]
[1]Department of Natural and Applies Sciences, Faculty of Health and Applied Sciences, Namibia University of Science and technology, Windhoek, Namibia.
[2]Department of Physics, School of Mathematics and Natural Sciences, Copper belt University, Kitwe, Zambia.
[3]Department of Physics, College of Education, Oju, Benue State, Nigeria.
*Corresponding: sonjefu@nust.na

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Abstract

Gamma spectroscopy was performed to determine the concentrations of ^{40}K, ^{226}Ra and ^{232}Th in maize meal samples collected from shop outlets and open markets in Namibia. The activity concentrations and Excess Lifetime Cancer Risk were determined using a high purity germanium (HPGe) detector. The average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th were found to be 29.98 ± 4.05, 0.99 ± 0.40 and 0.35 ± 0.08 $Bq.kg^{-1}$ in the maize meal samples. The result showed the activity concentrations of ^{40}K significantly higher than the other radionuclides in all the maize meal samples. The average excess life cancer risk varies from 1.33×10^{-13} to 6.05×10^{-13} for ^{40}K, 8.76×10^{-13} to 1.19×10^{-12} for ^{232}Th and 2.43×10^{-11} to 2.83×10^{-11} for ^{226}Ra. Hence, when compared with internationally acceptable limits, all values fall within the safety limits. Thus, the study concludes that the maize meals consumed in Namibia are radiologically safe for consumption.

Keywords: Natural radioactivity, maize meal, daily intake, Excess lifetime cancer risk

Introduction

The earth is continuously exposed to radiation mainly from natural and artificial sources (UNSCEAR, 2008). Natural radioactivity from uranium, thorium, and their progenies and potassium form the largest contributions to internal radiation dose received by humans owing to their wide distribution in the environment, whereas the contributions from anthropogenic sources are minimal (Al-Mastri *et al.*, 2004). The anthropogenic release of radionuclides are localized to specific area through routine and/or accidental release and unplanned disposal of industrial and/or radioactive waste etc., that eventually find their way into the environment and food chain (Al-Mastri *et al.*, 2004; Uwatse *et al.*, 2015). All foods consist of naturally occurring radionuclides with concentrations varying with agricultural practices, geographical location and food type (WHO, 2011). Once radionuclides are ingested they are easily assimilated into the tissues of humans where they ultimate cause biological damages which could be for the entire lifetime (Onjefu *et al.*, 2017).

Worldwide, maize is one among most commonly consumed staple foods. This has necessitated studies on radionuclides concentrations in maize meal samples in different regions around the globe (Nkuba and Sungita, 2017; Changizi *et al.*, 2013; Olatunji *et al.*, 2014). The measurement of natural radionuclides in food is relevant in quantifying radiological risk to humans due to ingestion (IAEA, 1989). This study is therefore aimed at determining the activity concentrations of natural radionuclides in different maize meals sold in both open markets and shop outlets in Windhoek-Namibia and to assess the Excess Lifetime Cancer Risk arising from gamma emitting radionuclides in maize meal consumed by the general public in Windhoek-Namibia.

Materials and methods

Sample collection and preparation for γ-pectroscopy

Different maize meal samples were collected from shop outlets and open markets in Windhoek, Namibia to determine the natural radioactivity of the maize meal samples using gamma ray spectrometry; the Hyper Pure Germanium (HPGe) detector with relative efficiency 45% of the energy resolution at 1332.5 keV energy peak of 122 keV was connected to a multi-channel analyzer (MCA). The HPGe detector was placed in the lead shield 64.80 mm thick, coated with tin and copper with a thickness of each 1 mm and 1.6 mm to reduce the effects of background radiation. Gamma ray spectrometry system was calibrated using a mixture of radioactive sources ^{60}Co, ^{88}Y, ^{85}Sr, ^{57}Co, ^{113}Sn and ^{137}Cs.

The concentration of radium, thorium and potassium was measured for each variety of maize meal namely: meme mahangu, namib braai pap, namib super meal (Okuryangava), maize meal, super meal, and top score. The samples were thoroughly crushed. About 500 g of each sample was taken to carry out further procedure. The samples were placed and sealed in a Marinelli beaker and left for 30 days for secular equilibrium to be attained (Onjefu *et al.*, 2017). Initially, samples were laid in the HPGe detector, and then gamma spectrum was obtained using equation 1 (Onjefu *et al.*, 2017):

$$C(Bq.kg^{-1}) = \frac{C_n}{\varepsilon P_{\gamma M_S}} \qquad (1)$$

where C is the activity concentration of the radionuclide in the sample in units of Bq.kg $^{-1}$, C_n is the count rate of gamma rays associated with a peak per second (cps), ε is the detector efficiency at the specific γ- ray energy, P_γ is the absolute transition probability of the specific γ- ray, and M_S is the mass of the sample (kg).

The activity of the daughter radionuclide ^{214}Bi and ^{214}Pb were obtained from the 609.31 keV and 351.92 keV gamma peak respectively and were chosen as indicators of uranium (^{238}U) while the activity of ^{212}Bi (^{232}Th) was determined from its 727.17 keV gamma ray peak and was used as an indicator for thorium (^{232}Th). Potassium-40 was determined by measuring the 1460.3 keV gamma rays emitted during its decay (Jibiri and Emelue, 2008).

Calculation of radiobiological impact

The daily intake of radionuclides from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K due to the consumption of maize meal was calculated from equation 2 (Nahar *et al.*, 2018).

$$D_{int} = \frac{A_c \times A_{ig}}{Y_d} \qquad (2)$$

where D_{int} represents the daily intake of radionuclides (Bq.kg $^{-1}$) by an individual, A_C is the activity concentration of radionuclides (Bq.kg $^{-1}$), A_{ig} is the per capital per year consumption of maize meal where for Namibia is at 44 kg (Shifiona *et al.*, 2016), Y_d is the days in a year.

Another radiological parameter called the annual committed effective dose (µSv.y^{-1}) to an individual from ingestion of radionuclides in maize meal is defined from the following formula (Asaduzzaman *et al.*, 2015; Nahar *et al.*, 2018):

$$E_{eff} = A_c \times A_{ig} \times D_{cf} \quad (3)$$

where E_{eff}, A_c, A_{ig} and D_{cf} is the annual effective dose (µSv.y^{-1}), activity concentration of radionuclides (Bq.kg^{-1}), annual intake of maize meal (44 kg) (kg.y^{-1}) and ingestion dose conversion factor for radionuclides investigated (2.8 x 10^{-7} Sv.Bq^{-1} for ^{226}Ra, 2.3 x 10^{-7} Sv.Bq^{-1} for ^{232}Th and 6.2 x 10^{-9} Sv.Bq^{-1} for ^{40}K) (16) (IAEA, 2011).

The gamma index (I_γ) was calculated using equation 4 (Senthilkumar & Narayanaswamy, 2016),

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_k}{1500} \quad (4)$$

where $I_\gamma, A_{Ra,}\ A_{Th,}\ and\ A_k$ is the gamma index, activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Bq.kg^{-1}). The total ingested dose from the consumption of maize meal was determined using the relationship in equation 5 (Asaduzzaman *et al.*, 2015):

$$E_t = \sum([A_{cr}^f \times C_y^f])D_{cf}^r \quad (5)$$

where f represents a food group, the coefficients A_{cr}^f and C_y^f denote the average activity concentration of radionuclides in (Bq.kg^{-1}) and the consumption rate per year (kg), respectively and D_{cr}^r is the dose coefficient for an intake by the ingestion of radioisotope, r given in unit of (Sv.Bq^{-1}).

Excess life time cancer risk (ELCR) was obtained from equation 6 (Nahar *et al.*, 2018):

$$ELCR = E_f \times D_L \times R_c \quad (6)$$

where $ELCR$ is the life cancer risk, E_f should be the annual effective dose ($SvYr^{-1}$), D_L the average lifespan (70 years) and R_c is the risk factor (Sv^{-1}).

Results and Discussions

Activity concentrations of radionuclides

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the maize meal samples are given in Table 1. The activities range and mean values (in brackets) for ^{226}Ra, ^{232}Th and ^{40}K are BDL - 3.20 ± 1.20, (0.99 ± 0.40), BDL- 0.64 ± 0.13, (0.35 ± 0.08), and 11.04 ± 1.66 - 50.19 ± 6.64 (29.98 ± 4.05) Bq/kg, respectively. The results show that the mean activities of ^{226}Ra, ^{232}Th and ^{40}K in the maize meal samples were below the world average of 32, 45 and 412 Bq/kg respectively (UNSCEAR, 2008).

The mean activity concentrations were in the order ^{40}K > ^{226}Ra > ^{232}Th. This clearly show that ^{40}K dominates over ^{226}Ra and ^{232}Th because of its relative abundance in terrestrial bodies (Wild, 1993, Dar and El-Saharty, 2013). The meme mahangu maize meal had the highest activity for ^{40}K, while namib super meal had the highest activity of ^{232}Ra. The highest activity of ^{232}Th was recorded for super meal maize meal. The differences in the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the maize meal samples maybe attributed to differences in soil properties and geographical setting of the soil and the type of fertilizer added to the soil to improve soil fertility (Karunakara *et al.*,2013).

The obtained mean activities of ^{40}K, ^{226}Ra and ^{232}Th has been compared with those reported from other countries (Table 2). It shows that the activity of ^{40}K, ^{226}Ra and ^{232}Th in maize meal sold in Windhoek, Namibia is lower than the reported maize meal range for the populations of Tanzania, Malaysia and Iran respectively (Olatunji *et al.*, 2014; Nkuba and Sungita, 2017; Changizi *et al.*, 2013).

Table 1: Activity concentrations in maize meal samples (Bq/kg)

Sample	Activity Concentrations		
	40K (Bq/kg)	226Ra (Bq/kg)	232Th (Bq/kg)
Meme Mahangu	50.19 ± 6.64	2.75 ± 1.19	BDL
Namib Braai Pap	24.30 ± 3.31	BDL	0.55 ± 0.13
Namib Super Meal	36.44 ± 4.86	3.20 ± 1.20	0.43 ± 0.12
Okuryangava Maize Meal	11.04 ± 1.66	BDL	0.47 ± 0.12
Super Meal	30.33 ± 4.08	BDL	0.64 ± 0.13
Top score	27.55 ± 3.72	BDL	BDL
Minimum	11.04 ± 1.66	BDL	BDL
Maximum	50.19 ± 6.64	3.20 ± 1.20	0.64 ± 0.13
Mean	29.98 ± 4.05	0.99 ± 0.40	0.35 ± 0.08

BDL= Below Detection Limit

Table 2: Average activity concentrations (Bq.kg $^{-1}$) of ^{40}K, ^{226}Ra and ^{232}Th in maize meal samples investigated in this study, compared with those reported from other countries.

Origin	**^{40}K**	**^{226}Ra**	**^{232}Th**	**Reference**
Namibia	29.98	0.99	0.35	**Present study**
Tanzania	42.0-434.6	-	2.2-38.9	Nkuba and Sungita (2017)
Iran	91.73	1.67	0.5	Changizi *et al.*, (2013)
Malaysia	26.4-129	0.05-19.18	ND	Olatunji *et al.*, (2014)

ND = No Data

Table 3: Daily intake (Din) of ^{40}K, ^{226}Ra and ^{232}Th and annual effective dose due to the consumption of maize meal.

Sample ID	Din (Bq.d $^{-1}$)			Annual effective dose, E_{eff} ($\mu Sv.y^{-1}$)		
	^{40}K	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th
Meme Mahangu	6.05	0.33	-	1.37 x 10^{-05}	3.38 x 10^{-05}	-
Namib Braai Pap	2.93	-	0.07	6.63 x 10^{-06}	-	5.53 x 10^{-06}
Namib Super Meal	4.39	0.39	0.05	9.94 x 10^{-06}	3.95 x 10^{-05}	4.35 x 10^{-06}
Okuryangava Maize Meal	1.33	-	0.06	3.01 x 10^{-06}	-	4.77 x 10^{-06}
Super Meal	3.66	-	0.08	8.27 x 10^{-06}	-	6.45 x 10^{-06}
Top score	3.32	-	-	7.52 x 10^{-06}	-	-
Average Value	3.61 ±0.79	0.36 ± 0.03	0.07 ±0.008	8.17 x 10^{-06}	3.67 x 10^{-05}	5.28 x 10^{-06}

ND = No Data

Daily intake and Annual Effective Dose

The daily intake of ^{40}K, ^{226}Ra and ^{232}Th and annual effective dose due to the consumption of maize meal was calculated and the results shown in Table 3. The estimated daily intakes of activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th into the human body by ingestion of the maize meal varied from 1.33 to 6.05 Bq.d $^{-1}$ with an average value of 3.61±0.79 for ^{40}K, 0.33 to 0.39 Bq.d $^{-1}$ with an average value of 0.36±0.03 for ^{226}Ra, and 0.05 to 0.08 Bq.d $^{-1}$ with an average value of 0.07±0.008 for ^{232}Th, respectively. The daily intake of ^{40}K was found to be significantly higher than the other radionuclides in all the maize meal samples. This radionuclide is an essential element for the human body. However, the use of fertilizers for improve crop yield may have informed the high levels of ^{40}K activity concentrations in all the samples (Jayasinghe *et al.,* 2020). The annual effective dose in µSv.y $^{-1}$ due to ingestion of maize meal were in the range 3.01 x 10^{-06} to 1.37 x 10^{-05} for ^{40}K, 3.38 x 10^{-05} to 3.95 x 10^{-05} for ^{226}Ra and 6.45 x 10^{-06} for ^{232}Th respectively. The Annual effective dose for Namib Super Meal was the highest for all radionuclides except for ^{232}Th. These values are however far below the threshold dose values for safety from ingestion of uranium (6.3 µSv.y $^{-1}$) and thorium (0.38 µSv.y $^{-1}$) radionuclides as reported by UNSCEAR (2000).

Gamma index and excess lifetime cancer risk

Table 4 present the gamma index and excess lifetime cancer risk. The calculated values of the gamma Index ranges from 0.01 (Okuryangava Maize Meal) to 0.03 (Super Meal), with a mean value of 0.03±6.66. The I_γ values for all maize meal sample were lower than the critical value of unity (UNSCEAR, 2000). The Excess life time cancer risk (ELCR) varied from 1.33 x 10^{-13} to 6.05 x 10^{-13} for ^{40}K, 2.43 x 10^{-11} to 2.83 x 10^{-11} for ^{226}Ra and 7.99 x 10^{-13} to 1.02 x 10^{-12} which are lower than the acceptable ELCR limit as set by USEPA (1989). The United States Environmental Protection Agency (USEPA) considers acceptable for regulatory purposes an excess life time cancer risk of between 1 × 10^{-6} and 1 × 10^{-4} (USEPA, 1989).

Conclusions

Concentration of natural radionuclides in various types of maize meal samples consumed in Namibia has been determined. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th were found to be 29.98 ± 4.05, 0.99 ± 0.40 and 0.35 ± 0.08 Bq.kg $^{-1}$ in maize meal samples. The daily intake of radionuclides was found to be in the order ^{40}K > ^{226}Ra > ^{232}Th. From the measured values of the activity concentrations, the effective dose, gamma index and excess lifetime cancer risk were calculated and found to be lower than internationally accepted threshold limits. The study reveals that radionuclides intake from consumption of maize meals pose no radiological threat to members of the public in Windhoek-Namibia. The findings from this study will help in establishing baseline information for radionuclides exposure to members of the public due to consumption of maize meal.

Table 5: Gamma index, alpha index and excess life time cancer risk

Sample ID	Gramma Index (I_γ)	40K	ELCR 226Ra	232Th
Meme Mahangu	0.05	6.05 x 10-13	2.43 x 10-11	-
Namib Braai Pap	0.02	2.93 x 10-13	-	1.02 x 10-12
Namib Super Meal	0.05	4.39 x 10-13	2.83 x 10-11	7.99 x 10-13
Okuryangava Maize Meal	0.01	1.33 x 10-13	-	8.76 x 10-13
Super Meal	0.03	3.65 x 10-13	-	1.19 x 10-12
Top score	0.02	3.32 x 10-13	-	-
Mean	0.03±6.66	3.61 x 10-13	8.77 x 10-12	6.48 x 10-13

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