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Assessment of Radiological Hazards in Some Foods Products Consumed by the Malian Population Using Gamma Spectrometry

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ABSTRACT

Background: Food consumption is one of the most important routes for radionuclide intake for the public; therefore, there is the need to have a comprehensive understanding of the amount of radioactivity in food products. Consumption of radionuclide-contaminated food could increase potential health risks associated with exposure to radiation such as cancers. The present study aims to determine radioactivity levels in some food products (milk, rice, sugar, and wheat flour) consumed in Mali and to evaluate the radiological effect on the public health from these radionuclides.

Materials and Methods: The health impact due to ingestion of radionuclides from these foods was evaluated by the determination of activity concentration of radionuclides ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs using gamma spectrometry system with high-purity germanium detector and radiological hazards index in 16 samples collected in some markets, mall, and shops of Bamako-Mali.

Results and Discussion: The average activity concentrations were 9.8±0.6 Bq/kg for ^{238}U, 8.7±0.5 Bq/kg for ^{232}Th, 162.9±7.9 Bq/kg for ^{40}K, and 0.0035±0.0005 Bq/kg for ^{137}Cs. The mean values of radiological hazard parameters such as annual committed effective dose, internal hazard index, and risk assessment from this work were within the dose criteria limits given by international organizations (International Commission on Radiological Protection and United Nations Scientific Committee on the Effects of Atomic Radiation) and national standards.

Conclusion: The results show low public exposure to radioactivity and associated radiological impact on public health. Nevertheless, this study stipulates vital data for future research and regulatory authorities in Mali.

Keywords: Activity Concentration, Annual Committed Effective Dose, Foodstuff, Internal Hazard Index, Risk Assessment, Stochastic Effects

Original Research

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Introduction

Natural radioactivity is mostly caused by the primordial radionuclides, namely ^{40}K, and ^{238}U-^{232}Th decay series, which are present in earth formations. It is important to understand the concentrations and distributions of naturally occurring radioactive materials (NORM) since it gives helpful information to monitor environmental radioactivity. Artificial radionuclides such as ^{137}Cs which are occasioned by anthropogenic activities also contribute to environmental monitoring [1].

Several human activities enhance the level of NORM in the environment. For example, there are the burning of fossil fuels and the unrestrained mining processes, etc. These radionuclides accumulated in the soil can reach foods or plants through metabolic processes and ultimately can be transferred to animals and subsequently to humans when they consume contaminated foods. The level of risk to human health is dependent on the type, amount of radionuclide, and the exposure time. Radiation exposure to humans differs from one place to another depending on the geographical and geological conditions [2, 3].

The key objective of this study is to calculate the activity concentration of radionuclides and evaluate the radiological hazards in some food products consumed by the Malian population using gamma spectrometry.

This study will offer a basis for more assessment of exposures to radionuclides in food products and useful data for the Malian regulatory body Agence Malienne de Radioprotection (AMARAP) and other relevant authorities.

Materials and Methods

1. Sample Collection, Preparations, and Measurement

Mali is the second largest importing country in West Africa. Around 13.91% of agricultural products are imported and 13.45% of this value is foods only [4]. Based on the collected data from Direction Généraledu Commerce, de la Consommation et de la Concurrence (DGCCC) and Office des Produits Agricoles du Mali (OPAM), four different kinds of the most consumed foods by the Malian population (powdered milk, rice, sugar, and wheat flour) were selected for sampling. Thirteen samples were collected: three from powdered milk, three from sugar, three from rice, and four from wheat flour from different markets, malls, and shops around Bamako city (Mali), between them, five samples were made in Mali (one rice, one sugar, and three wheat flour samples).

Sixteen samples were prepared and stored for almost 1 month for secular equilibrium between the U-Th series and their daughters to be reached. The activity concentration of samples was obtained using a gamma spectrometry system with a high-purity germanium (HPGe) detector at the Ghana Research Reactor-1 (GHARR-1) of the Ghana Atomic Energy Commission (GAEC). The gamma spectrometry system was made up of an HPGe detector connected to a computer-based multi-channel analyzer. The detector has a relative efficiency of 40% with an energy resolution of 2.0 keV at gamma-ray energy of 1,332 keV of ^{60}Co. The individual radionuclides were identified by their characteristic gamma-ray energies and the quantitative analysis of radionuclides was done with the Genie 2000 gamma acquisition and analysis software (Mirion).

2. Calculations of Activity Concentration and Annual Committed Effective Dose

1) Activity concentration

After the secular equilibrium time, all the samples were read for 10 hours, the activity concentrations of ^{238}U and ^{232}Th were assessed by averaging the peaks of different daughters for the U-Th series, ^{40}K and ^{137}Cs were calculated using the photopeak in the spectrum. The activity concentrations of ^{238}U were obtained by using the gamma-ray energies and the respective gamma-intensity of ^{214}Bi at 609.3 keV (44.8%) and ^{214}Pb at 351.9 keV (35.8%). That of ^{232}Th was obtained using gamma energies of ^{228}Ac at 911 keV (26.6%), ^{212}Pb at 238.6 keV (43.3%), and ^{208}Tl at 583 keV (30.1%), and 2,614.7 keV (35.3%) considering a branching ratio of 33.7% from ^{212}Bi towards ^{208}Tl. For ^{40}K, it was estimated from its energy line at 1,460.8 keV (10.7%) while the ^{137}Cs were calculated from the gamma energy line at 661.67 keV (85.1%). All the energies and yields of the various radionuclides were from a standard library.

Therefore, the activity concentration ($A_{E,i}$) in Bq/kg, for a radionuclide i with a photopeak at energy E, was calculated as:

$$A_{E,i} = \frac{N_{E,i}}{\epsilon_E \cdot t \cdot \gamma_d \cdot M} \quad (1)$$

where $N_{E,i}$ is the net peak-area of i radionuclide at energy E, ϵ_E is efficiency at energy E, t is counting time (s), γ_d is the gamma emission probability, and M is the mass (kg).

2) Annual committed effective dose

The annual committed effective dose (AED) (Sv/yr) was calculated using the activity concentration of all radionuclides detected and analyzed in the samples as:

$$AED = \sum e(g)_j \cdot A_j \cdot U_j \quad (2)$$

where $e(g)_j$ is the effective dose conversion factor for ingestion of nuclide j (Sv/Bq), Aj is the activity concentration of nuclide j (Bq/kg) and U_j is the consumption rate of food (kg/yr). In this study, the international values of annual consumption rate were used [5].

3) Internal hazard index

The internal exposure to radon and its short-lived daughters is also dangerous to the respiratory organs. To account for this threat the internal hazard index (H_{in}) was quantified using the activity concentration of ^{40}K, ^{238}U, and ^{232}Th. It should be below one to provide safe levels for the respiratory organs of individuals. The internal exposure from the daughters of ^{238}U, ^{232}Th, and ^{40}K, was calculated using Equation (3) [6]:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

where A_U is activity concentration of ^{238}U (Bq/kg), A_{Th} is activity concentration of ^{232}Th (Bq/kg), and A_K is activity concentration of ^{40}K (Bq/kg).

4) Risk assessment calculation

Risk is estimated by the assumption that a linear dose-effect relationship has no threshold according to the International Commission on Radiological Protection (ICRP) [7]. Lower doses have a fatal cancer risk factor (RF) of 0.05 Sv^{-1} reported by International Atomic Energy Agency (IAEA) [7]. This RF determines the likelihood of an individual dying of cancer by a 5% increase of 1 Sv dose received throughout his entire life.

The *AED* (Sv/yr) in food is estimated to determine the cancer risk of an adult using Equation (4).

$$Risk\ assessment\ (RA) = AED \cdot LE \cdot RF \quad (4)$$

with where *LE* is life expectancy in Mali which is 59.3 years [8] and *RF* is 0.05 Sv^{-1} [7] for low doses.

Results and Discussion

1. Results

1) Activity concentration

In the present study, 16 food samples were analyzed. Table 1 shows the activity concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs. The minimum detection activity obtained for ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs were 0.038, 0.044, 0.31, and 10^{-3} Bq/kg, respectively.

2. Radiological Hazard Indices

1) Annual committed effective dose

Owing to the unavailability of updated and reliable national consumption rate values of foods in Mali, the *AED* was calculated using international consumption rate values reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2008 [5] as presented in Table 2.

2) Internal hazard index

The H_{in} was determined in the various samples of powdered

Table 1. Activities Concentration of Radionuclide in Some Imported and Locally Consumed Food Products by the Malian Population (Bq/kg Dried Weight) Compared with the National Standard by the Regulatory Authority in Mali [9]

Sample type	Sample code	Activity concentration (Bq/kg)			
		^{238}U	^{232}Th	^{40}K	^{137}Cs
Milk	M-01	32.8±2.3	10.3±0.6	117.9±6.0	<0.001
	M-02	<0.038	14.3±0.8	228.2±14.7	<0.001
	M-03	<0.038	<0.044	382.2±19.5	0.0026±0.0004
	Average±SD	32.8±2.3	12.3±1.0	242.8±6.8	0.0026±0.0004
Rice	R-01	<0.038	<0.044	3.2±0.2	<0.001
	R-02	<0.038	7.9±0.5	<0.31	<0.001
	R-03	1.7±0.1	8.5±0.5	<0.31	0.0044±0.0006
	RF-01	6.3±0.3	11.5±0.6	<0.31	<0.001
	RF-02	<0.038	3.3±0.2	<0.31	<0.001
	RF-03	11.3±0.7	11.2±0.9	<0.31	<0.001
	Average±SD	6.3±0.3	8.5±0.3	3.2±0.2	0.0044±0.0006
Sugar	S-01	1.1±0.1	<0.044	<0.31	0.0025±0.0004
	S-02	<0.038	0.8±0.05	<0.31	<0.001
	S-03	<0.038	0.01±0.001	<0.31	<0.001
	Average±SD	1.1±0.1	0.4±0.04	<0.31	0.0025±0.0004
Wheat flour	WF-01	2.8±2.0	8.7±0.5	<0.31	0.0043±0.0006
	WF-02	10.1±0.6	33.9±2.2	<0.31	0.0039±0.0006
	WF-03	1.9±0.1	6.4±0.4	<0.31	<0.001
	WF-04	<0.038	0.6±0.03	<0.31	<0.001
	Average±SD	5.0±0.2	12.4±1.0	<0.31	0.0041±0.0006
Mean		9.8±0.6	8.7±0.5	162.9±7.9	0.0035±0.0005
Malian standard [9]		1,000	1,000	100,000	10,000

SD, standard deviation.

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Table 2. Annual Committed Effective Dose of Radionuclide in the Samples

Sample code	Activity concentration (Bq/kg)				Annual committed effective dose, *AED* (μSv/yr)				
	^{238}U	^{232}Th	^{40}K	^{137}Cs	Age 1–2 yr	Age 2–7 yr	Age 7–12 yr	Age 12–17 yr	Age > 17 yr
M-01	32.8	10.3	117.9	< 0.001	1,708.0	1,044.9	810.2	623.7	480.6
M-02	< 0.038	14.3	228.2	< 0.001	2,086.9	1,175.8	853.7	584.1	494.0
M-03	< 0.038	< 0.04	382.2	0.0026	2,201.3	963.1	596.2	319.5	248.8
R-01	< 0.038	< 0.04	3.2	< 0.001	7.0	3.1	3.8	2.2	2.8
R-02	< 0.038	7.9	< 0.31	< 0.001	159.3	123.9	205.3	177.0	253.3
R-03	1.7	8.5	< 0.31	0.0044	179.3	138.7	230.1	199.2	282.4
RF-01	6.3	11.5	< 0.31	< 0.001	266.7	203.6	338.4	296.5	409.6
RF-02	< 0.038	3.3	< 0.31	< 0.001	66.7	51.9	85.9	74.1	106.0
RF-03	11.3	11.2	< 0.31	< 0.001	288.3	217.5	362.1	320.2	432.6
S-01	1.1	< 0.04	< 0.31	0.0025	5.8	3.8	6.5	6.4	6.7
S-02	< 0.038	0.8	< 0.31	< 0.001	15.8	12.3	20.4	17.6	25.1
S-03	< 0.038	0.01	< 0.31	< 0.001	0.3	0.2	0.3	0.3	0.4
WF-01	2.8	8.7	< 0.31	0.0043	190.2	146.3	242.9	211.5	296.2
WF-02	10.1	33.9	< 0.31	0.0039	741.5	570.6	947.2	824.2	1,155.9
WF-03	1.9	6.4	< 0.31	< 0.001	140.3	107.1	179.3	156.0	218.8
WF-04	< 0.038	0.6	< 0.31	< 0.001	11.9	9.2	15.3	13.2	18.8
Mean					504.3	298.3	306.1	239.1	277.0
					326.0 (~0.33 mSv/yr)				

Table 3. Internal Hazard Index (H_{in}) Values

Sample	Radionuclide activity concentrations (Bq/kg)			H_{in}
	^{238}U	^{232}Th	^{40}K	
Powder milk	32.8	12.3	242.8	0.3
Rice	6.3	8.5	3.2	0.1
Sugar	1.1	0.4	< 0.3	0.01
Wheat flour	5.0	12.4	< 0.3	0.1

milk, rice, sugar, and wheat flour as presented in Table 3.

3) Risk assessment

The *RA* was calculated using Equation (4) above and the results are shown in Table 4.

3. Discussion

The range of activity concentrations for ^{238}U varies from 1.1 ± 0.1 to 32.8 ± 2.3 Bq/kg, for ^{232}Th from 0.01 ± 0.001 to 33.9 ± 2.2 Bq/kg, for ^{40}K from 3.2 ± 0.2 to 382.2 ± 19.5 Bq/kg, and for ^{137}Cs from 0.0025 ± 0.0004 to 0.0044 ± 0.0006 Bq/kg. The peaks of ^{40}K and ^{137}Cs for most of the rice, wheat flour, and sugar samples were below the detection limit as indicated in Table 1.

The result of samples showed that S-01, S-03, R-01, WF-04 represented the lowest activities concentrations level of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs, respectively; M-01, WF-02, M-03, and R-03 represented the highest values of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs, respectively. The results proved that the samples of powdered milk contained the maximum values of activity concentrations of NORM; the R-03 contains the maximum value of ^{137}Cs. All of which are imported from Europe and Asia. Special or more investigation must be carried out on the milk because they are more consumed by infants and children.

The activity concentrations of measured radionuclides in the food samples are much lower than the Malian standard 1,000 Bq/kg for ^{238}U and ^{232}Th, 10,000 Bq/kg for ^{137}Cs, and 100,000 Bq/kg for ^{40}K and in comparison, to other works as shown in Table 5 [1, 9–13].

The *AED* from ingestion is calculated for various age groups (from infant to adult). The range of values for *AED* (μSv/yr) of samples was; for powdered milk 248.8 (M-03) to 2,201.3 (M-03), for rice 2.2 (R-01) to 432.6 (RF-03), for sugar 0.2 (S-03) to 25.1 (S-02), and for wheat flour 9.2 (WF-04) to 1,155.9 (WF-02), as shown in Table 2. The highest values of AED were reported again in powdered milk. The *AED*'s mean value for the consumption of these foods was around 0.33 mSv/yr. This compared well with the UNSCEAR worldwide average annual dose due to the ingestion of foodstuffs of 0.29 mSv/yr.

Based on the calculated values ($H_{in} < 1$), the obtained values of this index due to the ingestion of these food products were below one. For consumption of these foods products, the calculated H_{in} means good safe levels for the respiratory organs due to internal exposure to radon and its short-lived

Table 4. Risk Assessment Values

Variable	Age range (yr)				
	1–2	2–7	7–12	12–17	> 17
AED (Sv/yr)	5.04×10^{-4}	2.98×10^{-4}	3.06×10^{-4}	2.39×10^{-4}	2.77×10^{-4}
RA	1.50×10^{-3}	7.07×10^{-4}	9.08×10^{-4}	7.09×10^{-4}	8.21×10^{-4}
Mean value of RA			9.28×10^{-4}		

AED, annual committed effective dose; RA, risk assessment.

Table 5. Evaluation of the Average Activity Concentration (Bq/kg) of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs in Foods in the Present Study and Other Published Data around the World

Country	Sample	^{238}U	^{232}Th	^{40}K	^{137}Cs	Reference
India	Rice	-	-	120.8 ± 2.1	-	[1]
Ghana	Rice	-	-	104.36 ± 10.22	-	[1]
USA	Rice	-	13.67	231.87	-	[12]
New-Zealand	Powder milk	-	-	349.86 ± 36.45	0.7 ± 0.62	[13]
Europe	Powder milk	-	-	337.6 ± 19.83	0.43 ± 0.05	[13]
Iraq	Wheat flour	6.60 ± 3.72	1.95 ± 1.33	133.10 ± 67.04	-	[11]
Sudan	Wheat flour	2.83 ± 0.95	3.19 ± 2.03	11.87 ± 7.12	-	[10]
Mali	Powder milk	32.8 ± 2.3	12.3 ± 1.0	242.8 ± 6.8	0.0026 ± 0.0004	Present study
Mali	Rice	6.3 ± 0.3	8.5 ± 0.3	3.2 ± 0.2	0.0044 ± 0.0006	Present study
Mali	Sugar	1.1 ± 0.1	0.4 ± 0.04	-	0.0025 ± 0.0004	Present study
Mali	Wheat flour	5.0 ± 0.2	12.4 ± 1.0	-	0.0041 ± 0.0006	Present study
Malian standard		1,000	1,000	100,000	10,000	[9]

Values are presented as mean ± standard deviation.

progenies as in Table 3.

The RA was calculated for different ages from 1 year to more than 17 years, the range of RA varied from 7.07×10^{-4} (for 1 to 2 years) to 1.5×10^{-3} (for 2 to 7 years). It is 4 to 8.5 times less than the risk (6.0×10^{-3}) from all natural radiation sources based on the global average annual radiation dose which is 2.4 mSv/yr to man [5]. The mean value of *RA* is 9.28×10^{-4}, which is 6.5 times less than the risk 6.0×10^{-3} as mentioned above as shown in Table 4.

The cancer risk is based on an annual dose limit of 1 mSv for the public, which gives an annual death probability of 10^{-5}, i.e., 1 in 100,000 reported by ICRP in 1990 [14]. That means the death probability by cancer due to the ingestion of these food products is much lower than the estimated value reported by ICRP in 1990 [14].

Conclusion

Natural and artificial radionuclides (^{137}Cs) in selected foods were studied for their radiological hazards. The radionuclides of ^{238}U, ^{232}Th (through their daughters) and ^{40}K, and ^{137}Cs were the main radionuclides detected in the food samples in this research. The analysis revealed that the results of activity concentrations of the ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs in samples were generally lower than the national standard and global reference. The calculated *AED* values were less than the authorized limit for the public which is 1 mSv/yr. The mean radiological parameters such as *AED*, H_{in}, and *RA* were below the dose criteria limits given by international organizations (ICRP and UNSCEAR) and national standards.

The results of this study proved that these foods are safe for human consumption even if the risk (stochastic effect) associated with internal exposure due to low dose intakes exists. Based on obtained values, the probability of someone dying of cancer due to the ingestion of these foods is less than 10^{-5} in the Malian population.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Ethical Statement

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Department of Radiation Protection of School Nuclear and Allied (SNAS) of University of Ghana (UG) (IRB approval no. 10751253). Written informed consent by the patients was waived due to a retrospective nature of our study.

Author Contribution

Conceptualization: Coulibaly A, Kpeglo DO, Darko EO. Methodology: Coulibaly A, Kpeglo DO, Darko EO. Formal analysis: Coulibaly A. Supervision: Kpeglo DO, Darko EO. Funding acquisition: Coulibaly A. Project administration: Coulibaly A. Investigation: Coulibaly A, Kpeglo DO, Darko EO. Visualization: Kpeglo DO, Darko EO. Validation: Coulibaly A, Kpeglo DO, Darko EO. Writing - original draft: Coulibaly A. Writing - review & editing: Coulibaly A. Approval of final manuscript: all authors.

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