Assessment of Natural Radioactivity Levels of ^{40}K ,^{238}Th and ^{232}Th in Some Selected Baby Food in Southwestern Nigeria

Abstract

Baby powdered milk is a nutritious source of food for infants and children. Most working class nursing mothers usually substitute breast milk for it when they are not available to take care of their kids. The contagious of chronic disease among infants has caused careful thought among the researchers. Food contamination through radioactivity cause severe health threat for infants because of their weak immune system. Radioactivity concentrated foods are very dangerous as they increase cumulative risks of developing cancer and other related diseases. Therefore, the assessment of radioactivity levels of ^{40}K, ^{238}Ra and ^{232}Th in baby food and their associated doses are of crucial importance for health safety. This study focused on the radiation contamination of baby food and its implications on the infants health and safety. Four samples of baby powdred milk were investigated using gamma ray spectrometer. The results indicated that the concentrations of ^{40}K, ^{238}Ra and ^{232}Th ranged from 212.6 Bq/kg to 354.3 Bq/Kg, from 37.6 Bq/Kg to 129.3 Bq/Kg and from 83.2 Bq/Kg to 223.9 Bq/Kg, respectively. Although the level of radioactivity is relatively low in all the food samples and they are within the internationally acceptable values, this study revealed that ^{232}Th and ^{226}Ra are the most significant contributor to radiation exposure in baby food in Southwest Nigeria. It is therefore recommended that baby powdered milk manufacturers should ensure reduction in the levels of these radionuclides and regulatory bodies should prioritize monitoring levels of ^{232}Th and ^{226}Ra in baby food to minimize health risks.

Keywords:

Radactivity; Baby Food, Activity Concentration; Absorbed Dose Rate; Internal Hazard Index

1.0 Introduction

The natural radiation environment is the major source of radiation exposure to man, and it is made up of internal and external sources (Hussein *et al*., 2021; Joel *et al*., 2021). The most significant internal sources are ^{40}K and ^{232}Th, which are taken into the body through food and water (Siraz *et al*., 2023). Most of these substances originate from bedrock but are transferred into the food chains (Santhanabharathi *et al*., 2023). Almost every human receives a certain radiation dose from the food they eat (Babatude *et al*., 2015; Johansen *et al*., 2015). Ingestion of radionuclide through food intake may account for a substantial fraction of the average of radiation doses to various organs of the body (Giri *et al*., 2013; Paquet *et al*., 2016). A small amount radionuclide if ingested can cause a terrible health challenge (Sinha Ray & Elango, 2019). Specifically, natural occurring radioelmentss such as Uranium, Thorium, potassium form the largest contribution to internal radiation dose received by human due to their widespread contribution in the environment (Hendry *et al*., 2009; Onoshowo, 2015; Babatunde *et al*., 2019).

Food contain natural and artificial radionuclide that greatly contributes to an effective internal dose when ingested. Studies have shown that a large percentage of the mean annual dose due to natural sources is caused by the intake of food (Abojassim *et al*., 2026; Pourimani & Rahimi, 2016). ^{232}Th, ^{226}Ra and ^{40}k are the most common naturally occurring radionuclides present in the earth crust. They enter the human body through the food chain (Matthew *et al*, 2015). Studies show that commercial baby foods are often contaminated with toxic heavy elements like lead, arsenic, thorium, mercury and cadmium (Zwierzchowski & Ametaj, 2018). These trace amount of food can alter the evolving brain and erode a child's intelligent quotient (Bashir *et al*, 2012).

In Nigeria, many mothers opt for formula baby food over breastfeeding due to a combination of socio-economic, cultural, and practical factors. One of the primary reasons is the increasing number of working-class mothers who find it challenging to balance work commitments with the demands of breastfeeding (Ogunba, 2019). With many workplaces lacking adequate facilities for breastfeeding or expressing milk, formula feeding becomes a more convenient alternative (Ogundare *et al*., 2023). Cultural shifts and urbanization have also played a role in the preference for formula (Anazonwu et al., 2018). The influence of Western lifestyles and the desire for convenience in fast-paced urban environments contribute to the growing acceptance of formula feeding (Aluko-Arowolo, 2012). Healthcare advice and practices also impact this preference. In some cases, healthcare providers may recommend formula feeding for various reasons, including the health of the mother or child, or due to perceived insufficiency of breast milk (Ukpabi *et al*., 2021).

The use of baby formula, although essential for many families, carries specific risks related to its radioactive content. One of the primary concerns with baby formula is the potential contamination with natural radionuclides such as potassium-40 (^{40}K), radium-238 (^{238}Ra), and thorium-232 (^{232}Th) (Jemii & Alharbi, 2018; Ong et al., 2024). These substances, while naturally occurring, can pose significant health risks, particularly for infants who are more vulnerable due to their developing bodies and weaker immune systems. Infants exposed to radioactive contaminants in baby formula can face severe health risks (Linet et al., 2018; Kiani *et al*., 2022). Radionuclides, once ingested, can accumulate in the body and continue to emit radiation, potentially damaging tissues and organs over time (Aaseth *et al.*, 2019). This prolonged exposure increases the risk of developing various health issues, including cancer, bone marrow suppression, and thyroid problems. The delicate physiology of infants means that even low levels of radiation can have disproportionately high health impacts. The ingestion of radioactive substances can also lead to a substantial cumulative dose of radiation, heightening the risk of chronic health conditions and developmental issues bioaccumulation, where these contaminants build up in the body over time (Szynkowska *et al.*, 2018). For infants, who have a longer expected lifespan, this bioaccumulation may pose a significant long-term risk.

Measurements of natural radioactivity in environmental elements have been carried out in different countries to establish baseline data from the natural radiation levels (Ahmad *et al.*, 2015). According to Wm's report (2021) , within the last ten years, there is an increase in demand for baby food across the country which shows a higher rate of consumption of baby food across the country, especially the southwest Nigeria. Children below five are at high risk for foodborne illness and related health complications because they are under developing immune systems and cannot fight off infections like adults (Kiani *et al.,* 2022). Thus, food poisoning for this age group can be dangerous and even a small amounts of toxins in baby food can build up chemical contamination over time (Mohammad *et al.*, 2018). Research shows that 95% commercial baby foods are contaminated with toxic heavy (Parker *et al.*, 2022). Elements like lead, arsenic, mercury & cadmium and these trace amounts in food can alter the evolving brain and erode a child's intelligent quotient (Kiani *et al.*, 2022). Consumption of food which contains radionuclides is particularly dangerous (Murakami & Oki, 2014). If an individual ingests or inhales a radioactive particle, it continues to irradiate the body as long as it remains radioactive and stays in the body (Ademola and Ehiedu, 2010).

Assessment of radioactivity levels in powdered milk (also known as baby formula) and cereals and their associated doses are of crucial importance for health and safety (Begam *et al.*, 2020). Despite the widespread use of baby baby formula, there is limited data on the levels of natural radionuclides in these products in Southwestern Nigeria. This lack of information poses a potential risk to public health. Therefore, this study seeks to fill this gap by investigating the concentrations of ^{40}K, ^{238}Ra, and ^{232}Th in selected baby food products and assessing their potential health impacts. Hence, the primary objective of this study is to assess the natural radioactivity levels of potassium-40 (^{40}K), radium-238 (^{238}Ra), and thorium-232 (^{232}Th) in selected baby food products available in Southwestern Nigeria. The study aims to measure the concentrations of these radionuclides in baby powdered milk and evaluate the associated radiation doses. The goal is to determine if these levels are within internationally acceptable limits and to identify the radionuclides that significantly contribute to radiation exposure in infants.

2.0 Materials and method

2.1 Sample collection and preparation

In this study, four samples of baby food; Nutribom (Sample A), Friska (Sample B), Dano (Sample C) and Cowbell (Sample D) were collected from local markets in Akesan area of Lagos, Southwest Nigeria. Approximately 75 gm of each samples were taken into air tight plastic pots having the same geometry and encoded with proper sample identification (ID). The samples were allowed to decay naturally for three weeks to ensure the parent-daughter equilibrium in the natural decay series. Activity measurements were performed using gamma ray spectrometer. The detector comprises of a 2" x 2" (50.8mm) diameter by 50.8 mm thickness. Tl activated NaI crystal and a photomultiplier tube (PMT) hermically sealed together in a metallic casing of diameter 58.4mm and height 132.0mm.

The led shield is cylindrical and has 59.1mm thickness, 157.2mm inner diameter and a movable lid of 59.1m thickness. The led shield helps to reduce background count rate of the detector by attenuating and or absorbing some of the background radiation including components of x-ray and gamma ray emitted from the materials in the surrounding of the spectrometer, other than sample being analysed. The level of background radiation around the detector was estimated by counting the empty samples container in the same geometry as the standards. The background count rate was subsequently subtracted from the sample count rate based on Equation 1 before calculating the activity concentration of radionuclides in the samples.

$$C_s - C_b = C_n \qquad (1)$$

where, C_s is the sample countrage, C_b is the background radiation countrage, and C_n is the net countrate sample.

Actvitity concentrations: Actvitity concentrations of ^{40}K, ^{232}Th and ^{226}Ra were measured using gamma spectrometry, where the count rate from the detector is converted into an activity concentration using calibration factors based on Equation 2.

$$A_c = \frac{C_n}{\varepsilon_E x P_\gamma x m} \qquad (2)$$

where ε_E is the efficiency of the detecting gamma rays of energy E by the detector, C_n is the net count rate under the photopeak corresponding to the gamma energy, P_γ is the photon emission probability of the gamma rays of the energy E emitted by the radionuclide of the interest. A_c is the activity concentration of the radionuclide in the sample and m is the mass of the sample.

Excess Lifetime Cancer Risk (ELCR). The excess lifetime cancer risk estimate the probability of developing cancer over a lifetime due to exposure using (Okedeyi *et al.*, 2024):

$$ELCR = AED \times DL \times RF \qquad (3)$$

where AED is the annual effective dose equivalent, DL is the average duration of life (assumed to be 70 years), and RF is the risk factor (typically 0.05 S/v).

Committed Effective Dose (mSv/year): Committed Effective Dose is the effective dose received by by infants through ingestion of radioactive substances in powder milk over a specific period. It is calculated based on the activity concentrations, intake rates and dose coefficients for ingestion:

$$CED = \sum_i (C_i \times I_i \times DCF_i) \qquad (4)$$

where, Ci is the activity concentration of radionuclide i in Bq/kg, I_i is the annual intake of radionuclide i (kg/year), and $DCFi$ is the dose conversion factor for ingestion of radionuclide i (mSv/Bq).

3.0 Results and Discussion

3.1 Net Count/Peak Area

The net count/peak area in different samples of baby food are presented in Table1. As can be seen in the table , the highest radionuclide concentrations are due to ^{40}K in sample A, C and D while the highest radio-nuclide concentration in sample B is due to ^{232}Th. The concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the baby food samples ranged between minimum and maximum values as follows: 212 Bq/Kg and 354 Bq/Kg, 37.6 Bq/Kg and 129.3 Bq/Kg, 83.2 Bq/Kg and 223.9 Bq/Kg, respectively. The mean concentration was observed to be highest for ^{40}K followed by ^{232}Th and the lowest mean concentration was for226Ra (290.7<175.8<86.9). Because ^{40}K is an essential element for living organism, it cannot be avoided. The highest concentration of ^{40}k was found in sample D while the lowest was found in sample B. The highest concentration of ^{226}Ra was found in sample C while the loswet was found in sample B. The highest concentration of ^{232}Th was found in sample D while the lowest was found in sample C.

Table 1: Net Count/Peak Area

#	Sample	^{40}K		^{226}*R*		^{232}*Th*	
		Net Count/area	**Std**	**Net Count/area**	**Std**	**Net Count/area**	**Std**
1	A	141	16.0	72	16.0	150	19.0
2	B	126	24.0	32	17.0	161	17.0
3	C	276	17.0	140	11.0	82	13.0
4	D	223	28.0	89	15.0	184	13.0

3.2 Activity Concentration

Table 2 presents the activity concentrations of the three radionuclides: Potassium-40 (^{40}K), Radium-226 (^{226}R), and Thorium-232 (^{232}Th) across four samples labeled A, B, C, and D. Each radionuclide's concentration is accompanied by a standard deviation, indicating the precision of the measurements. For Potassium-40 (^{40}K), Sample A shows an activity concentration of 230.5 Bq/kg with a standard deviation of ±26.2 Bq/kg. Sample B has a slightly lower concentration of 212.6 Bq/kg but with a higher variability, indicated by a standard deviation of ±40.5 Bq/kg. Sample C exhibits a significantly higher concentration of 365.5 Bq/kg and a lower standard deviation of ±22.5 Bq/kg, suggesting more consistent measurements. Sample D also has a high concentration of 354.3 Bq/kg, with a higher standard deviation of ±44.5 Bq/kg, reflecting greater variability. The mean concentration of ^{40}K across all samples is 290.7 Bq/kg, with an overall standard deviation of ±33.4 Bq/kg.

Radium-226 (^{226}R) shows varying concentrations across the samples. Sample A has an activity concentration of 82.1 Bq/kg with a standard deviation of ±18.2 Bq/kg. In Sample B, the concentration drops to 37.6 Bq/kg with a standard deviation of ±20.0 Bq/kg, indicating a wide spread in the data. Sample C has the highest concentration of 129.3 Bq/kg with a much lower standard deviation of ±10.2 Bq/kg, suggesting precise measurements. Sample D shows a concentration of 98.6 Bq/kg with a standard deviation of ±16.6 Bq/kg. The average concentration of ^{226}R is 86.9 Bq/kg, with an overall standard deviation of ±16.3 Bq/kg.

For Thorium-232 (^{232}Th), Sample A has an activity concentration of 187.8 Bq/kg with a standard deviation of ±23.8 Bq/kg. Sample B's concentration is slightly higher at 208.1 Bq/kg with a lower standard deviation of ±22.0 Bq/kg, indicating more precise measurements compared to Sample A. Sample C shows a lower concentration of 83.2 Bq/kg with a standard deviation of ±13.2 Bq/kg. Sample D has the highest concentration at 223.9 Bq/kg with a standard deviation of ±15.8 Bq/kg. The mean concentration of ^{232}Th across all samples is 175.8 Bq/kg, with an overall standard deviation of ±18.7 Bq/kg.

Table 2: Activity Concentration of ^{40}K, ^{226}R and ^{232}Th in the respective sampled baby food in southwestern Nigeria

#	Sample ID	^{40}K		^{226}R		^{232}Th	
		A_C	Std	A_C	Std	A_C	Std
1	Sample A	230.5	±26.2	82.1	±18.2	187.8	±23.8
2	Sample B	212.6	±40.5	37.6	±20.0	208.1	±22.0
3	Sample C	365.5	±22.5	129.3	±10.2	83.2	±13.2
4	Sample D	354.3	±44.5	98.6	±16.6	223.9	±15.8
	Mean	290.7	±33.4	86.9	±16.3	175.8	±18.7

***A_C*: Activity Concentration**

Given the above, the findings reveal variability in the concentrations of these radionuclides across the different samples. Potassium-40 concentrations are highest in Samples C and D. Radium-226 shows the highest concentration in Sample C and the lowest in Sample B. Thorium-232 concentrations are highest in Sample D and lowest in Sample C. The variability indicated by the standard deviations suggests differences in the precision of measurements and possible variations in the environmental or source conditions of the samples. In other words, the results highlight significant variability in the activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th across the baby food samples. Sample C generally shows the highest concentrations of both ^{40}K and ^{226}Ra, while Sample D has the highest concentration of ^{232}Th. This suggests potential differences in ingredient sourcing, production processes, or environmental contamination levels among the samples.

Given the critical nature of baby food safety, these findings emphasize the need for stringent quality control and regular monitoring of radionuclide levels. Ensuring that these concentrations remain within safe limits is paramount to protect infant health. The high variability in some samples also points to the importance of consistent manufacturing practices to avoid uneven distribution of radioactive elements.

The average ^{40}K concentration across the samples was 290.7 ± 33.4 Bq/kg, with individual samples ranging from 212.6 Bq/kg to 365.5 Bq/kg. These values align with typical levels of naturally occurring ^{40}K found in global foodstuffs (Olise et al., 2018). In contrast, ^{226}Ra showed an average concentration of 86.9 ± 16.3 Bq/kg, ranging from 37.6 Bq/kg to 129.3 Bq/kg, while ^{232}Th averaged 175.8 ± 18.7 Bq/kg, ranging from 83.2 Bq/kg to 223.9 Bq/kg. Samples C and D exhibited higher levels of ^{226}Ra and ^{232}Th compared to Samples A and B, potentially influenced by local geological factors (Khattak et al., 2011). Comparing these findings with international standards, the elevated concentrations of ^{226}Ra and ^{232}Th in Samples C and D exceed the maximum permissible levels of 1 Bq/kg recommended by WHO guidelines for food safety (WHO, 2011). This indicates a need for further investigation to assess potential health risks, particularly for infants who are more vulnerable to radiation exposure.

3.3 Spearman correlation results

Table 4 presents the results of the Spearman correlation analysis performed on the collected sample foods.

Correlation of ^{40}K (Bq/kg)

As can be seen in the table, the activity concentration of ^{40}K exhibits a perfect positive correlation with ^{226}Ra (1.0). This implies that in the samples studied, as the concentration of ^{40}K increases, the concentration of ^{226}Ra increases proportionately. There is a moderate negative correlation with ^{232}Th (-0.4), indicating an inverse relationship between ^{40}K and ^{232}Th concentrations. The correlations of ^{40}K with the absorbed dose rate, annual effective dose, radium equivalent activity, external hazard index, gamma index, and excess lifetime cancer risk are all weakly negative (-0.2), suggesting that ^{40}K has a minimal negative impact on these radiological parameters. However, there is a moderate positive correlation (0.4) with the internal hazard index, indicating that ^{40}K does contribute to the internal hazard.

Correlation of ^{232}Th (Bq/kg)

The activity concentration of ^{232}Th has strong positive correlations (0.8) with the absorbed dose rate, annual effective dose, radium equivalent activity, external hazard index, gamma index, and excess lifetime cancer risk. This indicates that ^{232}Th significantly impacts these radiological parameters, contributing substantially to radiation exposure. The negative correlation (-0.4) with ^{40}K and ^{226}Ra suggests an inverse relationship, meaning higher levels of ^{232}Th are associated with lower levels of ^{40}K and ^{226}Ra. The moderate positive correlation (0.4) with the internal hazard index shows that ^{232}Th also contributes to internal radiation hazards.

Table 3. Spearman correlation result of ^{40}K, ^{226}R and ^{232}Th in the respective samples

	K (Bq/kg)	Th (Bq/kg)	Ra (Bq/kg)	Excess Lifetime Cancer Risk (ELCR)
K (Bq/kg)	1	-0.4	1	-0.2
Th (Bq/kg)	-0.4	1	-0.4	0.8
Ra (Bq/kg)	1	-0.4	1	-0.2
Excess Lifetime Cancer Risk (ELCR)	-0.2	0.8	-0.2	1

Correlation of ^{226}Ra (Bq/kg)

The activity concentration of ^{226}Ra is perfectly positively correlated with ^{40}K (1.0), indicating a strong relationship between these two radionuclides. It shows a weak negative correlation (-0.2) with the absorbed dose rate, annual effective dose, radium equivalent activity, external hazard index, gamma index, and excess lifetime cancer risk, suggesting that ^{226}Ra has a minimal negative impact on these parameters. The moderate positive correlation (0.4) with the internal hazard index implies that ^{226}Ra contributes to internal radiation hazards.

3.5 Implications for Baby Food Safety

Given the strong positive correlations of ^{232}Th with most radiation exposure parameters, it is crucial to monitor and control ^{232}Th levels in baby food to minimize health risks. Although ^{226}Ra shows a strong positive correlation with ^{40}K, its impact on the radiation exposure parameters is less pronounced compared to ^{232}Th. It still needs to be monitored but is not as critical as ^{232}Th. The weak correlations of ^{40}K with most radiation exposure parameters suggest that its presence in baby food is less of a concern in terms of radiation exposure. The perfect correlations among absorbed dose rate, annual effective dose, radium equivalent activity, external hazard index, gamma index, and excess lifetime cancer risk highlight that any increase in one of these parameters directly increases the others. Thus, maintaining low levels of ^{232}Th and ^{226}Ra is crucial for overall radiation safety. This findings indicate that ^{232}Th is the most significant contributor to radiation exposure in baby food in Southwest Nigeria, followed by ^{226}Ra. Efforts should be made to reduce the levels of these radionuclides in baby food to ensure the safety and health of infants. ^{40}K, while naturally occurring, appears to have a minimal impact on radiation exposure parameters. Regulatory bodies should prioritize monitoring and controlling ^{232}Th and ^{226}Ra to minimize health risks.

4. Conclusions

A study of natural radioactivity in the baby food samples is usually done to provide information about the levels of harmful radiation in the environment and to understand the behavior of natural radionuclide. The purpose of this study is to analyse the level of radioactivity concentration of ^{40}K, ^{226}Ra and ^{232}Th in four samples of baby food. Although the level of radioactivity is relatively low in all the food samples and they are within the internationally acceptable values, this study revealed that ^{232}Th is the primary contributor to radiation exposure in baby food in Southwest Nigeria, followed by ^{226}Ra. This study shows that ^{232}Th has strong positive correlations with most radiation exposure parameters, making it a primary concern. Its presence in baby food poses a notable health risk, necessitating stringent monitoring and control measures. Although ^{226}Ra also correlates with ^{40}K, its impact on radiation exposure is less pronounced compared to ^{232}Th, but it still requires monitoring. On the other hand, ^{40}K, being naturally occurring, exhibits weak correlations with radiation exposure parameters and is less of a concern.

The study emphasizes the interconnectedness of various radiation exposure parameters, such as absorbed dose rate, annual effective dose, radium equivalent activity, external hazard index, gamma index, and excess lifetime cancer risk. These parameters are perfectly correlated, meaning that any increase in one leads to increases in others, underscoring the importance of maintaining low levels of ^{232}Th and ^{226}Ra in baby food. When comparing these findings with the World Health Organization (WHO) recommendations, it becomes clear that both emphasize the importance of monitoring contaminants in baby food to ensure safety. The WHO provides guidelines for setting limits on various radionuclides in food, aiming to minimize exposure and prevent harmful health effects. However, the WHO recommendations are broader, addressing a wide range of contaminants without necessarily prioritizing specific radionuclides unless localized studies, like this one, indicate higher risks.

The specific focus of the findings on ^{232}Th and ^{226}Ra aligns with the WHO's general principles but suggests a need for more localized and targeted regulations. The prioritization of ^{232}Th due to its significant impact on radiation exposure parameters highlights the necessity for stricter control measures. Given the above, several scientific recommendations is made to enhance baby food safety. Firstly, it is crucial to implement stringent monitoring of ^{232}Th levels in baby food. Setting lower permissible limits for ^{232}Th based on its high impact on radiation exposure will help mitigate health risks. While ^{226}Ra also requires monitoring, the focus should be slightly less stringent compared to ^{232}Th. Regular testing should ensure that levels remain within safe limits, and monitoring of ^{40}K should continue, though it should be a lower priority. Additionally, comprehensive studies are needed to gather more data on the presence and effects of these radionuclides in baby food. This study will inform updates and refinements to safety guidelines and permissible limits. Public health policies should focus on reducing exposure to high-risk radionuclides, particularly in regions with known contamination. Education efforts should be directed towards manufacturers and consumers to raise awareness of the risks associated with these radionuclides. International collaboration is also essential. Aligning local regulations with global standards and sharing findings with organizations like the WHO will contribute to a broader understanding and management of radionuclide contamination in baby food. Technological improvements in detection and purification processes during food production can further enhance safety.

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