World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

WJARR World Journal of Advanced Research and Reviews

(Review Article)

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Environmental pathways of radionuclide transfer in food chains in west Africa: Current knowledge and research gaps

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World Journal of Advanced Research and Reviews, 2026, 29(03), 749-760

Publication history: Received on 20 January 2026; revised on 06 March 2026; accepted on 06 March 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.3.0499

Abstract

Radionuclide transfer through food and water pathways remains an important but undercharacterized source of internal radiation exposure in West Africa. The region is influenced by both natural geological enrichment and anthropogenic activities such as mining, oil and gas operations, and fertilizer use, all of which can mobilize naturally occurring radionuclides into environmental media and subsequently into the human diet. This review synthesizes published evidence on the transfer of key radionuclides, including uranium series radionuclides, thorium series radionuclides, potassium-40, radium-226, radon-222, lead-210, and caesium-137, through major dietary pathways in West Africa, with specific attention to rice, cassava, fish, and potable water.

A structured literature review approach was applied using Scopus, Web of Science, PubMed, and the IAEA International Nuclear Information System, with studies from West African countries screened for relevance, methodological clarity, and reported activity concentrations in food and water matrices. The evidence indicates that potassium-40 is commonly the dominant contributor to measured activity concentrations, while radium-226, uranium isotopes, and radon-222 present more significant concern in mining influenced areas, granitic terrains, and other high-background settings. Available studies suggest substantial spatial variability, but the regional evidence base remains fragmented, with limited longitudinal monitoring, inconsistent analytical reporting, and insufficient integration of local dietary patterns into dose assessment.

The review identifies critical research gaps, including the need for locally derived soil-to-plant transfer factors, improved assessment of processing effects on staple foods, stronger groundwater surveillance, and national baseline monitoring frameworks. Strengthening these areas is necessary to support realistic exposure assessment, food safety regulation, and public health protection in West Africa.

Keywords: Environmental radioactivity; Radionuclide transfer; Food pathways; Internal exposure; West Africa; Research gaps

1. Introduction

The assessment of radiation exposure to human populations from natural and anthropogenic sources is a fundamental component of environmental health protection. Although external gamma exposure is commonly reported, ingestion of

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contaminated food and water is a major pathway of internal dose in the general population [1]. For this reason, food-chain transfer remains central to realistic environmental radiation assessment.

This review is situated in West Africa, where naturally occurring radionuclides and human activities such as mining, mineral processing, petroleum operations, and fertilizer use can influence radionuclide occurrence in soil, water, and sediment. However, evidence on transfer from these environmental compartments into commonly consumed foods and drinking water remains scattered across countries, matrices, and study designs.

The review focuses on the ingestion pathway and examines transfer of primordial radionuclides such as ^{238}U, ^{232}Th, and ^{40}K, together with relevant anthropogenic radionuclides where reported, into four matrices of direct public-health relevance: rice, cassava, fish, and potable water.

These matrices were selected because they represent major dietary staples or exposure media in the region and because they capture distinct transfer processes. Rice reflects flooded or intensively managed cultivation systems, cassava reflects direct soil-root interaction, fish reflects aquatic bioaccumulation, and drinking water reflects both groundwater and surface-water exposure.

The literature reviewed in this paper is heterogeneous in geographic coverage, analytical approach, and reporting depth, with many studies providing single-time-point measurements rather than sustained monitoring. This review therefore synthesizes the available evidence on radionuclide transfer through these pathways, identifies methodological and evidentiary gaps, and outlines priorities for stronger exposure assessment and radiation-protection decision making in West Africa.

2. Methodology

2.1. Literature Search Strategy

A structured literature review was conducted to identify studies reporting radionuclide activity concentrations, transfer-relevant measurements, or ingestion dose estimates for food and water matrices in West Africa. The primary databases searched were Scopus, Web of Science, and PubMed. To broaden coverage of regional technical reports and grey literature, the IAEA International Nuclear Information System (INIS) was also searched.

Search strings combined geographic terms such as "West Africa," "Nigeria," "Ghana," and "Ivory Coast" with radiological terms including "radionuclides," "natural radioactivity," "NORM," "uranium," and "thorium," together with matrix terms such as "food," "diet," "rice," "cassava," "fish," and "water," as summarized in Table 1. The search window covered January 2000 through December 2024.

Table 1 Search strategy and scope of the review

Parameter	Standardized description
Databases searched	Scopus, Web of Science, PubMed, and IAEA INIS
Search period	January 2000 to December 2024
Geographic scope	West Africa, focusing on ECOWAS member states
Target radionuclides	^{238}U, ^{232}Th, ^{40}K, ^{226}Ra, ^{222}Rn, ^{210}Pb, and ^{137}Cs
Target matrices	Rice, cassava, fish and seafood, and surface or groundwater

Note. INIS = International Nuclear Information System.

2.2. Study Selection and Screening

Records were screened first by title and abstract and then by full text where necessary. Studies were excluded if they focused only on external gamma dose rates without reporting activity concentrations or other ingestion-relevant metrics in food or water, were conducted outside West Africa, or did not describe sampling and analytical methods clearly enough for appraisal. Duplicate records were removed during screening.

2.3. Data Extraction

Data were extracted from selected articles using a standardized template (Table 2). The template captured the following variables:

- Study Location: Country, locality, and relevant geological or industrial setting (for example, mining, oil-producing, agricultural, or background area).
- Sample Characteristics: Matrix type, food item or water source, sample size where reported, and sample preparation method.
- Radionuclides: Isotopes measured in each study.
- Measurement: Analytical technique (for example, HPGe gamma spectrometry, NaI(Tl), RAD7, or alpha spectrometry), counting conditions where reported, and detection limits.
- Results: Reported activity concentrations (Bq/kg or Bq/L), summary statistics, and measurement uncertainty where available.
- Risk Assessment: Ingestion dose metrics and any reported excess lifetime cancer risk or related indices.

Table 2 Variables extracted from eligible studies

Variable	Operational definition
Study location	Country, locality, and relevant geological or industrial setting
Matrix or sample	Food item, aquatic organism, or water source analysed
Radionuclides measured	Nuclides reported in each study, for example ^{238}U, ^{232}Th, ^{40}K, ^{226}Ra, or ^{222}Rn
Activity concentration	Reported mean or range in Bq/kg or Bq/L, with matrix basis where stated
Analytical method	Detector or method used, including counting conditions where reported
Dose metric	Ingestion dose estimate, usually reported in mSv/year

Note. Bq = becquerel; L = litre.

2.4. Environmental Sources of Radionuclides in West Africa

2.4.1. Geological Sources

Natural radionuclide occurrence in West Africa is controlled primarily by local geology and weathering processes. Rocks and soils containing uranium, thorium, and potassium contribute to background environmental radioactivity, and weathering can redistribute these radionuclides into surrounding soils, sediments, and water. Within the reviewed literature, localized elevated natural radioactivity has been documented in mining environments in Ghana [2].

2.4.2. Anthropogenic Sources

Across the regional literature reviewed, anthropogenic mobilization is discussed mainly in relation to mining and mineral processing, petroleum activities, and intensive agricultural inputs.

Mining and mineral processing can enhance the redistribution of naturally occurring radioactive materials by disturbing overburden, exposing mineralized strata, and generating wastes such as tailings and contaminated runoff. In Ghana, elevated natural radioactivity has been reported in gold mining environments [2].

Oil and gas operations may also generate technologically enhanced naturally occurring radioactive material, particularly in produced water, scales, and sludges. In this manuscript, those pathways are treated as plausible regional sources, but the supporting evidence base within the reviewed West African food-chain literature is limited.

Agricultural inputs, especially phosphate fertilizers, can contribute additional radionuclide burdens to cultivated soils over time. However, the West African evidence synthesized in this review is stronger for transfer and exposure outcomes than for direct long-term field quantification of fertilizer-derived accumulation.

2.4.3. Environmental Transport Mechanisms

Radionuclides move from environmental sources to food and water through a sequence of release, transport, retention, and biological uptake processes. In terrestrial systems, soil-to-plant transfer depends on soil chemistry, mineral composition, moisture conditions, and crop physiology. In aquatic systems, radionuclides may partition between water and sediment, after which uptake can occur through direct absorption, sediment contact, or dietary transfer within the food web.

2.5. Radionuclide Transfer in Major Food Pathways

2.5.1. Rice Pathways

Rice (Oryza sativa) is a key staple food in West Africa and is widely cultivated in lowland environments such as seasonal wetlands, inland valleys, and river floodplains, where sustained water tables and sediment deposition favor production and nutrient accumulation [3-5]. These settings also create prolonged soil-water interaction in which radionuclides and other trace elements present in soil and water can be taken up by rice plants [6-9].

Available studies (Table 3) show that rice plants can accumulate ^{226}Ra, ^{232}Th, and ^{40}K in roots, straw, husk, and grains, with ^{40}K commonly dominant in the edible grain fraction [6-11]. Measurable activity concentrations in rice grain have been reported in pot, field, and market-based studies, and ingestion-dose assessments identify rice as a plausible contributor to internal exposure where consumption is high [6-11].

Flooded paddy conditions markedly alter soil redox potential and pH, driving reductive dissolution and shifts in contaminant speciation and bioavailability [12-16]. Under prolonged submergence, cadmium tends to become less bioavailable while arsenic can become more mobile, and drainage can reverse part of this pattern [12-16]. Although these studies focus mainly on trace metals rather than radionuclides, they remain relevant because the same flooding and drainage cycles help explain why paddy conditions can modify root-zone availability and transfer behavior in rice systems.

Fertilization practices further modify this system. Applications of NPK fertilizers can alter nutrient balance and soil chemistry and may influence the uptake of ^{226}Ra, ^{232}Th, and ^{40}K by rice plants [7,17]. Pot studies on naturally radioactive soils show that fertilizer formulation and application timing can significantly change radionuclide activities in rice grain, even when resulting ingestion doses remain within reported safety limits [7,10,17]. Market and field-based data from Nigeria also suggest that local geology and agricultural inputs may both contribute to the activity concentrations measured in rice [8-9].

Table 3 Summary of radionuclide transfer issues in rice systems

Aspect	Concise summary	References
Cultivation setting	Rice is widely cultivated in floodplains, wetlands, and irrigated lowlands in West Africa.	[3-5]
Activity in plant tissues	^{226}Ra, ^{232}Th, and ^{40}K have been reported in roots, straw, husk, and grain; ^{40}K is often dominant in edible grain.	[6-11]
Regional evidence	Studies from Nigeria report measurable radionuclide activities in field and market rice.	[8-9]
Flooding and redox	Flooding changes soil Eh and pH, which can alter element mobility and plant availability.	[12-16]
Water-regime analogue evidence	Flooding tends to reduce Cd uptake and increase As mobility; drainage can partly reverse this pattern.	[12,14-16]
Fertilizer effects	NPK formulation and application timing can modify radionuclide uptake in rice.	[7,10,17]

Note. Eh = redox potential.

2.5.2. Cassava Pathways

Cassava (Manihot esculenta) is a major staple root crop in West Africa, with individual studies noting its large dietary contribution and wide cultivation in Ghana and Nigeria [19,24,60]. As a root and tuber crop, cassava develops large storage roots within the soil profile, creating direct contact with soil matrices and potential uptake of naturally occurring radionuclides such as ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K from surrounding soils [18-27,51].

Soil-to-plant transfer studies from Nigeria and Ghana show that cassava roots can accumulate natural radionuclides, although reported transfer factors and activity concentrations vary markedly across sites [18-27,51]. Across the cited studies, that variability is linked to differences in local geology, mining or industrial influence, soil characteristics, and the specific radionuclides measured, rather than to a single uniform regional pattern [19-27,51,60]. Studies from mining-impacted, oil-producing, cement-affected, and coal-mining settings also report measurable cassava activities and dose or hazard estimates, indicating the potential for site-specific elevation where geogenic enrichment or industrial disturbance occurs [19-20,24-27,60].

Post-harvest and culinary processing can reduce non-radionuclide contaminants in cassava products. Peeling, fermentation, pressing, boiling, and drying have been shown to reduce cyanogenic compounds in traditional cassava foods, and one recent Ghana study also reported reductions in some heavy metals after boiling [28-31]. However, equivalent reduction factors for natural radionuclides through gari, fufu, and related processing chains remain poorly documented in the cited West African radioecological literature, because those studies mainly analyze raw or dried cassava roots rather than finished cassava foods [18-27,60]. This remains an important evidence gap for realistic ingestion dose assessment.

Table 4 Summary of radionuclide transfer issues in cassava systems

Aspect	**Concise summary**	**References**
Dietary importance	Cassava is a major staple root crop in Ghana and Nigeria and contributes substantially to household diets in many study settings.	[19,24,60]
Root-soil pathway	Storage roots remain in direct contact with soil and can take up natural radionuclides from surrounding matrices.	[18-27,51]
Site variability	Reported activity concentrations and transfer factors vary markedly across locations and study designs.	[18-27,51]
Geology and disturbance	Mining and other industrial settings can elevate cassava activities or dose indicators at specific sites.	[19-20,24-27,60]
Processing evidence	Peeling, fermentation, boiling, and drying reduce cyanogenic compounds and some non-radionuclide contaminants.	[28-31]
Radionuclide processing gap	Direct reduction factors for radionuclides in gari, fufu, and related products remain poorly documented.	[18-27,60]

Note. The evidence gap is strongest for processed cassava foods actually consumed by households.

2.6. Fish and Aquatic Food Chains

Aquatic ecosystems in West Africa, particularly the Gulf of Guinea and major river systems like the Niger and Volta, are recipients of industrial effluent and mining runoff. Fish species exhibit varying bioaccumulation factors, as shown in Table 5. Benthic species (e.g., Catfish) typically show higher concentrations of ^{226}Ra and ^{238}U compared to pelagic species due to interaction with sediments. ^{210}Po is also a critical radionuclide in marine seafood, though often under-reported in regional studies.

Table 5 Representative radionuclide patterns in fish and aquatic food chains

Representative group	**Habitat or pathway**	**Radionuclides commonly highlighted**	**Summary pattern**
Tilapia	Freshwater	^{40}K, ^{226}Ra	Usually reflects freshwater background conditions, with site-specific variation.
Catfish	Benthic freshwater	^{226}Ra, ^{232}Th	Sediment interaction can increase exposure relative to pelagic feeders.
Marine pelagic fish, for example mackerel	Marine water column	^{40}K; ^{210}Po where measured	Natural ^{40}K is often prominent, while ^{210}Po remains underreported in regional studies.

Note. This table is qualitative because the reviewed studies were not sufficiently standardized to support a single comparable concentration range.

2.7. Drinking Water and Irrigation Water

Groundwater supplied through wells and boreholes is an important drinking-water source in many West African settings. Radon-222 (^{222}Rn), a radioactive noble gas generated from the decay of radium-226 in uranium-bearing rocks and soils, can dissolve into groundwater and reach elevated concentrations in confined, fractured, or granitic aquifers [33-39].

Investigations in Ghana and Nigeria show that some borehole and groundwater sources in mining or granitic terrains contain elevated ^{222}Rn concentrations, in some cases above drinking-water screening or reference values used for radiological assessment [33-38]. Surface waters are generally lower because radon degasses rapidly during groundwater discharge and mixing, although short-term temporal variability can still occur [39]. These findings point to the need for targeted surveillance of groundwater sources in structurally controlled and mining-affected areas.

3. Factors influencing radionuclide transfer in West Africa environment

Radionuclide transfer in agro-ecosystems is highly heterogeneous and controlled by interacting soil, climatic, and management factors, Table 6 [46-49]. These controls modify radionuclide speciation, mobility, and bioavailability, and thus the soil-to-plant transfer factor and subsequent entry into food chains [46-48].

3.1.1. Soil properties

Many tropical soils are acidic, and low pH generally enhances the solubility and mobility of uranium (U) and related radionuclides, increasing their availability for plant uptake and leaching [50-53]. In contrast, organic-matter-rich or humic soils can strongly complex U and other radionuclides, creating relatively stable organo-metal complexes that immobilize U(VI) and reduce its immediate bioavailability, sometimes over long-time scales [51, 54-56]. However, some studies also show that dissolved or colloidal organic matter can, under certain conditions, increase U mobility by promoting desorption from mineral surfaces and transport in the aqueous or colloidal phase [51, 55-56].

3.1.2. Climate and hydrology

Seasonal patterns in rainfall, evapotranspiration, and water-table dynamics strongly affect radionuclide redistribution. High rainfall enhances leaching of U and Ra into deeper soil horizons and groundwater, especially in sandy or low-CEC soils [48, 53]. Intense storm events can mobilize radionuclide-bearing particles and colloids from mine tailings and agricultural fields into rivers and reservoirs, analogous to “first-flush” behavior observed for other contaminants [49, 51, 53]. Conversely, drought and seasonal drying concentrate dissolved radionuclides in shrinking surface waters and can promote re-oxidation and remobilisation of previously reduced U phases [49, 51, 55].

3.1.3. Agricultural practices

Table 6 Environmental factors influencing radionuclide transfer in West African agro-ecosystems

Factor	Main mechanism	Likely effect on transfer	References
Acidic soil pH	Changes solubility and speciation of U and related radionuclides.	Greater mobility, plant availability, and leaching potential.	[50-53]
Soil organic matter	Promotes complexation, sorption, and colloid formation.	Often immobilizes U, although dissolved organic matter can enhance mobility under some conditions.	[51,54-56]
Rainfall and hydrology	Drives leaching, runoff, fluctuating water tables, and concentration effects.	High rainfall enhances redistribution; drought can concentrate dissolved radionuclides.	[48,49,51,53,55]
Phosphate fertilizers	Add U-bearing material to cultivated soils over time.	Can increase soil loading and uptake potential in intensively managed systems.	[46,48,53,57]
Crop management and processing	Tillage, crop type, root depth, peeling, washing, and milling alter transfer to edible tissues.	Can change radionuclide entry to food and reduce ingested activity in some products.	[46-48,58-60]

Note. U = uranium.

Long-term application of phosphate fertilizers is a well-documented source of U and, to a lesser extent, Th in agricultural soils, leading to measurable enrichment and plant uptake, especially in intensively fertilized systems [46, 48, 53, 57]. Soil management (tillage, crop type, root depth) further modulates soil-to-plant transfer by altering root distribution, soil structure, and nutrient competition effects [46-48, 58-59]. Post-harvest processing steps (e.g., peeling, washing, milling) can partially remove radionuclides associated with outer tissues and soil particles, thereby reducing ingested dose, although quantitative reduction factors are still sparse for West African foods [59-60].

3.2. Radiological risk assessment approaches used in literature

The standard methodology for assessing risk in West African studies aligns with international protocols, yet variations exist.

3.2.1. Annual Effective Dose (AED)

Most studies calculate AED using activity concentrations and average annual consumption rates. A critical limitation is the reliance on generic consumption data (e.g., UNSCEAR or FAO regional averages) rather than local dietary surveys, potentially skewing dose estimates.

3.2.2. Dose Coefficients

Studies predominantly use ICRP dose conversion factors.

3.2.3. Hazard Indices

Radium Equivalent Activity (Raeq) and Excess Lifetime Cancer Risk (ELCR) are commonly reported.

A significant methodological critique is the widespread use of default Transfer Factors (TFs) from temperate zones (IAEA TRS-472) to model risk when local measurement data is missing. Given the distinct lateritic and tropical soil types in West Africa, default TFs may not accurately predict uptake.

3.3. Current Knowledge Gaps and Research Needs

Despite the growing body of literature, critical gaps persist, Table 7:

- Site-Specific Transfer Factors (TFs): There is a paucity of derived TFs for tropical crops (yam, cassava, local rice varieties) grown in West African soils.
- Longitudinal Data: Most studies are cross-sectional. There is a lack of time-series data covering seasonal variations (wet vs. dry season).
- Processing Factors: Few studies quantify the reduction of radioactivity during traditional food processing (e.g., fermentation of cassava into Gari).
- Polonium-210 Data: While ^{210}Po is a major contributor to ingestion dose from seafood, it is rarely analyzed in the region due to the complexity of alpha spectrometry.

Table 7 Main knowledge gaps identified in the reviewed literature

Gap area	Description	Priority for future work
Data coverage	Limited data on ^{210}Po and ^{210}Pb in diet and aquatic foods.	High
Transfer modelling	Lack of site-specific transfer factors for West African conditions.	High
Dose assessment	Reliance on generic consumption rates instead of local diet surveys.	Medium
Food preparation	Few studies compare processed foods with raw foods.	Medium

Note. Priority reflects the likely value of the gap area for improving realistic ingestion-dose assessment.

4. Implications for radiation protection and public health

Radionuclide exposure from food and water in much of West Africa appears heterogeneous rather than uniformly high. Several studies on staple foods and other commonly consumed products report annual ingestion doses that remain within commonly used public dose reference levels, suggesting low to moderate radiological risk for the general population under routine conditions [8,52-55]. At the same time, investigations in mining-impacted or high-background settings report elevated doses or activity concentrations in drinking water and locally grown foods, showing that localized hotspots can depart substantially from regional averages [56-57,60,62-63]. This contrast indicates that broad regional reassurance should not replace site-specific surveillance in geologically mineralized or industrially disturbed areas [56-57,60,62-63].

Strengthening radiation protection therefore depends on competent national systems, clear institutional responsibilities, trained personnel, and routine surveillance rather than ad hoc measurements alone [64,66-67]. The available regulatory and professional literature from Ghana and Nigeria emphasizes the importance of integrated safety management, inspection capacity, quality systems, and sustained attention to radiation protection across sectors [64-67]. For food and environmental exposure pathways, these same system-level capacities are necessary to support sampling programmes, laboratory oversight, risk communication, and timely regulatory response when elevated radionuclide levels are identified [64,66-67].

A key priority is the development of national screening or reference levels for radionuclides in staple foods and potable water that are interpreted alongside local geology and consumption patterns, rather than through generic global assumptions alone [8,38,52-55]. Evidence from cereals, tubers, sugar, and mixed food products shows substantial variability in measured activity concentrations and estimated ingestion doses, which supports the use of country-specific intake data when translating activity measurements into realistic dose assessments [8,52-55]. Embedding such benchmarks within routine surveillance and public-health guidance would improve hotspot identification and strengthen protection of communities in mining and other high-background settings [38,56-57,60,62-63].

Table 8 Public health and regulatory implications of the reviewed evidence

Aspect	**Concise implication**	**References**
Non-hotspot exposure	Many reviewed studies report annual ingestion doses within commonly used public reference levels.	[8,52-55]
Potential hotspots	Mining-affected water and locally grown foods can show elevated activities or dose indicators at specific sites.	[56-57,60,62-63]
Institutional capacity	Effective surveillance depends on competent institutions, inspection capacity, laboratory quality systems, and trained personnel.	[64,66-67]
Routine monitoring	Food and environmental pathways require structured sampling, laboratory oversight, and risk communication.	[64,66-67]
National screening approach	Screening levels for food and drinking water should reflect local diet and geology.	[8,38,52-55]

Note. These implications summarize the reviewed evidence and the manuscript's final synthesis.

5. Conclusions

This review highlights that environmental transfer of radionuclides in West Africa is driven by a combination of unique geological baselines and intensifying anthropogenic activities. Food pathways, specifically rice, cassava, and fish, act as significant vectors for internal exposure. While ^{40}K remains the dominant contributor to activity concentration, the presence of ^{226}Ra and uranium isotopes in mining-impacted areas raises public health concerns.

The current literature provides a solid baseline but is limited by fragmented geographic coverage and a reliance on generic transfer models. Groundwater radon concentrations in granitic regions pose a distinct and potentially underestimated risk.

To ensure robust public safety, future efforts must move beyond basic concentration surveys to comprehensive risk modeling that incorporates local dietary habits, seasonal variability, and specific soil-to-plant transfer mechanics characteristic of tropical environments.

5.1. Recommendations for Future Research

To address the identified gaps, the following actions are recommended:

- Establishment of national-scale sampling programs to establish radiological baselines for key staples, distinguishing between background and industrial impact zones.
- Research should focus on experimentally deriving Soil-to-Plant Transfer Factors (TFs) for West African soil types to replace reliance on temperate zone defaults.
- Future radiological studies should be coupled with local dietary recall surveys to improve the accuracy of Annual Effective Dose (AED) calculations.
- Investigate the efficacy of traditional cooking and processing methods in reducing radionuclide content in ready-to-eat foods.

Compliance with ethical standards

Acknowledgments

The authors acknowledge all researchers whose published work contributed to this review.

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Authors' Contributions

Henry Lawluvi conceived the review topic and study design, conducted the literature search and screening, extracted, organized, and synthesized the data, and drafted the manuscript. Bernard Boahene Akuamoah Boateng, Emmanuel Nyankah, Ernest Sanyare Warmann Beinpuo, Nelson Agbemava, Etornam Ann Mensah, Kwame Appiah, Cyril Cyrus Arwui, and Emmanuel Akrobortu contributed to interpretation of the evidence, critically revised the manuscript for intellectual content, and approved the final version. All authors read and approved the final manuscript.

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