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Assessment of Potassium Bromate Levels and Dietary Health Risk in Commonly Consumed Breads in Ijebu-Ode, Ogun State, Nigeria

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Abstract

The continued use of potassium bromate as a dough improver in bread production is often driven by its technological advantages, including enhanced loaf volume and improved texture; however, its potential adverse health effects remain a major public health concern. In addition, contamination of bread with heavy metals may further compromise consumer safety. This study therefore quantified potassium bromate and selected heavy metals (Pb, Cd, Cr, Ni, Fe, and Zn) in commercial bread samples and evaluated associated dietary risks. Potassium bromate concentrations ranged from 1.52 ± 0.64 to 22.38 ± 0.98 mg/kg (mean: 9.35 ± 0.58 mg/kg), with 100% exceedance of the maximum permissible limit established by the World Health Organization and Food and Agriculture Organization. Heavy metals (mg/kg, mean ± SD) were: Pb (0.11 ± 0.052), Cd (0.04 ± 0.020), Cr (0.17 ± 0.060), Ni (0.12 ± 0.051), Fe (20.55 ± 5.42), and Zn (10.75 ± 2.70). Hazard Index values ranged from 0.062–0.197 (adults) and 0.291–0.923 (children). Although heavy metal exposure remained within non-carcinogenic safety thresholds (HI < 1), the widespread occurrence of potassium bromate classified as a possible human carcinogen by the International Agency for Research on Cancer indicates significant regulatory non-compliance and potential long-term health risks.

Keywords: $KBrO_3$; Heavy metals; Bread contamination; Dietary risk assessment; Hazard index.

INTRODUCTION

Bread is a widely consumed staple in Nigeria, including Ijebu-Ode, and constitutes a major dietary source of carbohydrates and energy. Potassium bromate ($KBrO_3$), used to improve dough strength and loaf volume, is classified as a possible human carcinogen and may induce oxidative stress, nephrotoxicity, and thyroid dysfunction when residual levels are ingested (Omotoso, 2021). Although banned in Nigeria, bromate residues continue to be reported in bread. Airaodion et al. (2019) found that all 30 samples analyzed in Ibadan exceeded permissible limits, while Naze et al. (2018) documented excessive levels in Port Harcourt. Similarly, Adeoye et al. (2025) reported widespread non-compliance in Ogbomoso, whereas Abbas et al. (2024) observed compliance in some samples from Azare, indicating regional variability.

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Beyond bromate, heavy metal contamination of bread represents an additional public health concern. Metals such as Pb, Cd, Cr, Ni, Fe, and Zn can be introduced into the food chain via contaminated soils, fertilizers, irrigation water, atmospheric deposition, and processing equipment (Angon et al., 2024). These elements are persistent and bioaccumulative, with chronic exposure to Pb and Cd linked to neurodevelopmental impairment, renal dysfunction, immunotoxicity, and cardiovascular effects (Uddin et al., 2021). Roadside vending and open-air marketing may further promote atmospheric deposition of metals onto bread surfaces, while milling and baking equipment can contribute trace contamination (Boahen, 2024). Nigerian market surveys have confirmed the presence of multiple metals in bread, occasionally exceeding regulatory limits (Olusola et al., 2024).

Given the potential co-occurrence of banned additives and toxic metals in a highly consumed staple food, comprehensive safety assessment requires quantitative risk characterization rather than mere detection. Dietary risk metrics such as Estimated Daily Intake (EDI), Hazard Quotient (HQ), and Hazard Index (HI) integrate contaminant concentrations with exposure parameters to evaluate potential health risks. However, most previous studies have examined isolated contaminants, and regional variability underscores the need for localized, integrated assessments.

Accordingly, this study aimed to determine residual potassium bromate and selected heavy metals (Pb, Cd, Cr, Ni, Fe, and Zn) in commonly consumed bread samples in Ijebu-Ode, Ogun State, Nigeria, and to evaluate potential health risks for adult and child consumers using established dietary risk assessment models.

MATERIALS AND METHODS

Study Area and Sample Collection

The sample size of ten (n = 10) was selected to represent commonly consumed bread brands available within the study area. Sampling was designed to capture variability across different production sources, including major bakeries and frequently consumed commercial brands. Samples were placed in clean, labeled polyethylene bags, transported to the laboratory, and stored at 4 °C until analysis.

Chemicals, Reagents and Standards

Potassium bromate standard (analytical grade, ≥99% purity), Nitric acid (HNO_3), acetic acid, hydrochloric acid (HCl), sodium thiosulfate, and starch indicator (analytical grade), Certified AAS standard solutions for lead (Pb), Cadmium (Cd) Chromium (Cr), Nickel (Ni), Ion (Fe) and Zinc (Zn), Deionized water for all dilutions and reagent preparation. All reagents were of analytical grade and prepared in glassware washed with deionized water before use.

Qualitative and Quantitative Determination of Potassium Bromate

Potassium bromate in the bread samples was qualitatively and quantitatively determined using a previously reported method (Adebiyi et al., 2022) with slight modifications. Briefly, 1.0 g of each homogenized bread sample was accurately weighed using an analytical balance and transferred into a clean test tube. Ten millilitres (10 mL) of distilled water were added, and the mixture was vigorously shaken to facilitate extraction. The suspension was allowed to stand for 20 min at room temperature (28 ± 2°C) and subsequently filtered to obtain a clear extract.

An aliquot (5.0 mL) of the filtrate was transferred into a separate test tube, followed by the addition of 5.0 mL of freshly prepared 0.5% (w/v) potassium iodide (KI) solution in 0.1 M hydrochloric acid (HCl). Subsequently, 1.0 mL of freshly prepared 1% (w/v) soluble starch indicator solution was added. In the presence of potassium bromate, iodide ions are oxidized to iodine in acidic medium according to the reaction in Eq 1

$BrO_3^- + 6I^- + 6H^+ \rightarrow Br^- + 3I_2 + 3H_2O$ (1)

The liberated iodine forms a blue–purple complex with starch, indicating the presence of potassium bromate. For quantitative determination, the absorbance of the iodine–starch complex was measured at 620 nm using a UV–Visible spectrophotometer (Shimadzu UV-1800, Shimadzu Corporation, Japan) at the Department of Chemical Sciences, Tai Solarin Federal University of Education, Ijagun, Ogun State, Nigeria. Potassium bromate concentrations were calculated from a calibration curve constructed using standard potassium bromate solutions treated under identical experimental conditions. All analyses were performed in triplicate.

Determination of Heavy Metals by Atomic Absorption Spectroscopy (AAS)

The concentrations of Pb, Cd, Cr, Ni, Fe, and Zn were determined using an Air–Acetylene Flame Atomic Absorption Spectrophotometer (Buck Scientific 210VGP, East Norwalk, CT, USA) equipped with hollow cathode lamps for each metal. The slit width was set at 0.7 nm, and wavelengths of 283.30 nm (Pb), 228.80 nm (Cd), 357.90 nm (Cr), 232.00 nm (Ni), 248.30 nm (Fe), and 213.90 nm (Zn) were used. The instrument was calibrated with standard solutions, and all measurements were performed in triplicate.

Sample Preparation

The method of Joseph & David (2024) was adopted for sample preparation and analysis for AAS determination of heavy metals in bread. Briefly, 5 g of each sample was oven-dried at 60–70 °C to constant weight, ground to a fine powder, and transferred to a digestion flask. Ten milliliters of concentrated nitric acid (HNO_3) was added, and the mixture was heated gently on a hot plate until complete digestion (clear solution) was achieved. After cooling, the digests were filtered and diluted to 50 mL with deionized water prior to analysis.

Atomic Absorption Spectrophotometry (AAS) Analysis

A calibrated AAS was used with element-specific hollow-cathode lamps. Operational wavelengths and conditions followed manufacturer guidelines and typical values for Pb, Cr, Ni, Cd, Fe and Zn in food analysis (Omeje et al., 2021). Calibration curves were prepared using certified standards for each metal. Sample absorbance values were measured and concentrations calculated from the calibration curves. This approach aligns with established analytical practices for heavy metals in food matrices using AAS.

Health Risk Assessment

The health risk assessment was carried out to evaluate potential health risks associated with the consumption of potassium bromate and heavy metals in bread. Risk was quantified using Estimated Daily Intake (EDI) and Hazard Quotient (HQ).

Estimation of daily intake (EDI)

The estimation of daily potassium bromate ($KBrO_3$) intake was based on the measured concentration of $KBrO_3$ in bread samples, the average daily consumption rate of bread, and the mean body weights of adults and children in Ijebu Ode, Ogun state, Nigeria. These parameters were used to assess potential exposure levels and acceptable contamination thresholds. The EDI was calculated according to the standard risk assessment model adopted in this study Eq. 2.

$$EDI = \frac{(C \times D)}{BW} \quad (2)$$

where:
C = average concentration of contaminants in bread measured in mg/kg, D = Average daily bread intake (kg/day) and BW = Average body weight per individual for both Adults and Children (kg). Based on previous reports, the average daily bread consumption was estimated at 0.1 kg for children and 0.2 kg for adults as adapted with slight modifications from Nkwatoh et al. (2023) and Olusola et al. (2021). The mean body weights of Nigerian children and adults

were assumed to be 15 kg and 70 kg, respectively as adapted with slight modifications in weights from Olusola et al. (2021) and Adebiyi et al. (2022). The EDI of potassium bromate and heavy metals were calculated using the mean concentration (mg/kg) detected in the analyzed bread samples and the standard exposure assessment model adopted in this study.

Hazard Quotient (HQ)

To evaluate the potential non-carcinogenic health risks associated with dietary exposure to $KBrO_3$ and heavy metals in the analysed bread samples, the hazard quotient (HQ) approach was applied. Specifically, the chronic hazard quotient (cHQ) was calculated using Eq. 3

$$CHQ = \frac{EDI}{ADI} \tag{3}$$

With ADIs based on FAO/WHO guidelines
Where, EDI represent the daily intake through ingestion (mg/kg/day). ADI is the acceptable daily intake (mg/kg/day). For the present study, an acceptable daily intake (ADI) value of 0.02 mg/kg body weight for potassium bromate in bread was adopted, in accordance with the recommendations of the U.S. Food and Drug Administration and relevant regulatory guidelines (Olusola et al., 2020). This reference value was subsequently used to estimate the chronic health risk associated with $KBrO_3$ exposure from the analyzed bread samples. Table 1 showed the recommended maximum daily intake for each contaminant (mg/kg/day) of heavy metals.

Table 1. The ADI of heavy metals analysed.

Contaminant	ADI (mg/kg/day)	Reference
Lead (Pb)	0.0035	WHO, 2011
Cadmium (Cd)	0.001	EFSA, 2009
Chromium (Cr)	0.0030	USEPA, 2022
Nickel (Ni)	0.013	EFSA, 2020
Iron (Fe)	0.8	IOM UL (2001)
Zinc (Zn)	0.30	FAO/WHO, 2011

Hazard Index (HI)

The Hazard Index (HI) was calculated using Eq 4 to evaluate the combined non-carcinogenic risk from individual contaminants i.e. potassium bromate and heavy metals.

$$HI = \sum HQi \tag{4}$$

where: HQ_i = Hazard quotient for each contaminant

Quality Control and Data Analysis

The quality control procedures in the present study involved recovery analysis. Recovery was assessed by spiking pre-analyzed bread samples with known concentrations of potassium bromate (20, 60, and 100 ppm). The percentage recovery was calculated using Eq. 5

$$\%\ \text{recovery} = \frac{\text{Detected} - \text{Original}}{\text{Spiked}} \times \frac{100}{1} \tag{5}$$

Sensitivity of the analytical instrument was determined in terms of Limit of detection (LOD) and quantification (LOQ) using Eq. 6 and 7 respectively

$$LOD = \frac{3.3\sigma}{S} \tag{6}$$

$$LOQ = \frac{10\sigma}{S} \tag{7}$$

where: σ = standard deviation of the response (blank) and S = slope of the calibration curve

Statistical Analysis

All analyses were performed in triplicate with reagent blanks and quality controls. Calibration curves exhibited correlation coefficients (R^2) ≥0.995 for all analytes. Results were expressed as mean ± standard deviation (SD).

RESULTS AND DISCUSSION

Validation of the spectrophotometry procedure

Table 2 displays validation parameters of the UV–Visible Method for Potassium Bromate Determination from the study area, whose reliability was assessed using sensitivity (LOD and LOQ) and accuracy (recovery). The calibration curve exhibited good linearity over the concentration range of 10 – 80.0 mg/L, with a regression equation of y = 0.0045C + 0.0694 and a coefficient of determination (R^2 = 0.9974), indicating excellent correlation between absorbance and bromate concentration. The high R^2 value satisfies ICH acceptance criteria ($R^2 \geq$ 0.995), confirming the suitability of the method within the studied range. The calculated LOD and LOQ were 0.00019 mg/kg and 0.0042 mg/kg, respectively, demonstrating adequate sensitivity for detecting bromate at concentrations relevant to regulatory limits. The low LOD indicates the method is capable of detecting trace levels of bromate in bread matrices. Recovery values ranged from 94.20% to 103.50%, indicating satisfactory accuracy and minimal matrix interference from bread components. The recovery results fall within the acceptable range of 80–120% recommended for food contaminant analysis.

Table 2. Validation Parameters of the UV–Vis Method for Potassium Bromate Determination.

Parameter	Result	Acceptance Criteria	Status
Linearity Range	10 –80.00 mg/L	—	Acceptable
Regression Equation	A = 0.0045C + 0.0694	—	—
R^2	0.9974	≥ 0.995	Pass
LOD	0.12 mg/L	—	Adequate
LOQ	0.36 mg/L	—	Adequate
Recovery	94.20–103.50%	80–120%	Pass

Qualitative Determination of Potassium Bromate in Bread Samples

As shown in Table 3. Qualitative screening of potassium bromate in the ten bread samples (A–J) using potassium iodide (KI) reagent showed positive reactions in all samples. The appearance of purple coloration ranging from light purple (Samples A, I, and J) to dark purple (Sample B), while others showed distinct purple coloration confirms the presence of residual potassium bromate in 100% of the analyzed samples. Variation in colour intensity suggests differences in bromate concentration, which were subsequently evaluated quantitatively.

The persistence of potassium bromate in finished bread products is of regulatory and public health concern because, under appropriate baking conditions, bromate is expected to be fully reduced to bromide. Its detection therefore indicates possible excessive addition, insufficient baking temperature or duration, or poor adherence to Good Manufacturing Practices. The use of potassium bromate in bread production has been banned by the National Agency for Food and Drug Administration and Control, and international food safety authorities such as the World Health Organization discourage its presence in finished bakery products due to its toxicological implications. The findings of this study are consistent with previous reports. Magomya et al. (2020) reported widespread detection of potassium bromate in bread samples marketed in Jalingo, with several samples testing positive despite regulatory restrictions. Similarly, Airaodion et al. (2019) documented detectable levels of bromate in commercial bread from Ogbomoso, indicating continued usage. Internationally, In Baghdad, Abdullah et al. (2025) also reported high detection frequencies in locally produced bread. The 100% positivity rate observed in the present study aligns with these earlier findings and suggests persistent non-compliance in the study area.

Table 3. Qualitative and quantitative determination of potassium bromate in the samples.

s/no	Sample	Qualitative analysis Bread samples colour reactions with KI	Quantitative Analysis (mg/kg)
1	Sample A	light purple	3.23 ± 0.89
2	Sample B	Dark purple	22.38 ± 0.98
3	Sample C	Purple	10.69 ± 1.20
4	Sample D	Purple	6.74 ± 0.24
5	Sample E	Purple	7.18 ± 0.74
6	Sample F	Purple	10.87 ± 0.62
7	Sample G	Purple	12.74 ± 0.20
8	Sample H	Purple	14.55 ± 0.19
9	Sample I	Light purple	1.52 ± 0.64
10	Sample J	Light purple	3.58 ± 0.12

Quantitative Determination of Potassium Bromate in Bread Samples

The concentrations of potassium bromate in the analysed bread samples are presented in Table 3. Bromate levels ranged from 1.52 ± 0.64 to 22.38 ± 0.98 mg/kg, with a mean concentration of 9.35 ± 0.58 mg/kg. Sample B recorded the highest concentration (22.38 ± 0.98 mg/kg), while Sample I had the lowest level (1.52 ± 0.64 mg/kg). Notably, 70% of the samples contained bromate concentrations above 5 mg/kg, and 40% exceeded 10 mg/kg. According to the World Health Organization, potassium bromate is classified as a food contaminant of toxicological concern, and its presence in finished bakery products is discouraged due to carcinogenic risk (WHO, 2016). The United States Food and Drug Administration previously permitted potassium bromate in flour at concentrations not exceeding 75 mg/kg of flour during dough preparation (21 CFR §136.110), provided that it is completely reduced during baking and leaves no detectable residue in the final product (USFDA, 2023).

In Nigeria, the National Agency for Food and Drug Administration and Control officially banned the use of potassium bromate in flour and bread production in 2003, implying that the acceptable level in finished bread is zero tolerance (NAFDAC, 2003).

Therefore, under current Nigerian regulation and international safety recommendations, potassium bromate should not be detectable in bread. The detection of 1.52–22.38 mg/kg in all samples analysed in this study indicates clear non-compliance with national regulatory standards.

The concentrations observed in this study fall within the range reported in other developing countries. For example, Magoiga et al. (2025) reported bromate levels up to 18 mg/kg in Tanzanian bread samples, while a study conducted in Iraq reported concentrations reaching 29.78 mg/kg in commercial bread (Hama et al., 2022). The maximum concentration detected in the present study (22.38 mg/kg) is therefore comparable to the upper range reported internationally. Moreover, studies in Nigeria and other countries have consistently reported the presence of potassium bromate in commercial bread despite bans and regulatory efforts; a comprehensive review revealed that a majority of bread sold in Nigeria contained residual bromate above safe limits, suggesting ongoing non-compliance and potential consumer exposure risks (Omotoso, 2021). These findings corroborate the present study's result that all bread samples exhibited positive bromate reactions, underscoring the persistence of bromate use in bread production and the need for continued surveillance and enforcement.

Dietary Risk Assessment of Potassium Bromate in Bread: Estimated Daily Intake (EDI)

The result of EDI values ranged from 0.00434 to 0.06394 mg/kg/day for adults and 0.01013 to 0.14920 mg/kg/day for children (Table 4). These values indicate that dietary exposure via bread is non-negligible and substantially higher in children. Although international agencies such as the World Health Organization have not established a formal Acceptable Daily Intake (ADI) for potassium bromate due to its carcinogenic classification, they emphasize that exposure should be minimized because of documented toxic effects, including oxidative stress and potential carcinogenicity in renal tissues of experimental animals (WHO, 2016). Regulatory frameworks in various countries therefore adopt a zero-tolerance policy by expecting undetectable bromate residues in finished products (USFDA, 2023; NAFDAC, 2003).

Comparative studies show similar exposure concerns. For example, Magoiga et al. (2025) reported EDI estimates for potassium bromate in Tanzanian bread consumption that exceeded safe exposure benchmarks, particularly in children. Likewise, Iraqi studies have demonstrated elevated bromate intake in bread consumers, with children again showing disproportionately high exposure compared to adults (Hama et al., 2022). The consistently higher EDI values in children across these studies reflect a common pattern in dietary risk assessments for food contaminants, highlighting their increased vulnerability.

Table 4. Dietary Exposure and Non-Carcinogenic Risk of Potassium Bromate in Bread.

Sample	Bromate (mg/kg)	EDI Adults (mg/kg/day)	HQ Adults	EDI Children (mg/kg/day)	HQ Children
A	3.23	9.23×10^{-3}	2.31	2.15×10^{-2}	5.38
B	22.38	6.39×10^{-2}	15.99	1.49×10^{-1}	37.30
C	10.69	3.05×10^{-2}	7.64	7.13×10^{-2}	17.82
D	6.74	1.93×10^{-2}	4.82	4.49×10^{-2}	11.23
E	7.18	2.05×10^{-2}	5.13	4.79×10^{-2}	11.97
F	10.87	3.11×10^{-2}	7.77	7.25×10^{-2}	18.12
G	12.74	3.64×10^{-2}	9.10	8.49×10^{-2}	21.23
H	14.55	4.16×10^{-2}	10.39	9.70×10^{-2}	24.25
I	1.52	4.34×10^{-3}	1.09	1.01×10^{-2}	2.53
J	3.58	1.02×10^{-2}	2.56	2.39×10^{-2}	5.97

Hazard Quotient (HQ)

The Hazard Quotient (HQ) quantifies non-carcinogenic risk by comparing EDI with an oral reference dose (RfD). The calculated HQ values ranged from 1.09 to 15.99 for adults and 2.53 to 37.30 for children (Table 4). An HQ value greater than 1 signals potential health risk. Consistent with previous investigations, Sample B produced the highest HQ in both population groups, indicating that bread containing higher bromate levels poses significantly elevated risk. Elevated HQ in children is also in agreement with dietary exposure assessments for contaminants such as acrylamide and heavy metals, which demonstrate greater risk in children due to higher intake-to-body-weight ratios (Wang et al., 2020).

Comparable risk assessments in other regions reinforce these findings. Magoiga et al. (2025) observed HQ values exceeding unity for potassium bromate in Tanzanian bread consumers, especially among children. Similarly, risk assessment studies from Iraq reported HQs above safe limits, underscoring meaningful non-carcinogenic risk. These parallels suggest that bromate misuse in bread production, and resulting elevated HQ values, remains a concern in areas where regulatory enforcement is limited or compliance is poor.

Hazard Index (HI)

The Hazard Index (HI) integrates multiple HQ values into a cumulative risk metric. The calculated HI values were Adults 6.68 and Children 15.58. Both values greatly exceed the safety threshold of 1, indicating that chronic consumption of contaminated bread may present significant non-carcinogenic health risk. The HI values align with previous bromate risk assessments documented in developing countries. For instance, combined exposure metrics in the Tanzanian study yielded HI values above acceptable limits for both age groups, and stronger effects were observed in children (Magoiga et al., 2025). These consistencies strengthen the interpretation that bromate contamination in staple foods can result in cumulative health risk well above safe expectations.

Heavy Metal Contamination in Bread Samples

The concentrations of Pb, Cd, Cr, Ni, Fe, and Zn investigated in the analysed bread samples are presented in Table 5. Variations in trace elements were observed across all bread samples. Fe exhibited the highest mean concentration (20.55 ± 5.42 mg/kg) in bread sample, while Cd showed the lowest trace element concentration of 0.040 ±0.020 mg/kg. The standard deviation which is a measure of precision was observed to be relatively low for all the investigated trace metals in the bread samples (SD < 6). This indicated that there was no significant deviation in the concentration of the trace metals in the bread samples.

As shown in Table 5, lead (Pb) concentrations in the bread samples ranged from 0.00020 to 0.21 mg/kg, with a mean value of 0.11 ± 0.052 mg/kg. The observed Pb levels exceeded the FAO/WHO permissible limit of 0.025 mg/kg for food (FAO/WHO, 1993). Compared with previous studies, the Pb concentrations reported in this study were lower than those documented by Olusola et al. (2025) but higher than the values reported by Adebiyi et al. (2022). Such variations may be attributed to differences in environmental conditions, sampling locations, bread production practices, and analytical methodologies. Furthermore, the mean Pb concentration (0.11 mg/kg) obtained in this study is slightly higher than the 0.08 mg/kg reported by Ibeto et al. (2011) for bread samples from southeastern Nigeria, but comparable to the 0.12 mg/kg reported by Orisakwe et al. (2012) in roadside food products. The relatively elevated Pb levels, particularly in samples obtained from roadside vendors, may be associated with atmospheric deposition from vehicular emissions, resuspended road dust, and industrial particulates. Although leaded gasoline has been largely phased out, legacy contamination of urban soils, along with ongoing emissions from brake linings and tire wear, remains a significant source of environmental lead (WHO, 2011). Consequently, roadside exposure increases the likelihood of heavy metal deposition on unpackaged food items. From a toxicological perspective, even low levels of lead exposure can adversely affect human health. In children, chronic exposure has been linked to impaired neurological development, reduced intelligence quotient (IQ), and growth abnormalities, while in adults it may contribute to hypertension and other cardiovascular disorders (Roberts et al., 2022). Moreover, lead exposure in pregnant women is of particular concern due to its ability to cross the placental barrier, potentially affecting fetal development (Olusola et al., 2024).

The concentration of Ni in the bread samples ranged from 0.040 to 0.19 mg/kg, averaging 0.12±0.051 mg/kg. These values are within the permissible limit set by FAO/WHO of 1 mg/kg for nickel in food (FAO/WHO, 1993). The levels of Ni in this study were lower than those reported in a study reported by Adebiyi et al (2022) and Olusola et al. (2024). It is plausible that contact between the dough and metallic surfaces during mixing contributed to the elevated nickel concentration in the bread. Nickel (Ni) poses significant risks to human health, particularly concerning lung-related conditions such as lung cancer, chronic bronchitis, and diminished lung function. Nickel (Ni) exposure can lead to severe pulmonary ailments, including haemorrhage, oedema, alterations in alveolar cell structure, pulmonary fibrosis degeneration, and damage to the bronchial epithelium (Kiran et al., 2021). Individuals exposed to nickel may also be susceptible to developing adult respiratory distress syndrome (ARDS) (Olusola et al., 2024).

Cadmium (Cd) concentrations in the analyzed bread samples ranged from 0.010 to 0.060 mg/kg, with a mean value of 0.040 ± 0.020 mg/kg. These concentrations exceeded the maximum permissible limit of 0.030 mg/kg established by the Codex Alimentarius Commission (2019). The Cd levels observed in this study are comparable to those reported by Akinyele and Shokunbi (2015), who documented concentrations of 0.020–0.040 mg/kg in Nigerian bread samples, suggesting persistent low-level contamination. However, the values obtained in the present study are lower than those reported by Adebiyi et al. (2022). The presence of cadmium in bread is of significant toxicological concern due to its cumulative nature and long biological half-life. Chronic exposure to Cd has been associated with renal dysfunction, anemia, pulmonary disorders such as emphysema, cardiovascular diseases, and hypertension (Rahimzadeh et al., 2020). The observed contamination may be attributed to the uptake of cadmium from contaminated soils, particularly through the use of phosphate fertilizers, as well as contributions from industrial emissions and environmental deposition during cultivation and processing.

The concentration of Cr in the bread samples ranged from 0.080 – 0.260 mg/kg with a mean concentration of 0.17 ± 0.060 mg/kg, surpassing the World Health Organization's sanctioned threshold of 0.05 mg/kg for chromium in food. The elevated chromium levels observed in the bread samples may stem from cereal grains absorbing minerals from the soil, which subsequently become part of the flour (Adebiyi et al., 2022). While chromium (Cr) is essential for metabolic processes in the human body, excessive exposure can pose health risks, including skin allergies (Monga et al., 2022) and an increased likelihood of lung cancer at higher toxic concentrations (Hedberg, 2020).

The Zn content in the bread samples ranged from 6.20 to 15.30 mg/kg, with an average concentration of 10.75 ± 2.70 mg/kg, exceeding the acceptable limit for Zinc in food set by FAO/WHO at 1 mg/kg. However, these levels were above the ranges observed in studies conducted by Olusola et al. (2024). Zinc is generally considered safe, particularly when ingested orally. However, symptoms of acute poisoning may manifest, such as nausea, vomiting, discomfort in the upper abdomen, mental fatigue, and fatigue, especially in pregnant individuals (Olusola et al., 2024). Given that most samples were procured from roadside outlets, the contribution of traffic-related pollution cannot be overlooked. Studies have demonstrated that heavy metal concentrations in foods increase significantly with proximity to highways due to particulate deposition (Orisakwe et al., 2012).

Iron (Fe) concentrations in the analysed bread samples ranged from 12.40 to 28.70 mg/kg, with a mean value of 20.55 ± 5.42 mg/kg. The permissible level by standard organisations for Fe is not available. The present values for Fe in bread samples fall within the lower range of concentrations reported in a study in Iran (39.02 ± 22.63 mg/kg), reflecting the influence of flour fortification practices and regional processing conditions (Asadi et al., 2025). Similarly, other investigations have documented Fe concentrations in bread ranging from approximately 15 to 68.7 mg/kg, indicating substantial variability across different production systems and environmental conditions (Esfandiari et al., 2024). The relatively moderate Fe levels observed in this study suggest that the bread samples may not have undergone significant iron contamination. Iron in bread is primarily derived from wheat grains, fortification processes, water used during production, and contact with processing equipment such as metallic baking surfaces. While iron is an essential micronutrient required for oxygen transport and metabolic functions, excessive intake may pose health concerns, including oxidative stress and gastrointestinal disturbances.

Table 5. Elemental Composition (mg/kg) of the bread samples.

Sample	Pb	Cd	Cr	Fe	Zn	Ni
A	0.012± 0.040	0.010±0.020	0.080±0.040	12.40±5.50	6.20±3.10	0.180±0.040
B	0.29± 0.010	0.060±0.040	0.21±0.090	17.45±5.40	7.50±2.45	0.13±0.040
C	0.13±0.040	0.040±0.0012	0.17±0.060	19.76±4.96	12.74±2.90	0.040±0.040
D	0.21±0.050	0.030±0.030	0.21±0.020	20.75±5.43	15.30±2.20	0.12±0.050
E	0.0020±0.14	0.032±0.030	0.15±0.040	21.74±4.95	10.89±2.70	0.10±0.14
F	0.20±0.0040	0.015±0.020	0.18±0.070	22.67±6.90	10.45±3.00	0.13±0.0040
G	0.18±0.040	0.034±0.010	0.26±0.040	19.94±4.70	12.96±2.80	0.19±0.040
H	0.020±0.040	0.050±0.030	0.13±0.080	28.7±6.40	12.18±2.10	0.10±0.040
I	0.016±0.15	0.045±0.020	0.16±0.070	21.82±4.98	10.21±2.80	0.10±0.14
J	0.026±0.0020	0.052±0.020	0.14±0.090	20.28±4.95	9.05±2.95	0.10±0.0020
Range	0.0020-0.21	0.010– 0.060	0.080– 0.26	12.40-28.70	6.20 –15.30	0.040 – 0.19
Mean ± SD	0.11±0.052	0.040±0.020	0.17±0.060	20.55±5.42	10.75±2.70	0.12±0.051
FAO/ WHO (mg/kg)	0.025	0.030	0.050	NA	1.00	1.00

SD = standard deviation

Dietary Risk Assessment of Heavy Metals in Bread

The dietary risk assessment conducted in this study evaluated the potential non-carcinogenic health risks associated with heavy metals (Pb, Cd, Cr, Ni, Fe, Zn) through bread consumption. Estimated Daily Intakes (EDIs), Hazard Quotients (HQs), and Hazard Index (HI) values were calculated for individual samples (Tables 6–7).

Estimated Daily Intake (EDI)

EDI values as shown in Table 6 (a) and (b) reflected the contribution of each heavy metal to daily intake via bread, showing the following trend across samples Fe > Zn > Ni > Cr > Pb > Cd. This distribution is consistent with several international studies, which also report higher concentrations of essential elements (e.g., Fe, Zn, Ni) but lower levels of toxic non-essential metals like Pb and Cd in bread products. For example, an assessment of heavy metal levels in bread consumed in Nigeria found copper and zinc to be higher than lead and cadmium concentrations, with a similar hierarchical pattern of essential over non-essential metals (Adebiyi et al., 2021). While essential metals (Fe and Zn) contribute numerically higher EDIs, they are associated with higher tolerable intake thresholds (WHO/FAO guidelines). In contrast, the EDIs for toxic metals such as Pb and Cd were lower but remain toxicologically significant due to their low reference doses and cumulative effects even at low exposure levels. Across all samples, children exhibited significantly higher EDIs than adults because of their higher intake-to-body-weight ratios, a pattern widely documented in previous dietary risk assessments (Udowelle et al., 2017).

Table 6(a). Estimated Daily Intake (EDI) of Heavy Metals from Bread Consumption (Adults).

Sample	Pb	Cd	Cr	Ni	Fe	Zn
A	0.00014	0.000029	0.00011	0.00014	0.0020	0.0011
B	0.00017	0.000042	0.00013	0.00016	0.0021	0.0013
C	0.00020	0.000043	0.00016	0.00017	0.0023	0.0014
D	0.00023	0.000057	0.00017	0.00019	0.0026	0.0016
E	0.00019	0.000043	0.00014	0.00016	0.0021	0.0013
F	0.00021	0.000057	0.00017	0.00019	0.0027	0.0017
G	0.00017	0.000029	0.00013	0.00014	0.0020	0.0011
H	0.00023	0.000043	0.00016	0.00017	0.0024	0.0016
I	0.000071	0.000014	0.000057	0.000071	0.0014	0.00086
J	0.00010	0.000029	0.000086	0.00001	0.0017	0.0010

Table 6(b). Estimated Daily Intake (EDI) of Heavy Metals from Bread Consumption (Children).

Sample	Pb	Cd	Cr	Ni	Fe	Zn
A	0.00067	0.000013	0.00053	0.00067	0.0093	0.0053
B	0.00080	0.000020	0.00060	0.00073	0.0010	0.0060
C	0.00093	0.000020	0.00073	0.00080	0.0011	0.0067
D	0.00011	0.000027	0.00080	0.00087	0.0012	0.0073
E	0.00087	0.000020	0.00067	0.00073	0.0010	0.0060
F	0.00010	0.000027	0.00080	0.00087	0.0013	0.0080
G	0.00080	0.000013	0.00060	0.00067	0.0093	0.0053
H	0.00011	0.000020	0.00073	0.00080	0.0011	0.0073
I	0.00033	0.0000067	0.00027	0.00033	0.0067	0.0040
J	0.00047	0.000013	0.00040	0.00047	0.0080	0.0047

Hazard Quotient (HQ)

The HQs (Table 7 (a) and (b)) quantify individual metal risk relative to established oral reference doses (RfDs) from agencies such as the United States Environmental Protection Agency. An HQ value below 1 is generally considered acceptable, whereas values ≥ 1 suggest potential health concern. In this study, all HQ values for individual metals for adults were < 1 while Children HQ values for Pb and Cd only were also < 1 but approached higher proportions of their respective RfDs, indicating reduced safety margins. This pattern is corroborated by earlier work in Nigerian bread, where the target hazard quotient (THQ) for Pb was below 1 but with some samples violating permissible limits, emphasizing that even low Pb exposure warrants caution (Udowelle et al., 2017). Similarly, heavy metal studies in cereals from other countries (e.g., Turkey) reported HQs < 1 for most elements but highlighted the importance of monitoring trends over time (Adebiyi et al., 2021).

Table 7(a). Hazard Quotient (HQ) for Individual Metals (Adults)

Sample	HQ-Pb	HQ-Cd	HQ-Cr	HQ-Ni	HQ-Fe	HQ-Zn
A	0.041	0.029	0.038	0.007	0.003	0.004
B	0.049	0.043	0.043	0.008	0.003	0.004
C	0.057	0.043	0.052	0.009	0.003	0.005
D	0.065	0.057	0.057	0.009	0.004	0.005
E	0.053	0.043	0.048	0.008	0.003	0.004
F	0.061	0.057	0.057	0.009	0.004	0.006
G	0.049	0.029	0.043	0.007	0.003	0.004
H	0.065	0.043	0.052	0.009	0.003	0.005
I	0.020	0.014	0.019	0.004	0.002	0.003
J	0.029	0.029	0.029	0.005	0.002	0.003

(RfD values: Pb = 0.0035; Cd = 0.001; Cr = 0.003; Ni = 0.02; Fe = 0.7; Zn = 0.3 mg/kg/day)

Table 7(b). Hazard Quotient (HQ) for Individual Metals (Children)

Sample	HQ-Pb	HQ-Cd	HQ-Cr	HQ-Ni	HQ-Fe	HQ-Zn
A	0.190	0.133	0.178	0.033	0.013	0.018
B	0.229	0.200	0.200	0.037	0.014	0.020
C	0.267	0.200	0.244	0.040	0.015	0.022
D	0.305	0.267	0.267	0.043	0.017	0.024
E	0.248	0.200	0.222	0.037	0.014	0.020
F	0.286	0.267	0.267	0.043	0.018	0.027
G	0.229	0.133	0.200	0.033	0.013	0.018
H	0.305	0.200	0.244	0.040	0.016	0.024
I	0.095	0.067	0.089	0.017	0.010	0.013
J	0.133	0.133	0.133	0.023	0.011	0.016

Hazard Index (HI)

The cumulative risk from multiple metals was assessed using the Hazard Index (HI = ΣHQs), which integrates the combined risk. As shown in Figure 1. Adults HI ranged from 0.062 to 0.197 (HI < 1). Children ranged from 0.291 to 0.923, with two samples (D and F) approaching the threshold of 1, indicating a narrower margin of safety. The HI values confirm that, based on bread consumption alone, the combined non-carcinogenic risk remains below the level of concern (HI < 1). However, the proximity of some children's HI values to unity suggests caution, especially for habitual consumers and other dietary sources of heavy metals. Previous studies in Nigeria and other regions reported similar patterns, with HI values for bread and cereal products generally below regulatory thresholds but with values trending upward when dietary and environmental exposures are considered comprehensively (Adebiyi et al., 2021; Udowelle et al., 2017).

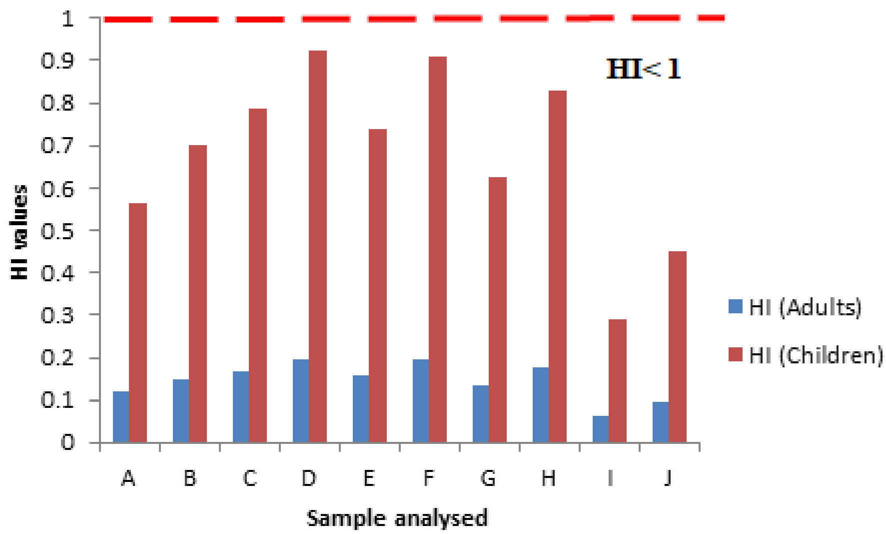

Figure 1. Cumulative Hazard Index (HI) for analysed bread samples, with all values below 1, suggesting no significant non-carcinogenic health risk to consumers.

Public Health Implications

The higher relative HI values in children underscore their vulnerability to dietary heavy metal exposure, consistent with prior studies in Nigeria and abroad. Although individual and cumulative risk values were within acceptable limits in this study, the narrow safety margins in children (HI approaching 1) suggest that combined bread consumption and other dietary sources could elevate risk beyond safe limits over time. Roadside vending and atmospheric deposition from vehicular emissions likely contribute to heavy metal presence, particularly Pb, aligning with global findings that traffic pollution can increase metal contamination in exposed foodstuffs.

CONCLUSION

This study evaluated potassium bromate and heavy metal contamination in commercially available bread and assessed associated dietary risks. Potassium bromate was detected in all samples at concentrations far exceeding the permissible limit established by the World Health Organization and Food and Agriculture Organization. Given its classification as a possible human carcinogen by the International Agency for Research on Cancer, its continued presence represents a significant food safety concern and suggests gaps in regulatory enforcement. Heavy metals (Pb, Cd, Cr, Ni, Fe, and Zn) were also detected in all samples, with Fe and Zn predominating. Although some samples showed partial exceedance for Pb, the calculated Hazard Quotients and cumulative Hazard Index values remained below unity, indicating no immediate non-carcinogenic risk from bread consumption alone. However, children exhibited higher exposure indices, reflecting increased vulnerability.

Overall, while heavy metal exposure appears within acceptable non-carcinogenic limits, the excessive levels of potassium bromate constitute a more critical public health issue. Strengthened regulatory surveillance and continuous monitoring of bakery products are therefore essential to ensure consumer safety and compliance with international food safety standards.

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