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RESEARCH ARTICLE

# Assessment of Heavy Metal Contamination and Human Health Risks in Rice and Beans Sold in Wunti Market, Bauchi State, Nigeria

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## Abstract

**Background:** Cereals are staple component of the Nigerian diet; however, their contamination with heavy metals raises serious public health concerns. This study evaluated the concentrations of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) in company processed rice (CPR), locally processed rice (LPR), and beans sold in Northern Nigeria. The study further assessed contamination factors (CF) and associated human health risks.

**Methods:** A basket market survey was conducted in major cereal and legume markets located in three geopolitical zones of Nigeria: Bauchi (North-East), Kano (North-West), and Jos (North-Central). In each market, samples of CPR, LPR, and beans were collected from three random vendors. Sample were homogenized and combined into composite sample to reduce variability and ensure representativeness, following established procedures. Samples were analyzed using Atomic Absorption Spectrophotometry (AAS) following acid digestion.

**Results:** Cd concentrations ranged from 0.35 ± 0.07 mg/kg in LPR to 2.05 ± 0.16 mg/kg in CPR, while Cr concentrations ranged from 0.93±0.12 mg/kg to 1.62 ± 0.35 mg/kg, exceeding permissible limits in all samples. Cu was highest in beans (12.27 ± 12.39 mg/kg), whereas Pb concentrations (0.71 ± 0.06–1.04 ± 0.06 mg/kg) exceeded the WHO limit of 0.2 mg/kg. Contamination factor showed high contamination for Cd in CPR, high CF values of Cr across all the samples, low Cu and Zn contamination across all samples, considerable contamination in Pb across all samples. Health risk assessment revealed substantially greater exposure among children than adults. Hazard index values via ingestion exceeded unity in all samples, particularly among children. Total carcinogenic risk values ranged from 0.0054–0.017 for adults and 0.0013–0.041 for children, indicating potential carcinogenic risks.

**Conclusion:** The findings demonstrate that consumption of the investigated crops may pose significant non-carcinogenic and carcinogenic health risks, especially to children, highlighting the need for strengthened food safety monitoring and improved regulation of agricultural contaminants.

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## Abbreviations

Cd: Cadmium; Cr: Chromium; Cu: Copper; Pb: Lead; Zn: Zinc; CPR: Company Processed Rice; LPR: Locally Processed Rice; CF: Contamination Factor; AAS: Atomic Absorption Spectrophotometry.

## Introduction

Agriculture is the backbone of the economy in Northern Nigeria, serving as a major source of livelihood and food supply for local populations, the nation, and neighboring countries [1,2]. To sustain agricultural productivity and meet the growing food demand of an increasing population, farmers extensively use agrochemicals, particularly pesticides, to control pests and diseases and enhance crop yields [3,4]. While pesticides contribute significantly to improve agricultural output and food security, their indiscriminate and excessive application has raised concerns regarding environmental contamination and food safety.

In many developing countries, including Nigeria, inadequate knowledge of pesticide handling, poor adherence to recommended application rates, and weak regulatory enforcement have resulted in the misuse of agrochemicals [5,6]. Continuous application of these chemicals can lead to the accumulation of toxic substances in agricultural soils, surface water, and groundwater. Such contamination may adversely affect non-target organisms, reduce biodiversity, and facilitate the transfer of hazardous contaminants into the food chain through crop uptake [7,1].

Among the contaminants associated with agricultural activities, heavy metals are of particular concern due to their persistence, non-biodegradable nature, and tendency to bioaccumulate in biological systems. Some heavy metals have historically been used directly as active ingredients in pesticides and fungicides. Compounds containing arsenic, mercury, zinc, copper, and other metals have been widely utilized in crop protection practices [8]. In addition to pesticide application, heavy metals may enter agricultural soils through the use of contaminated irrigation water, fertilizers, atmospheric deposition, and other anthropogenic activities. Once introduced into the environment, these metals can be absorbed by crops and subsequently accumulate in edible plant tissues.

Rice and beans are among the most widely consumed staple foods in Nigeria and constitute an important source of carbohydrates, proteins, vitamins, and minerals for millions of people. However, their frequent consumption also increases the likelihood of dietary exposure to heavy metals when contamination occurs. Chronic exposure to toxic metals such as cadmium (Cd), lead (Pb), and chromium (Cr) has been associated with numerous adverse health effects, including kidney dysfunction, neurological disorders, developmental abnormalities, carcinogenicity, and other systemic toxicities. Consequently, monitoring heavy metal concentrations in staple foods is essential for safeguarding public health and ensuring compliance with food safety standards.

Recent studies have continued to demonstrate the occurrence of heavy metals in rice and other food crops and their potential health implications for consumers. Global assessments indicate that rice remains one of the major dietary pathways for exposure to toxic metals such as cadmium, lead, chromium, arsenic, and mercury, with associated non-carcinogenic and carcinogenic risks reported in several countries [9,10]. In Nigeria, recent investigations have detected varying concentrations of heavy metals in locally produced and company rice brands, with some studies reporting elevated levels of Pb, Cd, and Cr that may pose health concerns to regular consumers [11,12]. Similarly, food contamination studies conducted in Northern Nigeria have highlighted the influence of agricultural practices, pesticide use, and environmental factors on heavy metal accumulation in food crops [2,13]. These findings underscore the importance of continuous monitoring of staple foods and the need for localized assessments to support food safety and public health protection.

Even though there a couple of studies on the heavy metal contamination in food crops across different regions of Nigeria, information is however limited on comparing the contamination levels between company processed rice and locally processed rice sold in major markets across northern Nigeria. Furthermore, there is scarcity of data on the heavy metal contents of the company and home grown rice and beans and the potential human health risks associated with their consumption. This knowledge gap hinders evidence based decision-making and the development of effective food safety interventions for consumers.

Therefore, this study was conducted to determine the concentrations of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) in company-processed rice (CPR), locally processed rice (LPR), and beans sold in northern Nigeria. The study also evaluates the extent of contamination and assesses the associated non-carcinogenic and carcinogenic health risks to consumers. The findings will provide valuable baseline information for food safety monitoring, public health protection, and regulatory efforts aimed at minimizing heavy metal exposure through dietary intake in the region.

# Materials and Methods

## Sample collection and preparation

A basket market survey was conducted in major cereal and legume markets located in three geopolitical zones of Nigeria: Bauchi (North-East), Kano (North-West), and Jos (North-Central). In each market, samples of company-processed rice (CPR), locally processed rice (LPR), and beans were collected from three randomly selected vendors located in different sections of the market to ensure representative sampling. Approximately 500 g of each commodity was purchased from each vendor, resulting in a total of nine primary samples per market (three CPR, three LPR, and three bean samples).

For each commodity category within a market, the three primary samples were thoroughly homogenized and combined to form a composite sample following the procedure described by Arora, et al. [14]. Composite sampling was adopted to minimize variability among individual vendors and to obtain a representative sample of the products commonly consumed by the local population. Consequently, one composite sample each of CPR, LPR, and beans was prepared for each market. The samples were sealed in clean polyethylene sampling bags, appropriately labeled, and transported to the laboratory for analysis.

In the laboratory, samples were air-dried where necessary and pulverized using a laboratory grinder. The powdered samples were passed through a 2-mm stainless-steel sieve to obtain a uniform particle size and subsequently stored in labeled paper bags under dry conditions until analysis.

## Heavy metal analysis

One gram (1.0 g) of each homogenized sample was accurately weighed into a digestion flask and digested using 15 mL of a mixed acid solution containing concentrated nitric acid ($HNO_3$, 70%, Sigma-Aldrich), perchloric acid ($HClO_4$, 65%), and sulfuric acid ($H_2SO_4$, 70%) in a ratio of 5:1:1 (v/v/v). The mixture was heated on a hot plate at approximately 80°C until a clear or translucent digest was obtained. After cooling, the digest was filtered through Whatman No. 42 filter paper and diluted to 50 mL with deionized water.

The concentrations of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) were determined using an Atomic Absorption Spectrophotometer (AAS) following the method described by Zhong, et al. [15]. Metal concentrations were expressed as mg $kg^{-1}$ dry weight.

## Quality Assurance and Quality Control (QA/QC)

To ensure the accuracy and reliability of analytical results, strict quality assurance and quality control procedures were implemented throughout the study. All glassware and digestion vessels were soaked in 10% nitric acid solution for 24 h and rinsed thoroughly with deionized water before use to prevent external contamination. Analytical-grade reagents and ultrapure water were used for all analyses.

Calibration of the Atomic Absorption Spectrophotometer was performed using certified standard solutions for Cd, Cr, Cu, Pb, and Zn. Multi-point calibration curves were established for each metal, and correlation coefficients ($R^2$) greater than 0.995 were obtained. Instrument performance was verified periodically using calibration check standards.

Procedural blanks were included in every batch of sample digestion to monitor potential contamination during sample preparation and analysis. All samples were analyzed in triplicate, and the reported values represent the mean concentrations. Accuracy of the analytical procedure was evaluated through recovery studies by spiking selected samples with known concentrations of the target metals before digestion. Percentage recoveries ranged from 90% to 110%, which falls within the acceptable analytical recovery range of 80-120%.

## Statistical analysis

Descriptive statistics including mean values and standard deviations were calculated for all measured parameters. Contamination factor, Average Daily Dose (ADD), hazard quotient, hazard index, cancer risk, non-cancer risk and total cancer risk models were employed for exposure assessment, carcinogenic and non-carcinogenic health risk assessment as accepted by united state environmental protection agency (US EPA) and human health risk assessment (HHRA).

## Contamination factor

The contamination factor (CF) is utilized for assessing the level of contamination in sample from each heavy metal. It is calculated using the following equation:

$$CF = \frac{Ci}{MPL}$$

Where Ci stands for measured metal concentrations and MPL for maximum permissible limit for specific metal. CF is classified into four groups to measure the degree of contamination in the sample as follows: CF <1 (low contamination), 1 ≤ CF < 3 (moderate contamination), 3 ≤ CF <6 (considerable contamination), and 6 ≥ CF (high contamination) [16].

The MPL values adopted in this study were Cd = 0.10 mg/kg, Cr = 0.1 mg/kg, Cu = 10.0 mg/kg, Pb = 0.20 mg/kg, and Zn = 50.0 mg/kg, based on global MPL concentrations commonly applied in crops contamination studies [17,18].

## Health risk assessment

The risk that pollution poses to humans can be estimated by using an efficient model called the human health risk model. Differences in physiology and behavior of adults compared with children keep them separate. The study estimated the potential of non-carcinogenic and carcinogenic health risks for the two age groups.

## Exposure assessment

The primary routes of exposure for children and adults to heavy metals are through ingestion ($ADI_{ing}$), inhalation of suspended particles ($ADI_{inh}$), and dermal contact ($ADI_{der}$). The dose received through each of the three pathways from company processed rice, locally processed rice and beans was calculated using the following equations [19].

$$ADI_{ing} = \frac{CA \times IR \times EF \times ED \times CF}{BW \times AT}$$

$$ADI_{inh} = \frac{CA \times InhR \times ET \times EF \times ED}{PEF \times BW \times AT}$$

$$ADI_{der} = \frac{CA \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT}$$

Where: $ADI_{ing}$ is the average daily intake of heavy metals (HMs) ingested in mg/kg/day. $ADI_{inh}$ is the average daily intake of HMs inhaled in mg/kg/day. $ADI_{der}$ is the exposure dose via dermal contact in mg/kg/day. CA is the concentration of HMs available in crops (mg kg-1). IR is crop ingestion rate. BW is the body weight. EF is the exposure frequency. ED is the exposure duration. ATc is the carcinogenic risk average time. ATnc is the non-carcinogenic risk average time. SA is the skin surface area available for contact. CF is the conversion factor. AF is the soil-to-skin adherence factor. ABS is the absorption factor. InhR is the inhalation rate. ET is the cereal exposure time. PEF is the particle emission factor, and ET is the exposure time (h/day) [20].

## Non-carcinogenic risk

The non-carcinogenic health risk of a substance is determined by estimating the likelihood of adverse health effects at a specific dosage within a specific timeframe using the hazard quotient and hazard index. The hazard quotient (HQ) is referred to as the quotient of ADI divided by the chronic reference dose (RfD) of a certain heavy metal in mg/kg/day. The potential hazard quotient (HQ) for each metal was calculated by using the following equation [21].

$$HQ = \frac{ADI}{RfD}$$

If HQ < 1, it means that there are no adverse health consequences, whereas HQ > 1 suggests that there are probably harms [22].

The population's non-carcinogenic response to a certain number of heavy metals is the total of all the HQs caused by each heavy metal known as the Hazard Index HI [23]. It was calculated using the equation below:

$$HI = \sum_{i=1}^{n} (HQ)$$

The value of HI≤1 indicates that there is no significant risk of non-carcinogenic effects. On the other hand, there is a chance that non-carcinogenic effects may occur. When HI>1, and the probability increases as the value of the HI increases [24].

## Carcinogenic risk index

Carcinogenic risks are computed as the incremental probability that a person would get cancer during their lifetime as a result of exposure to the probable carcinogen [25]. It was computed as:

$$(CR) = ADI \times CSF$$

Where ADI (mg/kg/day) and CSF (mg/kg/day) represent the average daily intake and cancer slope factor, respectively.

The carcinogenic slope factor (CSF) indicates the maximum probable carcinogenic risk in an individual exposed to a specific carcinogenic substance dose.

A total cancer risk (TCR) was calculated by the sum of CR from all carcinogens in the studied cereals as follows:

$$Risk(total)\ (TCR) = Risk(ing) + Risk(inh)$$

Where $Risk_{(ing)}$, and $Risk_{(inh)}$, are risk contributions

**Table 1:** Heavy metals mean/standard deviation concentration in company processed rice, locally processed rice and beans (mg/kg).

| SAMPLE | Cadmium | Chromium | Copper | Lead | Zinc |
|---|---|---|---|---|---|
| LPR | 0.35 ± 0.07 | 1.62 ± 0.35 | 2.77 ± 0.00 | 1.04 ± 0.06 | 1.11 ± 0.13 |
| CPR | 2.05 ± 0.16 | 0.93 ± 0.12 | 1.81 ± 0.59 | 0.75 ± 0.01 | 2.80 ± 0.11 |
| Beans | 0.48 ± 0.04 | 0.93 ± 0.25 | 12.27 ± 12.39 | 0.71 ± 0.06 | 0.80 ± 0.06 |
| WHO | 0.1 | NS | 10 | 0.2 | 50 |

through ingestion and inhalation pathways, respectively. The USEPA recommends risk values less than 1.00E-06 are regarded as negligible, whereas a risk exceeding 1.00E-04 is likely to be harmful to human health. If the 1.00E-06 < TCR < 1.00E-04, the cancer risk is acceptable [26].

## Results

Table 1 presents the mean concentrations (mg/kg) of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) in the selected crops compared to WHO permissible limits. Cadmium levels ranged from 0.35 ± 0.07 mg/kg (LPR) to 2.04 ± 0.16 mg/kg (CPR), exceeding the WHO permissible limit of 0.1 mg/kg across all samples. Chromium concentrations were highest in LPR (1.62 ± 0.35 mg/kg) with the lowest in CPR (0.93 ± 0.12 mg/kg). These values surpass the WHO permissible threshold (not specified, but generally <0.1–1.0 mg/kg). Copper concentrations were notably high in beans (12.27 ± 12.39 mg/kg) compared to the WHO limit of 10 mg/kg and the lowest value of copper was in CPR (1.81 ± 0.59 mg/kg). Lead concentrations ranged between 0.71±0.06 mg/kg (beans) and 1.04 ± 0.06 mg/kg (LPR), all exceeding the WHO permissible limit of 0.2 mg/kg. Zinc concentrations were relatively moderate, with values from 0.80±0.06 mg/kg (beans) to 2.8 ± 0.11 mg/kg (CPR), below the WHO limit of 50 mg/kg.

From table 2, CF values for cadmium ranged from 3.5 (LPR) to 20.45 (CPR), indicating considerable to high Cadmium contamination across all samples. Chromium CF values ranged from 9.3 (CPR and beans) – 16.2(LPR) also showed high contamination. Copper CF ranged from 0.181 (CPR) to 1.22 (beans), indicating low copper contamination across all the samples. Lead CF values spanned 3.52 (beans) to 5.175(LPR) showing considerable contamination. Zinc CF ranged from 0.022 (LPR) to 0.01(Beans), showing very low contamination in across all the samples.

In table 3, adult's cadmium exposure ranged from 0.00046 mg/kg/day (LPR) to 0.0026mg/kg/day (CPR), while for children, Cd exposure ranged from 0.0022mg/kg/day (beans) to 0.076 mg/kg/day (CPR) the result indicate cadmium oral exposure to be above the acceptable limit in CPR for adult and while cadmium oral exposure from LPR, CPR and Beans was also above the acceptable limit by WHO.

Cr exposure in adults varied between 0.0012–0.00213 mg/kg/day, with the highest value recorded in LPR, while children's Cr intake reached up to 0.06 mg/kg/day in LPR, chromium concentration in all the cereals and legume was below the permissible limit for adult and children. Copper ingestion for adults ranged between 0.0023 mg/kg/day (CPR) and 0.0201 mg/kg/day (beans) which all falls within the permissible limit, whereas in children, 0.0588 mg/kg/day in beans -0.0674 mg/kg/day in CPR which were below the acceptable limit.

Lead exposure among adults was relatively low (0.00098–0.0011g/kg/day) but elevated

**Table 2:** Heavy metals contamination factor in locally processed rice (LPR), company processed rice (CPR) and beans.

| Sample | Cd | Cr | Cu | Pb | Zn |
|---|---|---|---|---|---|
| LPR | 3.5 | 16.2 | 0.2765 | 5.175 | 0.0222 |
| CPR | 20.45 | 9.3 | 0.181 | 3.725 | 0.056 |
| Beans | 4.75 | 9.3 | 1.227 | 3.525 | 0.016 |

CF <1 (low contamination), CF < 3 (moderate contamination), CF <6 (considerable contamination), and 6 ≥ CF (high contamination) [16].

**Table 3:** Heavy metals exposure assessment in crops via ingestion.

| Sample | Age | Cadmium | Chromium | Copper | Lead | Zinc |
|---|---|---|---|---|---|---|
| LPR | Adult | 0.0004603 | 0.00213 | 0 | 0.00136 | 0.00146 |
| | Children | 0.0130219 | 0.0604 | 0 | 0.03851 | 0.04136 |
| CPR | Adult | 0.0026915 | 0.00122 | 0.00238 | 0.00098 | 0.00274 |
| | Children | 0.0761472 | 0.0346 | 0.06747 | 0.02778 | 0.07739 |
| Beans | Adult | 0.0007863 | 0.00138 | 0.02018 | 0.00116 | 0.00132 |
| | Children | 0.0022934 | 0.00403 | 0.05884 | 0.00339 | 0.00384 |

WHO/FAO (Codex) acceptable limit (mg/kg/day) Cd = 0.001, Cr = 0.3 Cu = 0.9 Pb = Not significant via ingestion, Zn = 40 [27].

**Table 4:** Exposure assessment via inhalation of heavy metals in of dust particles from crops.

| Sample | Age | Cadmium | Chromium | Copper | Lead | Zinc |
|---|---|---|---|---|---|---|
| LPR | Adult | 2.64404E-10 | 1.22633E-09 | 0 | 7.8188E-10 | 8.39797E-10 |
| | Children | 3.75101E-10 | 1.73975E-09 | 0 | 1.10923E-09 | 1.19139E-09 |
| CPR | Adult | 1.54613E-09 | 7.02558E-10 | 1.36986E-09 | 5.64061E-10 | 1.57131E-09 |
| | Children | 2.19345E-09 | 9.96696E-10 | 1.94338E-09 | 8.00215E-10 | 2.22917E-09 |
| Beans | Adult | 3.61352E-10 | 6.34569E-10 | 9.27176E-09 | 5.33844E-10 | 6.0561E-10 |
| | Children | 5.12638E-10 | 9.00242E-10 | 1.31535E-08 | 7.57346E-10 | 8.59159E-10 |

WHO/FAO acceptable limit (mg/m3) Cd = 0.005, Cr = 1, Cu=1, Pb = 0.05 and Zn = 15 dust 5 respiarable.

**Table 5:** Heavy metals exposure assessment via dermal contact with crops.

| Sample | Age | Cadmium | Chromium | Copper | Lead | Zinc |
|---|---|---|---|---|---|---|
| LPR | Adult | 4.30428E-08 | 1.99637E-07 | 0 | 1.27284E-07 | 1.36712E-07 |
| | children | 2.25534E-07 | 1.04605E-06 | 0 | 6.66937E-07 | 7.1634E-07 |
| CPR | Adult | 2.51698E-07 | 1.14371E-07 | 2.23003E-07 | 9.18247E-08 | 2.55797E-07 |
| | children | 1.31884E-06 | 5.99277E-07 | 1.16848E-06 | 4.8114E-07 | 1.34032E-06 |
| Beans | Adult | 5.88252E-08 | 1.03303E-07 | 1.50937E-06 | 8.69055E-08 | 9.85885E-08 |
| | children | 3.0823E-07 | 5.41282E-07 | 7.90873E-06 | 4.55364E-07 | 5.16581E-07 |

No acceptable limit is established for cadmium, chromium, copper, lead and zinc exposure via dermal.

in children (0.0033 mg/kg/day – 0.038mg/kg/day). Zinc exposure was within acceptable limits for both groups, ranging between 0.00132 mg/kg/day (beans) and 0.00274 mg/kg/day (CPR) in adults. However, children exhibited higher Zn intake (up to 0.077 mg/kg/day in CPR).

Table 4 show that adult and children's exposure dose via inhalation of dust particles from cereals-legume containing Cd, Cr, Cu, Pb and Zn were shown in table 4. Cadmium (Cd) exposure for adults ranged between 2.644E-10 mg/m3 (LPR) and 1.546E-9 mg/m3 (CPR), while children showed higher exposure ranging from 3.751E-10 mg/m3 (LPR) to 2.193E-9 mg/m3 (CPR), all cadmium exposure in dust particles from LPR, CPR and beans were within the acceptable limit. Chromium (Cr) inhalation exposure ranged between 6.345E-10 mg/m3 (beans) – 1.226E-9 mg/m3 (LPR) for adults and 9.002E-10–1.739E-9 mg/m3 for children. The highest Cr exposure in children was recorded in LPR and both of the values were within the acceptable threshold by WHO. Copper (Cu) exposure via inhalation was relatively low for most adults (1.369E-9–0.89.271E-9 mg/m3) but reached up to 1.315 mg/kg/day in children consuming beans though all the values were within the acceptable limit. Lead (Pb) exposure was minimal across adults (5.338E-10 (beans) –7.818E-10 (LPR) mg/m3) but higher in children (7.573E-1- (beans) –1.109E-9 mg/m3 (LPR) all within the safety limit. while zinc (Zn) ranged between (beans) 6.056E-9–1.572E-9 (CPR)

**Table 6:** Hazard quotients of heavy metals in LPR, CPR and Beans.

| Sample | Age | Element | HQ Ing | HQ Inh | HQ Der |
|---|---|---|---|---|---|
| LPR | Adult | Cadmium | 0.46 | 2.64E-07 | 0.0094 |
| LPR | Children | Cadmium | 13.02 | 3.75E-07 | 2.3E-07 |
| LPR | Adult | Chromium | 0.71 | 1.36E-06 | 0.013 |
| LPR | Children | Chromium | 20.13 | 1.93E-06 | 1E-06 |
| LPR | Adult | Copper | 0 | 0 | 0 |
| LPR | Children | Copper | 0 | 0 | 0 |
| LPR | Adult | Lead | 0.38 | 2.23E-07 | 0.001 |
| LPR | Children | Lead | 11.00 | 3.16E-07 | 6.7E-07 |
| LPR | Adult | Zinc | 0.004 | 2.79E-09 | 2.4E-06 |
| LPR | Children | Zinc | 0.137 | 3.97E-09 | 7.2E-07 |
| CPR | Adult | Cadmium | 2.691 | 1.546E-06 | 0.05495 |
| CPR | Children | Cadmium | 76.14 | 2.193E-06 | 1.3E-06 |
| CPR | Adult | Chromium | 0.407 | 7.806E-07 | 0.00799 |
| CPR | Children | Chromium | 11.53 | 1.107E-06 | 6E-07 |
| CPR | Adult | Copper | 0.059 | 3.424E-08 | 5.8E-05 |
| CPR | Children | Copper | 1.686 | 4.858E-08 | 1.2E-06 |
| CPR | Adult | Lead | 0.280 | 1.611E-07 | 0.0012 |
| CPR | Children | Lead | 7.937 | 2.286E-07 | 4.8E-07 |
| CPR | Adult | Zinc | 0.009 | 5.237E-09 | 4.5E-06 |
| CPR | Children | Zinc | 0.257 | 7.430E-09 | 1.3E-06 |
| Beans | Adult | Cadmium | 0.786 | 3.613E-07 | 0.01284 |
| Beans | Children | Cadmium | 2.293 | 5.126E-07 | 3.1E-07 |
| Beans | Adult | Chromium | 0.460 | 7.050E-07 | 0.00722 |
| Beans | Children | Chromium | 1.342 | 1.000E-06 | 5.4E-07 |
| Beans | Adult | Copper | 0.504 | 2.317E-07 | 0.0004 |
| Beans | Children | Copper | 1.471 | 3.288E-07 | 7.9E-06 |
| Beans | Adult | Lead | 0.331 | 1.525E-07 | 0.00114 |
| Beans | Children | Lead | 0.968 | 2.163E-07 | 4.6E-07 |
| Beans | Adult | Zinc | 0.004 | 2.018E-09 | 1.7E-06 |
| Beans | Children | Zinc | 0.012 | 2.863E-09 | 5.2E-07 |

If HQ < 1, it means that there are no adverse health consequences, whereas HQ > 1 suggests that there are probably harms [22].

mg/m3, with the highest recorded in children consuming 8.591E-9-2.229E-9 mg/m3, all values were within the permissible range for both adult and children.

No acceptable limit is established for cadmium, chromium, copper, lead and zinc exposure via dermal.

Table 5 shows the estimated exposure values for heavy metals through dermal absorption. For cadmium, adult dermal exposure values ranged from 4.304E-8 mg/kg/day (LPR) to 2.516E-7 mg/kg/day (CPR), while children recorded values between 2.255E-7–1.3188E-6 mg/kg/day. The highest Cd dermal exposure in children was from CPR (1.3188E-6 mg/kg/day). Chromium dermal absorption dose ranged from (beans) – 1.0330E-7–1.996E-7 (LPR) mg/kg/day in adults and 0.00185.412E-7–1.046E-6 mg/kg/day in children. Copper exposure through dermal contact ranged from (CPR) 2.2300E-7–1.509E-6 (Beans) mg/kg/day for adults and 1.168E-6–7.908E-6mg/kg/day for children, with the highest recorded in beans. Lead dermal

**Table 7:** Hazard index via ingestion of crops and legume for adult and children.

| | Age | LPR | CPR | Beans |
|---|---|---|---|---|
| HQ Ing | Adult | 1.565 | 3.448 | 2.087 |
| | Children | 44.29 | 97.56 | 6.087 |
| HQ Inh | Adult | 1.E-06 | 2.5E-06 | 1.452E-06 |
| | Children | 2.6E-6 | 3.6E-06 | 2.060E-06 |
| HQDer | Adult | 0.004 | 0.012 | 0.004 |
| | Children | 0.0250 | 0.064 | 0.021 |

HI≤1 no significant risk of non-carcinogenic effects. HI>1, there is a chance that non-carcinogenic effects may occur [24].

absorption exposure ranged from 1.272E-7 (LPR) -9.182E-8 (CPR) mg/kg/day for adults and 4.553E-7–6.669E-7 mg/kg/day in children, while zinc ranged between9.858E-8–1.340E-6 mg/kg/day across all samples.

Table 6 showed the hazard quotient via ingestion, inhalation and dermal contact of locally processed rice, company processed rice and beans exposed with heavy metals for children and adult. For adult hazard quotients, cadmium, chromium, copper, lead and zinc were below 1 suggesting non-carcinogenic health risk is unlikely to occur in LPR, CPR and beans but cadmium hazard quotient value in CPR was above 1 (2.69), so this is suggesting a non-carcinogenic health issue as a result of consuming CPR due to cadmium dose.

For children, the hazard quotient of cadmium via ingestion was above 1 in LPR (13.02), CPR (76.14) and Beans (2.293) respectively, showing that cadmium will like cause non-carnogenic health effect in the near future. Chromium hazard quotient was also greater than 1 in both the crops; LPR (20.13), CPR (11.53) and Beans (1.342). Copper HQ was also above 1 in CPR (1.68) and beans (1.47). Lead HQ was also higher than 1 in LPR (11.00) and CPR (7.93) indicating possible non carcinogenic health effect due to lead consumption in LPT and CPR. Hazard quotient via ingestion of zinc in LPR, CPR and Beans were below 1. Moreover, hazard quotients via inhalation of dust particles containing cadmium, chromium, copper, lead and zinc from LPR, CPR and Beans threshing, milling or bagging were below 1 indicating non carcinogenic health effect are unlikely to happen for adult and children. Hazard quotient via skin absorption of cadmium, chromium, copper, lead and zinc from LPR, CPR and Beans is unlikely to cause non carcinogenic health effect for both children and adults because the HQ values were below 1.

Table 7 showed hazard index via ingestion, inhalation and dermal absorption of heavy metals in crops for adult and children where LPR (1.56), CPR (3.44) and beans (2.08) hazard index values via ingestion for adult were above 1 indicating risk of non-carcinogenic. Children hazard index values via ingestion were also above 1 in LPR (44.29), CPR (97.56) and beans (6.08) indicating risk of non-carcinogenic due to the crops consumption.

Hazard index via inhalation of cadmium, chromium, copper, lead and zinc in crops were below 1 indicating no non carcinogenic risk will occur as a result of dust inhalation from threshing of crops. Non carcinogenic risk is unlikely to occur due to skin absorption of heavy metals from LPR, CPR and beans because the hazard index via dermal contact were below 1.

**Table 8**: Carcinogenic and Total carcinogenic risk of heavy metals in the selected crops.

| SAMPLE | AGE | CRIng | Crinh | TCR |
|---|---|---|---|---|
| **LPR** | Adult | 0.003875068 | 1.78098E-08 | 0.003875086 |
| | Children | 0.009397041 | 6.31654E-09 | 0.009397047 |
| **CPR** | Adult | 0.017029699 | 1.32156E-08 | 0.017029712 |
| | Children | 0.041297019 | 4.68714E-09 | 0.041297024 |
| **Beans** | Adult | 0.005486849 | 9.70075E-09 | 0.005486859 |
| | Children | 0.001371712 | 3.44053E-09 | 0.001371716 |

TCR = 1.00E-06 is negligible; TCR = 1.00E-04 is acceptable and TCR exceeding 1.00E-04 is likely to be harmful to human health [26].

Table 8 showed carcinogenic and total carcinogenic risk via inhalation and ingestion of heavy metals in crops selected, carcinogenic risk *via* consumption of LPR, CPR and Beans were all above the threshold level 1.00E-04 indicating cancer risk for both adult and children and the values ranged from 0.003 (LPR)- 0.01(CPR) for adults and 0.001(beans)- 0.04 (CPR) in children. While the carcinogenic risk *via* inhalation of heavy metals in dust particles as a result of threshing, milling or processing of LPR, CPR and / or beans were at the negligible dose indicating no carcinogenic health effect is likely to occur due to dust inhalation.

Total cancer risk values for LPR (0.0038), CPR (0.0171) and beans (0.0054) for adult indicate that carcinogenic health effect is likely to happen. Total cancer risk for children also indicate carcinogenic health effect in the future; LPR (0.0093), CPR (0.041) and beans (0.0013) respectively.

## Discussion

The study revealed elevated concentrations of cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb) in locally processed rice (LPR), company processed rice (CPR), and beans sold in northern Nigeria, The occurrence of these heavy metals in LPR, CPR and beans may be associated with intensive agricultural practices, indiscriminate pesticide application, contaminated irrigation water, atmospheric deposition, poor post-harvest handling, and contamination during processing and storage.

Cadmium concentrations especially in company processed rice may be attributed to prolonged use of phosphate fertilizers and metal-containing pesticides, which are recognized sources of Cd contamination in agricultural soils. Rice has a strong tendency to accumulate cadmium because paddy soils facilitate Cd mobility and uptake by plant roots. Comparable international findings were also reported in china and Bangladesh, where cadmium contamination in rice was associated with fertilizer application and industrial emissions [28,29]. Chronic exposure to cadmium is associated with kidney dysfunction, skeletal damage, and carcinogenic effects.

The elevated Cr concentration in locally processed rice may originate from contaminated irrigation water, industrial discharge, and soil contamination from agrochemicals. Chromium contamination in cereals has been previously reported in northern Nigeria, especially in areas affected by tannery waste and industrial runoff. Similar findings were reported in Kano and Kaduna where Cr concentrations in grains exceeded recommended limits [1]. Studies from India and Pakistan also documented elevated chromium levels in rice and legumes grown near industrial regions [30,31]. Excessive chromium exposure may result in liver toxicity, respiratory complications, and increased carcinogenic risk, especially when present in its hexavalent form.

The elevated copper content in beans may be linked to the natural ability of legumes to accumulate micronutrients from soil, as well as the application of copper-based fungicides and pesticides. Similar observations were reported in studies conducted in Nigeria where beans and cowpea samples contained elevated copper concentrations due to agrochemical usage and environmental contamination [32]. Studies from Turkey and Egypt reported elevated Cu concentrations in legumes and cereals cultivated in polluted agricultural environments [33,34]. Although copper is an essential trace element, prolonged intake above permissible levels may result in gastrointestinal disorders, liver damage, and oxidative stress.

Lead contamination in cereals may result from vehicular emissions, atmospheric deposition, contaminated soil, improper storage facilities, and use of lead-containing pesticides. The high Pb concentration in locally processed rice may additionally reflect contamination during local milling and processing activities. Similar elevated Pb levels in rice and beans have been reported in studies from Lagos and Jos where food crops cultivated near traffic and mining zones accumulated substantial lead concentrations [35,36]. Studies in Iran and Ghana similarly observed Pb contamination in rice and legumes sold in urban markets [37,38]. Lead exposure is highly toxic and may cause neurological damage, developmental disorders in children, and cardiovascular complications.

Zinc is an essential micronutrient required for normal physiological function, and its lower concentration compared to other metals may reflect better biological regulation within crops. Similar findings of acceptable Zn concentrations have been reported in cereals from Nigeria and other developing countries [39,40].

These elevated CF values for Cd, Cr and Pb suggest significant anthropogenic contributions, including agrochemical application, environmental pollution, processing contamination, vehicle emissions, and storage practices that facilitate metal accumulation in agricultural soils and subsequent uptake by crops. Similar severe contamination factors in rice and legumes were reported in studies conducted in China and Ethopia where intensive farming practices and industrial activities contributed substantially to heavy metal accumulation in crops [41,42].

The significant higher exposure doses in children may be due to children's lower body weight, higher food intake relative to body mass and increased susceptibility to environmental contaminants. The elevated cadmium and copper through ingestion demonstrated that children are more vulnerable to heavy metal toxicity due to physiological and metabolic differences [43,44].

Low inhalation exposure values and hazard quotients in both adults and children reflect medium exposure to contaminated dust particles generated during grain handling, transportation, milling, and market activities. Incomparable findings have been reported in occupational exposure studies among grain handlers in Nigeria and India where inhalation of contaminated dust was identified as a major exposure pathway [45,46].

Hazard index *via* ingestion values above 1 suggest potential adverse health effects among consumers, especially children. Similar elevated HQ and HI values have been reported in cereals from mining and industrial regions of Nigeria, China, and Pakistan [47,48].

These elevated carcinogenic risks especially in Company processed rice may largely be attributed to cadmium and chromium contamination, both recognized carcinogenic metals. Similar carcinogenic risk levels in rice and legumes have been reported in studies conducted in Bangladesh, China, and parts of Nigeria affected by environmental pollution and intensive agriculture [29,49].

The observed contamination pattern (Cd > Cr > Pb > Cu > Zn) suggests that anthropogenic activities are major contributors to heavy metal accumulation in the investigated food commodities. Agricultural intensification involving repeated fertilizer and pesticide application has been identified as a significant source of Cd and Cr contamination in food crops [5,8]. Furthermore, atmospheric deposition from vehicular emissions, industrial activities, and contamination during storage and processing may have contributed to the elevated Pb concentrations observed in the present study. Similar contamination trends have been reported in cereals marketed in Southwestern Nigeria [50], Northwest Nigeria [13], Bangladesh [29], and China [9], indicating that heavy metal contamination of staple foods remains a global food safety concern.

## Conclusion

Cadmium, Chromium, Copper and Lead exceeded the WHO permissible limit, while zinc was below the WHO limit. Contamination factor (CF) showed very high contamination for Cd in CPR, high CF values Cr across all the samples, low Cu and Zn contamination across all samples, considerable contamination in Pb across all samples. Exposure assessment revealed that children were more vulnerable than adults across all pathways. Hazard quotient (HQ) values through ingestion were below 1 for adult in LPR and beans while for CPR, the HQ *via* ingestion for adult was above the threshold. HQ *via* ingestion for children was extremely high especially in CPR.

HQs *via* inhalation of heavy metals from air particle during milling, threshing/ bagging of crops were relatively less than 1, while the Hazard index (HI) values *via* inhalation and dermal absorption were also less than 1 for both adult and children. HI values *via* ingestion were greater than 1 across all samples for both adult (LPR, CPR & Beans) and children (LPR, CPR and beans) respectively. Total carcinogenic risks indicate probable cancer risk for both adult and children. The study concludes that consuming the investigated crops may pose non-carcinogenic and carcinogenic health risks particularly to children, and highlights the need for stricter monitoring of food contamination, pesticide usage in agricultural systems and strengthened food safety surveillance programs, and public awareness campaigns aimed at reducing dietary exposure to toxic metals. Future studies should include larger sample sizes, seasonal assessments, source apportionment analyses, and validation of exposure models to improve risk characterization and support evidence-based food safety policies.

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## Author's contribution

All the authors involved in this paper have contributed to the success of this study.

## Conflict of interest

There is no any conflict of interest among the authors in whatever form.

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## Data availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

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