

Comparative Assessment of Heavy Metal Concentrations in Soya Beans, White Beans, and Red Beans Sold in Gamawa Local Government Area, Bauchi State, Nigeria

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ABSTRACT

This work quantified and compared four heavy metals — cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn) — across soya beans (*Glycine max*), white beans, and red beans (*Phaseolus vulgaris*) marketed in Gamawa Local Government Area, Bauchi State, Nigeria. A total of twenty-seven samples, drawn from three wards (Kafiromi, Alagarno, and Tumbi), were subjected to tri-acid digestion ($\text{HNO}_3\text{:HClO}_4\text{:H}_2\text{SO}_4$, 5:1:1) prior to elemental analysis using Microwave Plasma Atomic Emission Spectrophotometry (MP-AES 4200). Of the three legume types, soya beans carried the greatest burden of all four metals (Cd 0.12, Cr 0.85, Cu 8.45, Zn 25.60 mg kg^{-1}), with red beans intermediate and white beans lowest. Against FAO/WHO permissible limits, only cadmium in soya beans and red beans surpassed the 0.10 mg kg^{-1} ceiling; chromium, copper, and zinc stayed within acceptable bounds throughout. Metal loads varied by location, with Kafiromi ward showing the greatest contamination and Alagarno the least. Applying the Daily Intake of Metals (DIM), Hazard Quotient (HQ), and Hazard Index (HI) framework, all computed HI values (0.443–0.513) fell beneath the threshold of 1, pointing to no meaningful non-carcinogenic risk at present consumption levels. Overall, the three bean types appear largely safe to eat, though the cadmium overshoot in soya beans and red beans justifies ongoing surveillance of local soils, irrigation sources, and food crops, together with better agronomic practices and food-safety outreach.

Keywords: Heavy metals; Soya beans; White beans; Red beans; Bioaccumulation; Hazard index; Food safety.

INTRODUCTION

Growing global concern over food safety has driven substantial research into the health consequences of eating food contaminated with pesticides, heavy metals, and other toxicants (D'mello, 2019; Shaheen et al., 2020). Heavy metals in particular stand out among these contaminants as a leading public-health concern because they persist in the environment and accumulate within living tissue. Their contamination has spread across much of the world, disrupting ecosystems and threatening human health, driven largely by rapid urban growth, changing land use, and industrial expansion — pressures that are especially pronounced in densely populated developing nations (UN-HABITAT, 2019).

Metallic elements classed as heavy metals threaten human health and are typically defined by a density at least five times greater than that of water. After entering the environment through air, water, food, or human-made products, they reach the human body via inhalation, ingestion, and skin contact (Maigari et al., 2017). Because these metals can build up in body tissue faster than the body's own detoxification pathways can clear them, even sustained low-level exposure — not only acute high doses — can eventually reach harmful concentrations (Surudii & Khanna, 2020).

The International Agency for Research on Cancer classifies cadmium (Cd) and its compounds as Group 1 human carcinogens, with documented links to cancers of the lung, kidney, and prostate, as well as damage to the lungs, bones, and kidneys (IARC, 2021; Godt et al., 2006; Nishijo et al., 2017). Exposure to lead (Pb) produces effects spanning subtle metabolic and cognitive changes through to convulsions, coma, and kidney failure, and inorganic lead compounds are considered probable human carcinogens (IARC, 2006; Papanikolaou et al., 2005). Arsenic

and its inorganic forms carry the same Group 1 carcinogen classification, with exposure tied to cancers of the skin, liver, lung, and bladder (IARC, 2019).

Legumes such as soya beans, red beans, and white beans occupy a central place in Nigerian diets owing to their protein content, yet these same crops can take up heavy metals from polluted soils, irrigation sources, and farm inputs, creating a possible exposure route for consumers (Antonious & Konchhar, 2009; Barau, 2018). How much metal a legume absorbs is shaped by soil pH, organic-matter levels, fertilizer choice — phosphate fertilizers being a common cadmium source — and the quality of the water used for irrigation (Boyd & Rajakaruna, 2013; Chaffai & Koyama, 2011). Because the health risks of heavy-metal exposure are well established while data on contamination of legumes sold in Gamawa Local Government Area remain scarce, this study set out to quantify and compare cadmium, chromium, copper, and zinc levels in soya beans, white beans, and red beans across three of its wards (Kafiromi, Alagarno, and Tumbi), and to estimate the resulting non-carcinogenic health risk to consumers using standard USEPA risk indices.

MATERIALS AND METHODS

A. Study Area

This research took place in Gamawa Local Government Area (LGA), Bauchi State, Nigeria, situated roughly 270 km north of Bauchi town (11°18'49"N, 10°27'59"E). Spanning about 1,436 km² within the Sudan Savannah belt, the LGA is dominated by sandy loam and clay loam soils, experiences a tropical climate averaging 25–35 °C, and receives 800–1,000 mm of rain annually, mostly between June and September. Farming — encompassing legumes, cereals, and vegetables — is the main livelihood of residents. Three wards, Kafiromi, Alagarno, and Tumbi, were chosen at random for the study.

B. Sample Collection and Preparation

In each of the three wards, soya beans (*Glycine max*), white beans (*Phaseolus vulgaris* L.), and red beans (*Phaseolus vulgaris*) were obtained from three randomly chosen market points, with three replicate portions (about 500 g each) taken per point during the November–December harvest peak. Each sample was sealed in a clean, labeled black polythene bag to guard against light-induced degradation and cross-contamination, then transported without delay to the Chemistry Laboratory at Aminu Saleh College of Education, Azare, where it was held at 4 °C pending processing.

Each sample was rinsed under running tap water, followed by three deionized-water rinses, then air-dried for 48 hours at 25 ± 2 °C before oven-drying at 70 °C for 24 hours until a constant weight was reached. The dried material was reduced to a fine powder with a ceramic mortar and pestle, passed through a 2 mm sieve, and kept in sealed, labeled containers within a desiccator until analysis (Sharma, 2018).

C. Digestion and Instrumental Analysis

The digestion procedure was adapted from Sharma et al. (2018). About 2.0 g of each powdered sample was treated with 15 mL of a tri-acid blend (70% nitric acid, 65% perchloric acid, and 70% sulfuric acid in a 5:1:1 v/v/v ratio) and heated at 80 °C inside a fume hood for 2–3 hours until the digest ran clear. The digest was then filtered through Whatman No. 42 paper and brought up to a final volume of 100 mL with deionized water. A reagent blank underwent the same digestion procedure alongside the samples as a quality-control measure.

Zinc, copper, chromium, and cadmium levels in the digests were quantified using atomic absorption spectrophotometry (AAS, Buck Scientific 210 VGP) alongside Microwave Plasma Atomic Emission Spectrophotometry (MP-AES 4200), both calibrated against certified 1000 mg/L stock standards (Merck). Wavelengths of 213.9 nm, 217.0 nm, 357.9 nm, and 228.8 nm were used for Zn, Cu, Cr, and Cd respectively, with an air-acetylene flame and triplicate aspiration of every sample. Metal concentrations were derived from calibration curves and reported as mg kg⁻¹ on a dry-weight basis.

Quality assurance encompassed running samples in triplicate, correcting against blanks, spike-recovery checks that returned 95–105% recovery, establishing detection and quantification limits, and pre-soaking all glassware

in 10% HNO₃ before use. Data were analyzed in Minitab 17, with results presented as mean $\pm$ standard deviation; differences among bean types and wards were tested using one-way ANOVA, followed by Tukey's HSD post-hoc test where warranted, at a significance level of $p < 0.05$.

D. Health Risk Assessment

The Daily Intake of Metals (DIM, mg kg⁻¹ body weight day⁻¹) was obtained from the equation $DIM = (M \times K \times I) / W$, in which M denotes the metal concentration measured in the sample, K is a fresh-to-dry weight conversion factor (0.085), I represents the assumed daily bean consumption of a Nigerian adult (0.086 kg day⁻¹), and W is the mean adult body weight (60 kg). For each metal, the Hazard Quotient (HQ) followed $HQ = DIM / RfD$, using the USEPA (2006) oral reference doses (Cd = 0.001, Cr = 1.5, Cu = 0.04, Zn = 0.3 mg kg⁻¹ body weight day⁻¹). Summing the individual HQ values across all four metals yielded the Hazard Index (HI), a measure of cumulative non-carcinogenic risk; values below 1 signal no meaningful health concern (USEPA, 2006).

RESULTS AND DISCUSSION

A. Heavy Metal Concentrations in Bean Samples

The mean concentrations (mg kg⁻¹, n = 3) of cadmium, chromium, copper, and zinc measured in soya beans, white beans, and red beans, alongside the corresponding FAO/WHO permissible limits, are summarized in Table 1.

Table 1. Mean Concentrations of Heavy Metals in Soya Beans, White Beans, and Red Beans

Bean Sample	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Soya Beans	0.12	0.85	8.45	25.60
White Beans	0.09	0.72	7.90	22.40
Red Beans	0.11	0.78	8.10	24.10
FAO/WHO Permissible Limit	0.10	1.30	10.00	50.00

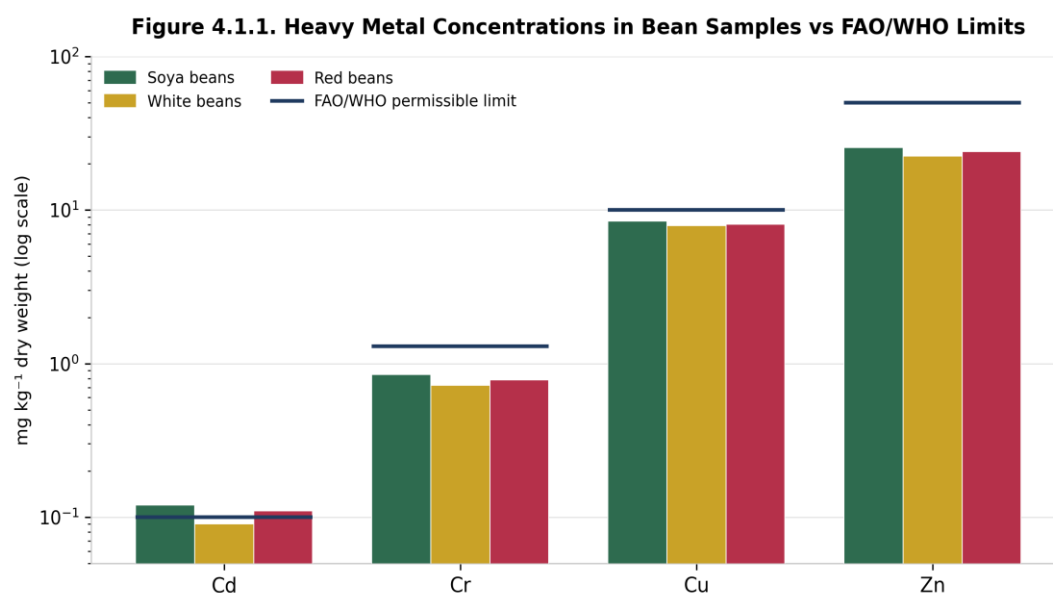


Figure 1. Heavy Metal Concentrations in Bean Samples vs FAO/WHO Limits

Both soya beans (0.12 mg kg^{-1}) and red beans (0.11 mg kg^{-1}) carried cadmium levels 10–20% above the FAO/WHO ceiling of 0.10 mg kg^{-1} , whereas white beans (0.09 mg kg^{-1}) stayed within bounds. This slight overshoot could stem from a stronger tendency of soya beans to take up cadmium compared with other legumes, compounded by local variation in soil pH, organic-matter content, or phosphate-fertilizer use, all factors known to raise cadmium's availability to plants (Blaylock & Huang, 2020). By contrast, chromium ($0.72\text{--}0.85 \text{ mg kg}^{-1}$), copper ($7.90\text{--}8.45 \text{ mg kg}^{-1}$), and

zinc ($22.40\text{--}25.60 \text{ mg kg}^{-1}$) all sat comfortably beneath their respective FAO/WHO limits of 1.30, 10.00, and 50.00 mg kg^{-1} . Notably, soya beans topped the concentration ranking for every metal measured, with red beans next and white beans lowest — a pattern that held consistently enough to point toward inherent physiological or genetic differences in metal uptake among the three legumes rather than chance variation in sampling.

B. Spatial Variation Across Sampling Wards

Table 2. Heavy Metal Concentrations in Bean Samples from Different Wards of Gamawa LGA

Ward	Bean Type	Cd	Cr	Cu	Zn
Kafiromi	Soya	0.13	0.88	8.62	26.10
Kafiromi	White	0.10	0.75	8.05	23.00
Kafiromi	Red	0.12	0.81	8.25	24.80
Alagarno	Soya	0.11	0.82	8.30	25.20
Alagarno	White	0.08	0.70	7.80	21.80
Alagarno	Red	0.10	0.75	8.00	23.50
Tumbi	Soya	0.12	0.85	8.45	25.50
Tumbi	White	0.09	0.72	7.85	22.40
Tumbi	Red	0.11	0.78	8.05	24.00

Across every bean type, Kafiromi ward showed the heaviest metal burden (for instance, soya beans: Cd 0.13 , Cr 0.88 , Cu 8.62 , Zn 26.10 mg kg^{-1}), Alagarno ward the lightest (for instance, white beans: Cd 0.08 , Cr 0.70 , Cu 7.80 , Zn 21.80 mg kg^{-1}), and Tumbi fell in between. Looking specifically at cadmium, both soya and red beans breached the FAO/WHO limit in Kafiromi and Tumbi, while in Alagarno only red beans reached the limit exactly, without exceeding it. Such geographic variation likely reflects differences among wards in soil pH, organic-matter content, irrigation-water quality, or phosphate-fertilizer application, given that more acidic soils are known to make metals more available for plant uptake (Boyd & Rajakaruna, 2013). Still, even in Kafiromi, the concentrations recorded fall short of signaling any acute risk under typical consumption.

C. Health Risk Assessment

For an adult eating 86 g of cooked beans daily, the calculated Daily Intake of Metals (DIM) fell well under the USEPA reference dose for every metal examined (Table 3). Cadmium's DIM from soya beans, for instance,

reached just $0.00015 \text{ mg kg}^{-1} \text{ day}^{-1}$ — only 15% of its RfD of 0.001 — while copper's DIM from soya beans (0.01030) accounted for 26% of its RfD (0.04), the closest any metal came to its reference threshold.

Table 3. Daily Intake of Metals (DIM) for Consumers

Bean Sample	Cd	Cr	Cu	Zn
Soya Beans	0.00015	0.00104	0.01030	0.03120
White Beans	0.00011	0.00088	0.00963	0.02730
Red Beans	0.00013	0.00095	0.00987	0.02940
RfD (USEPA, 2006)	0.001	1.50	0.04	0.30

Figure 4.3. Daily Intake of Metals (DIM) vs USEPA Reference Dose (RfD)

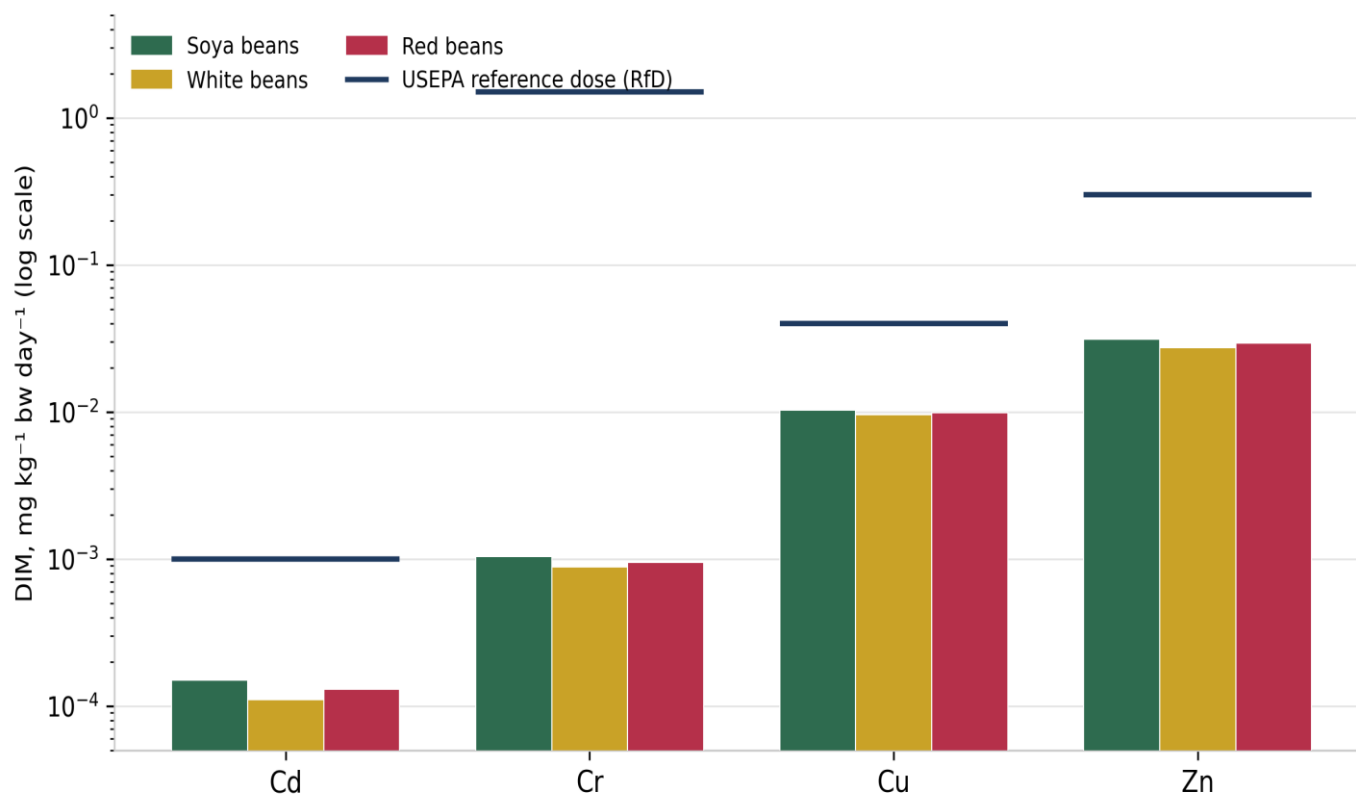


Figure 2. Daily Intake of Metals (DIM) vs USEPA Reference Dose (RfD)

Consistent with the low DIM values, the Hazard Quotients (Table 4) for all four metals stayed small, with copper (0.241–0.258) and cadmium (0.110–0.150) contributing the most to overall risk. Summed across metals, the Hazard Index ranged from 0.443 for white beans to 0.513 for soya beans, comfortably under the threshold of 1 for every bean type examined.

Table 4. Hazard Quotient (HQ) for Each Heavy Metal in Bean Samples

Bean Sample	HQ Cd	HQ Cr	HQ Cu	HQ Zn	HI (Total)
Soya Beans	0.150	0.0007	0.258	0.104	0.513
White Beans	0.110	0.0006	0.241	0.091	0.443
Red Beans	0.130	0.0006	0.247	0.098	0.476

Note: HI < 1 indicates no significant non-carcinogenic health risk.

Figure 4.4. Hazard Quotient (HQ) by Metal and Hazard Index (HI) per Bean Type

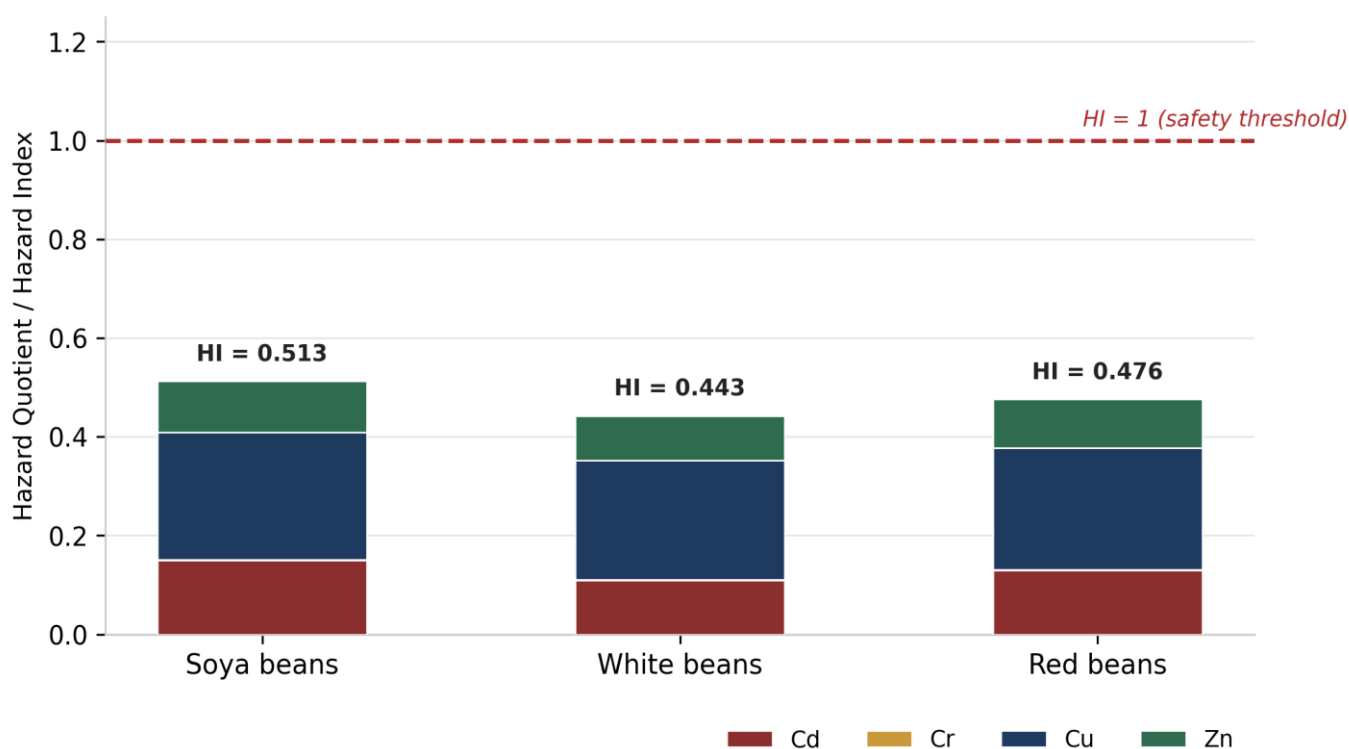


Figure 3. Hazard Quotient (HQ) by Metal and Hazard Index (HI) per Bean Type

By comparison, Zhou et al. (2020) reported far higher HI values — 5.41 for children and 4.12 for adults — in legumes grown in heavily industrialized or mining-impacted settings, underscoring that contamination levels in Gamawa LGA remain relatively modest. Nevertheless, the cadmium exceedance found in soya beans and red beans should not be brushed aside simply because it does not translate into an unsafe cumulative intake: cadmium persists in the body for 10–30 years and has been linked to chronic renal and skeletal harm (Godt et al., 2006). Sustained monitoring, particularly around Kafiromi ward, remains advisable.

CONCLUSION

This investigation measured cadmium, chromium, copper, and zinc in soya beans, white beans, and red beans marketed across three wards of Gamawa Local Government Area, Bauchi State, Nigeria, and evaluated the non-carcinogenic risk these levels pose to consumers. Chromium, copper, and zinc stayed within FAO/WHO permissible limits throughout, but cadmium in soya beans and red beans exceeded the recommended ceiling;

soya beans consistently accumulated the most of all four metals, and Kafiromi ward emerged as the most contaminated site overall. Even so, the resulting Hazard Index values (0.443–0.513) remained comfortably under the safety threshold of 1 across all bean types, indicating that present consumption habits carry no significant non-carcinogenic risk. That said, the cadmium exceedance documented here strengthens the case for regular monitoring of heavy metals in local soils, irrigation water, and food crops, for adopting agricultural practices that limit metal inputs, and for continued public education on food safety — particularly given cadmium's long biological persistence and its links to chronic kidney and bone damage.

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