

RISK EVALUATION OF THE CONCENTRATION OF HEAVY METALS IN SEEDS, CEREALS, AND LEGUMES SOLD IN NASARAWA MAJOR MARKET, NIGERIA

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Abstract

Heavy metal contamination in food crops can pose non carcinogenic and carcinogenic health risks, particularly to children. This study assessed selected metals in black eye bean, soya bean, millet, sorghum, sesame, and locust bean. The metals arsenic, nickel, aluminium, copper, magnesium, potassium, calcium, and sodium were evaluated using inductively coupled plasma optical emission spectrometry, and exposure was estimated using estimated daily intake, hazard quotient, hazard index, and target carcinogenic risk for adults and children. The essential macro elements were quantified and reported for nutritional context, while health risks for the potentially toxic metals were estimated using the United States Environmental Protection Agency framework for ingestion and dermal exposure pathways. The hazard quotient for arsenic, nickel, aluminium, and copper were below one for adults, but children showed elevated values for arsenic and copper. Hazard index values for potentially toxic metals were below one for both adults and children, indicating no significant non carcinogenic risk, and dermal exposure was negligible. However, the findings indicate that although non carcinogenic hazard from these crops remains within acceptable limits, chronic dietary exposure to arsenic and nickel poses a carcinogenic risk exceeding the recognised acceptable threshold of one in ten thousand across the entire study population, with sesame and sorghum identified as priority crops. Correlation, principal component analysis, and cluster analysis indicated meaningful associations among the metals, with several elements grouping in ways that suggest related behaviour or common accumulation pathways.

Keywords: heavy metals; food crops; health risk assessment; children; carcinogenic risk; adults

1. Introduction

Plant derived food crops such as legumes, cereals, and seeds offer an affordable source of high quality nutrients accessible to a broad population, particularly in developing nations (Pirsaheb et al., 2016). In Nigeria, these crops serve as a primary and economical component of both human and animal diets owing to their rich content of macro and micronutrients (Prasanthi et al., 2017). Legumes, among the earliest crops domesticated by humans, remain a dietary staple across many parts of the world, providing essential amino acid rich proteins, complex carbohydrates, dietary fibre, healthy unsaturated fats, vitamins, and vital minerals (Paiva et al., 2022; Poutanen, Sozer, and Della Valle, 2014). Cereals, belonging to the Poaceae family, are produced in larger quantities than any other crop and provide the greatest amount of food energy globally, supplying essential energy, proteins, vitamins, and minerals to populations worldwide (Nyachoti, Adebayo, and Godebo, 2021).

Plants absorb various heavy metals from the soil into their edible tissues, which can be either essential or non essential to plants and to the animals that consume them. Essential metals are required in either macro or trace amounts to support vital physiological functions, while imbalances, either deficiencies or excesses, can cause a range of health problems (McDowell, 2003). Non essential metals, often referred to as potentially toxic metals, provide no health benefits and may be harmful to humans and animals, with exposure leading to both non carcinogenic and carcinogenic outcomes depending on the metals involved (ATSDR, 2005). The introduction of such toxic metals into agricultural soils is continuously increasing owing to human activities, including the application of fertilisers and agrochemicals as well as atmospheric deposition from expanding urban and industrial sources (Pirsaheb et al., 2016).

Food safety is a critical global public health issue, with food consumption recognised as the primary pathway for human exposure to many environmental contaminants, accounting for more than ninety per cent of intake compared with inhalation or skin contact (Khan et al., 2008; TатаhMentan et al., 2023). Consuming heavy metals such as arsenic, nickel, copper, and aluminium can disrupt the essential nutrient balance of the body, potentially weakening immune defences and contributing to a range of adverse developmental and health outcomes. Given significant agricultural activities, ongoing industrialisation, urban growth, and rising population density, measuring heavy metal levels in consumer goods is crucial. This research therefore focused on measuring the levels of heavy metal concentrations, estimating daily intake levels, calculating the target hazard quotient and hazard index, and evaluating target cancer risks in frequently consumed legumes, cereals, and seeds in Nasarawa, Nigeria, to assess their overall safety and nutritional adequacy.

2. Materials and Methods

2.1 The Study Area

Nasarawa State, located in North Central Nigeria, comprises thirteen local government areas. Geographically, the state lies between latitudes 7 and 9 degrees North and longitudes 7 and 11 degrees East. One notable local government within the state is Nasarawa Local Government Area, with its administrative headquarters located in Nasarawa town at coordinates 8 degrees 32 minutes North and 7 degrees 42 minutes East. According to the 2006 census, the area has a population of approximately 189,835 and covers an area of 5,704 square kilometres. The surrounding areas are agriculturally productive, cultivating crops such as melon, sorghum, millet, soya bean, beans, locust bean, sesame seeds, shea nuts, yams, and cotton. The principal markets within the local government area, namely the Nasarawa town main market, the Mararaba Udege market, and the Laminga market, serve as vital hubs for food supply, especially for rural communities engaged in farming.

2.2 Sample Collection, Preparation and Analysis

The sampling methodologies provided by Ihedioha et al. (2016) were adjusted and applied. Samples were obtained at three separate markets within the Nasarawa local government, namely the Nasarawa main markets denoted A and B, the Mararaba Udege market denoted C, and the Laminga market denoted D. Six samples of cereal comprising millet and sorghum, legumes comprising black eyed beans and soya bean, and seeds comprising sesame seed and locust bean seed were purchased from various vendors at each market. A total of one hundred and forty four samples were collected from the four locations, and these were composited into twenty four representative samples for analysis, corresponding to four locations by six crop types.

The hard materials were pulverised in a porcelain mortar, sieved through a 100 micrometre standard sieve, and retained in plastic sample vials for digestion. The wet acid digestion procedure described by Akinyele and Shokunbi (2015) was used. Each homogenised sample weighed approximately 0.5 grams and was placed in a Teflon flask, to which a mixture of 20 cubic centimetres of aqua regia in a two to one ratio of 65 per cent nitric acid and hydrochloric acid was added and digested on a heating block in a fume hood at 90 degrees Celsius for 60 minutes. After cooling, 2 cubic centimetres of 30 per cent hydrogen peroxide was added and the mixture heated until it became colourless, indicating that digestion was complete. The digest was then filtered and diluted to 50 cubic centimetres with deionised water, and each sample and reference material was processed in triplicate using an inductively coupled plasma optical emission spectrometry apparatus.

2.3 Quality Assurance and Quality Control

An Agilent 720 spectrometer, equipped with a megapixel charge coupled device detector and an autosampler, was utilised to measure the elements arsenic, nickel, aluminium, copper, magnesium, potassium, calcium, and sodium in the

food crop samples. The analysis followed the United States Environmental Protection Agency Method 200.7, adapted with specific modifications, and calibration standards were prepared according to established guidelines. The final concentration of each metal in the food crop was calculated using the formula described by Oyekunle et al. (2020):

$$C_{\text{metal}} = (A \times V \times D_f) / W \quad (1)$$

where C is the concentration of the metal in the sample, A is the instrument reading, V is the final volume of the digest, D_f is the dilution factor, and W is the mass of the sample. The recovery analysis was performed to ascertain the accuracy of the analytical procedure. The percentage recovery was calculated as:

$$\% \text{ Recovery} = [(C - C_i) / A] \times 100 \quad (2)$$

where C is the spiked sample value, C_i is the sample value, and A is the spike added. The recovery rates for the elements ranged from 93 to 117 per cent, confirming the accuracy of the method.

2.4 Health Risk Assessment

Human health risk assessment reviews data on contaminant exposures, including heavy metal concentrations in crops, to identify potential threats through oral and dermal routes for adults and children. The estimated daily intake was calculated as:

$$\text{EDI} = (C \times \text{FIR}) / \text{BW} \quad (3)$$

where FIR is the food ingestion rate, taken as 2.2 kilograms per day for adults and 1.8 kilograms per day for children, C is the metal concentration in each crop, and BW is the average body weight, taken as 70 kilograms for adults and 16 kilograms for children. The target hazard quotient for the ingestion of heavy metals was calculated as:

$$\text{THQ} = (\text{EF} \times \text{ED} \times \text{FIR} \times C) / (\text{RfD} \times \text{BW} \times \text{AT}) \times 10^{-3} \quad (4)$$

where EF is the exposure frequency of 350 days per year, ED is the exposure duration of 65 years for adults and 12 years for children, RfD is the reference oral dose, and AT is the average exposure time. The target hazard quotient for the dermal pathway was calculated as:

$$\text{THQ}_{\text{dermal}} = (\text{SA} \times \text{AF} \times \text{ABS} \times \text{EF} \times \text{ED} \times C \times \text{CF}) / (\text{RfD} \times \text{BW} \times \text{AT}) \quad (5)$$

where SA is the skin exposure area of 18,000 square centimetres for adults and 6,600 square centimetres for children, AF is the adherence factor of 0.07 milligrams per square centimetre, ABS is the dermal absorption fraction, and CF is the unit conversion factor. The hazard index, representing the sum of the hazard quotients, was calculated as:

$$\text{HI} = \sum \text{THQ}_i \quad (6)$$

If the values of THQ and HI were less than one, no significant risk from the corresponding element was

assumed, whereas values greater than one indicate potential health risks. The target cancer risk was evaluated as:

$$\text{CR} = \text{EDI} \times \text{CSF}_o \quad (7)$$

where CSF_o is the oral cancer slope factor, taken as 1.5 and 1.7 milligrams per kilogram per day for arsenic and nickel respectively. The total target cancer risk for simultaneous exposure was obtained as:

$$\text{TCR} = \sum \text{CR}_i \quad (8)$$

Target cancer risk values were assessed against the acceptable range of one in one million to one in ten thousand, with values exceeding one in ten thousand considered an unacceptable lifetime cancer risk.

3. Results and Discussion

3.1 Mean Concentration of Heavy Metals in Food Crops

Mean concentrations vary widely across metals, indicating inconsistent uptake or exposure levels. Arsenic levels ranged from 5.0 to 31.1 milligrams per kilogram, occurring primarily in black eye bean and sesame, while nickel ranged from 6.2 to 17.5 milligrams per kilogram. Aluminium reached extremes of 104 to 580 milligrams per kilogram in soya bean and sesame, and copper ranged from 20.8 to 102 milligrams per kilogram in sorghum and sesame. Among the essential elements, magnesium ranged from 4,152 to 13,956 milligrams per kilogram, potassium from 10,824 to 35,533 milligrams per kilogram, calcium from 2,983 to 24,220 milligrams per kilogram, and sodium from 4,433 to 7,795 milligrams per kilogram.

The distribution of the four potentially toxic metals across crops is presented in Figure 1. The panels reveal that sesame consistently records the highest concentrations of arsenic, aluminium, and copper, while nickel is comparatively more evenly distributed, a pattern that anticipates the crop specific risk findings developed below.

Mean Concentration of Potentially Toxic Metals in Food Crops

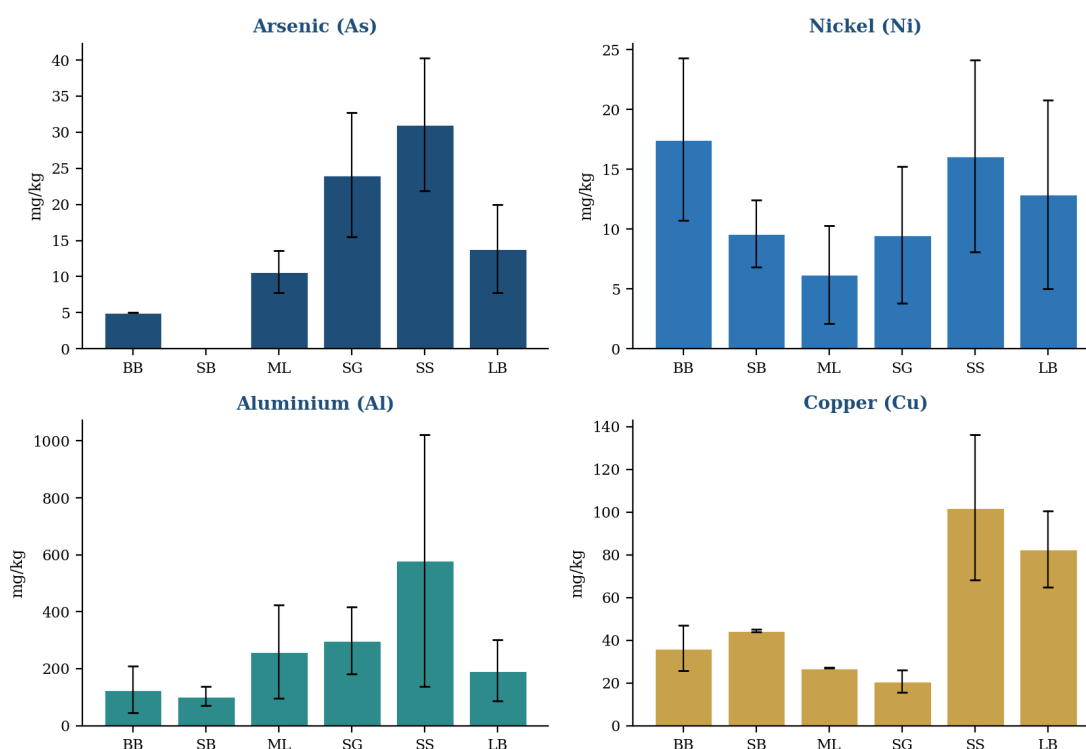


Figure 1: Mean concentration of potentially toxic metals (As, Ni, Al, Cu) in the six food crops, with error bars showing standard deviation. Key: BB, black eyed bean; SB, soya bean; ML, millet; SG, sorghum; SS, sesame; LB, locust bean. Source: Authors' laboratory analysis.

The results reveal elevated heavy metal levels in these Nigerian staples compared with prior studies, particularly for arsenic, nickel, aluminium, and copper, while the essential metals align broadly with nutritional ranges but show higher peaks. The arsenic concentration greatly exceeds typical Nigerian values reported in the range of 0.005 to 0.040 milligrams per kilogram for millet, sorghum, and beans (Obasi et al., 2020), and possible explanations for the elevated values include contamination from arsenic bearing agrochemicals, industrial activities in the region, and the sensitivity of the instrument. Nickel aligns closely with data from Ethiopia reported by Abadi et al. (2025), while copper peaks violate the Codex range of 40 to 73 milligrams per kilogram. Among the essential elements, locust bean recorded the highest magnesium and potassium content, and sesame the highest calcium and sodium, generally exceeding values reported in earlier studies (Chandra et al., 2016; Jayawardana et al., 2019).

3.2 Correlation, Principal Component and Cluster Analysis

The correlation matrix in Figure 2 reveals strong linear associations among heavy metals in the studied food crops. The copper, magnesium, and sodium triad, with copper and magnesium correlated at 0.93, magnesium and sodium at 0.93, and copper and sodium at 0.83, indicates exceptionally strong positive relationships that suggest near comobilisation through cation exchange sites on clay minerals under acidic conditions. These values exceed typical crop patterns, in which such correlations rarely exceed 0.7, signalling point source pollution over diffuse geogenic inputs. Calcium bridges this group to aluminium, reflecting competitive adsorption on the exchange complex, while the nickel associations with sodium and potassium indicate similar mobility.

The strength and structure of the inter metal associations are summarised in Figure 2. The heatmap makes the copper, magnesium, and sodium cluster immediately visible as a block of high positive coefficients, distinguishing it from the weaker associations involving potassium.

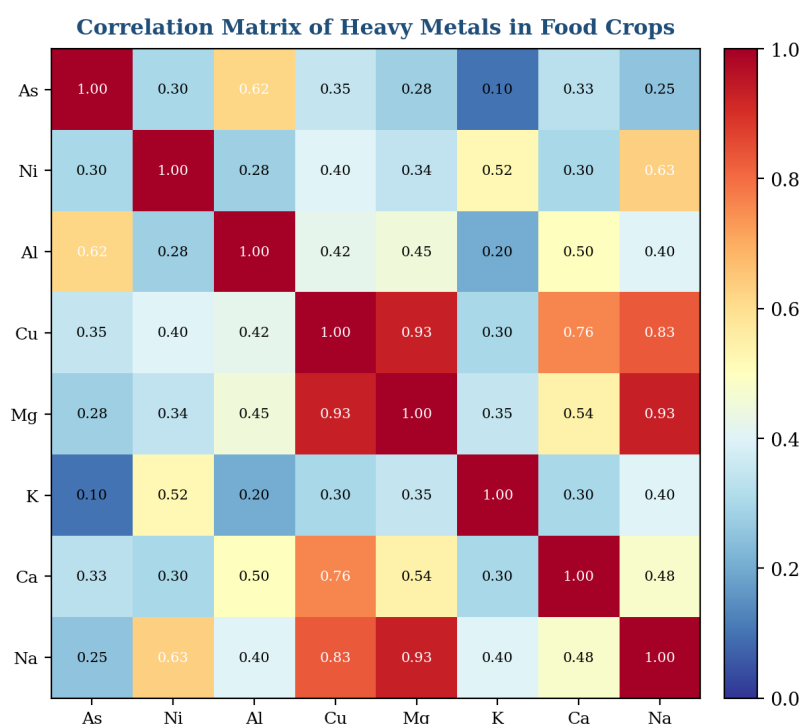


Figure 2: Correlation matrix of heavy metals in the food crops. Source: Authors' analysis.

Principal component analysis was applied to evaluate relationships among the metals and identify underlying sources. The first component, associated with arsenic, has an eigenvalue of 4.455 and explains 55.68 per cent of the total variance, suggesting a major underlying factor influencing a group of highly correlated metals. The second component, associated with nickel, has an eigenvalue of 1.733 and explains 21.67 per cent of the variance, pointing to possibly independent sources for nickel and its associated metals. Only these two components are significant, together accounting for 77.35 per cent of the variance, and the ranked contribution of the metals follows the order arsenic, nickel, aluminium, copper, magnesium, potassium, calcium, and sodium, a pattern that suggests anthropogenic contamination.

The relationships among metals in reduced dimensions are shown in Figure 3. The biplot separates arsenic and aluminium, which load negatively on the second component, from potassium, which loads strongly positive, while copper, magnesium, and sodium cluster together in the positive first component space consistent with their high mutual correlation.

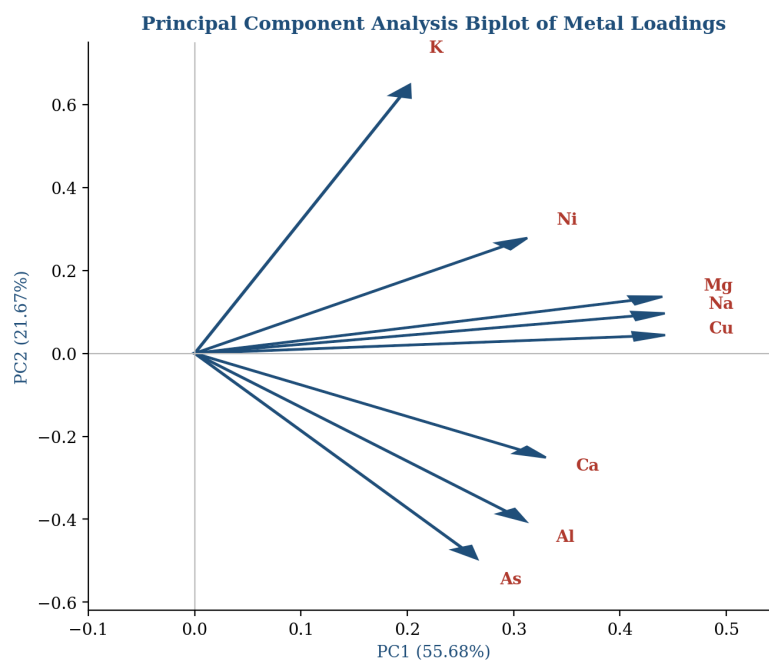


Figure 3: Principal component analysis biplot of metal loadings on the first two components. Source: Authors' analysis.

The cluster structure is confirmed in Figure 4. The dendrogram groups arsenic, nickel, copper, and aluminium in one branch and magnesium, sodium, and calcium in another, with potassium joining only at the highest distance, indicating a distinct distribution or uptake mechanism for potassium relative to the other elements.

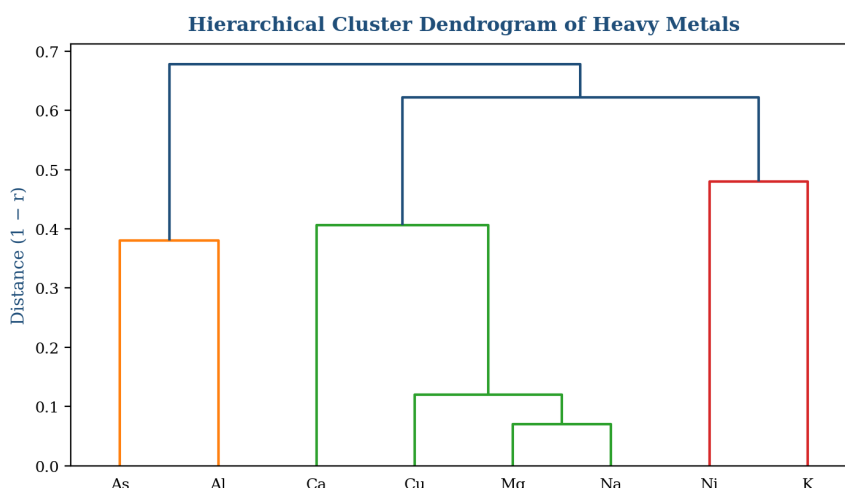


Figure 4: Hierarchical cluster dendrogram of the heavy metals based on correlation distance. Source: Authors' analysis.

3.3 Human Health Risk Assessment

The non carcinogenic health risk associated with the ingestion of arsenic, nickel, aluminium, and copper was evaluated using the hazard quotient and hazard index for both adults and children, as presented in Table 1. All individual metal hazard quotient values across the six crops were below one for both populations, indicating that exposure to any single metal through ingestion does not pose an immediate non carcinogenic risk.

Table 1. Non-carcinogenic health risk (hazard quotient and hazard index) via ingestion

Food crop	Population	As	Ni	Al	Cu	HI
Black eye beans	Adult	1.51E-04	2.64E-02	3.83E-03	2.73E-02	5.77E-02
	Child	5.39E-04	9.44E-02	1.37E-02	9.79E-02	2.07E-01
Soya bean	Adult	ND	1.45E-02	3.13E-03	3.35E-02	5.11E-02
	Child	ND	5.18E-02	1.12E-02	1.20E-01	1.83E-01
Millet	Adult	3.22E-04	9.34E-03	7.83E-03	2.04E-02	3.79E-02
	Child	1.15E-03	3.34E-02	2.80E-02	7.31E-02	1.36E-01

Food crop	Population	As	Ni	Al	Cu	HI
Sorghum	Adult	7.26E-04	1.43E-02	9.03E-03	1.57E-02	3.98E-02
	Child	2.60E-03	5.12E-02	3.23E-02	5.61E-02	1.42E-01
Sesame	Adult	9.37E-04	2.43E-02	1.69E-02	7.70E-02	1.19E-01
	Child	3.35E-03	8.68E-02	6.04E-02	2.76E-01	4.27E-01

ND, not detected. HI, hazard index. Source: Authors' analysis.

The cumulative hazard index followed a consistent rank order across both population groups, namely sesame, then locust bean, then black eye beans, then soya bean, then sorghum, then millet. For adults, the hazard index ranged from 3.79E-02 for millet to 1.19E-01 for sesame, while children recorded higher values ranging from 1.36E-01 for millet to 4.27E-01 for sesame, approximately 3.6 times greater than adults owing to their higher food ingestion rates relative to body weight. All values nonetheless remained below the threshold of one.

The comparative burden across populations is shown in Figure 5. The paired bars confirm that although children consistently experience roughly threefold higher hazard indices than adults, every value remains beneath the threshold of one, so that non carcinogenic risk from ingestion is not indicated for either group.

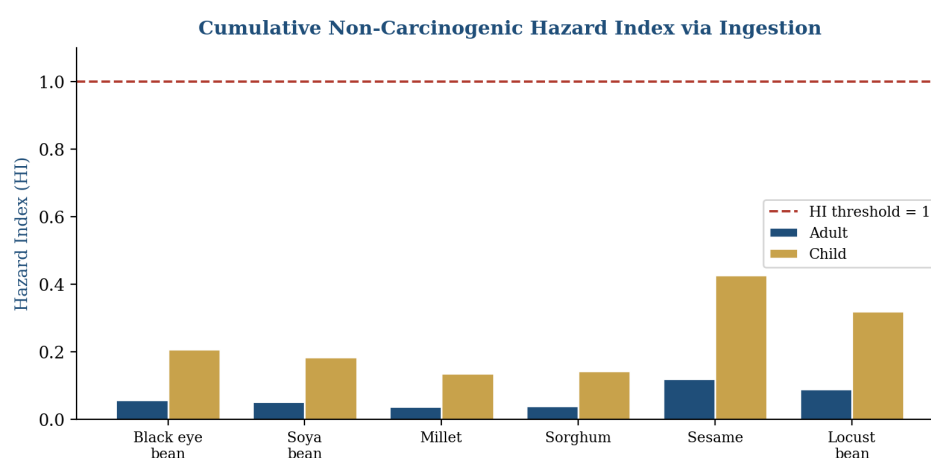


Figure 5: Cumulative non-carcinogenic hazard index via ingestion for adults and children, relative to the safe threshold of one. Source: Authors' analysis.

The dermal exposure results in Table 2 show that this pathway posed a very low non carcinogenic risk for both adults and children across all food crops, as all hazard quotient and hazard index values were well below one. Arsenic was identified as the dominant contributor to overall dermal risk, with sesame recording the highest values, yet cumulative hazard indices ranged only from 7.20E-04 to 4.39E-03 in adults and from 1.43E-03 to 8.72E-03 in children, all within safe limits.

Table 2. Non-carcinogenic health risk (hazard index) via the dermal pathway

Food crop	Population	As	Ni	Al	Cu	HI
Black eye bean	Adult	7.02E-04	1.51E-05	2.19E-06	6.27E-07	7.20E-04
	Child	1.38E-03	2.42E-05	3.52E-06	2.51E-05	1.43E-03
Soya bean	Adult	ND	8.28E-06	1.79E-06	7.68E-07	1.08E-05
	Child	ND	1.33E-05	2.88E-06	3.08E-05	4.70E-05
Millet	Adult	1.50E-03	5.35E-06	4.49E-06	4.68E-07	1.51E-03
	Child	2.96E-03	8.58E-06	7.20E-06	1.88E-05	2.99E-03
Sorghum	Adult	3.38E-03	8.20E-06	5.17E-06	3.59E-07	3.39E-03
	Child	6.67E-03	1.32E-05	8.30E-06	1.44E-05	6.71E-03
Sesame	Adult	4.36E-03	1.39E-05	9.66E-06	1.76E-06	4.39E-03
	Child	8.61E-03	2.23E-05	1.55E-05	7.07E-05	8.72E-03

ND, not detected. Source: Authors' analysis.

The carcinogenic risk posed by arsenic and nickel was evaluated using the target cancer risk model, and the results are presented in Table 3. All target cancer risk values for both adults and children across all six crops exceeded the upper acceptable threshold of one in ten thousand, indicating an unacceptable lifetime carcinogenic risk from dietary ingestion of

these crops. The total target cancer risk followed a consistent order for both groups, namely sesame, then sorghum, then black eye beans, then locust bean, then millet, then soya bean, with adult values ranging from 5.13E-04 for soya bean to 2.33E-03 for sesame and children recording higher values from 1.84E-03 to 8.33E-03.

Table 3. Target carcinogenic risk (As and Ni) for adults and children

Food crop	Population	As (CR)	Ni (CR)	TCR
Black eye beans	Adult	2.36E-04	9.35E-04	1.17E-03
	Child	8.44E-04	3.35E-03	4.19E-03
Soya bean	Adult	ND	5.13E-04	5.13E-04
	Child	ND	1.84E-03	1.84E-03
Millet	Adult	5.04E-04	3.31E-04	8.36E-04
	Child	1.81E-03	1.19E-03	2.99E-03
Sorghum	Adult	1.14E-03	5.08E-04	1.64E-03
	Child	4.07E-03	1.82E-03	5.88E-03
Sesame	Adult	1.47E-03	8.60E-04	2.33E-03
	Child	5.25E-03	3.08E-03	8.33E-03
Locust bean	Adult	6.55E-04	6.89E-04	1.34E-03

ND, not detected. CR, cancer risk. TCR, total target cancer risk. Source: Authors' analysis.

The carcinogenic risk findings are the central public health message of the study. Figure 6 plots the total cancer risk on a logarithmic axis, showing that every crop and both populations sit above the acceptable threshold, with sesame and sorghum standing out as the priority crops and children carrying the higher burden throughout.

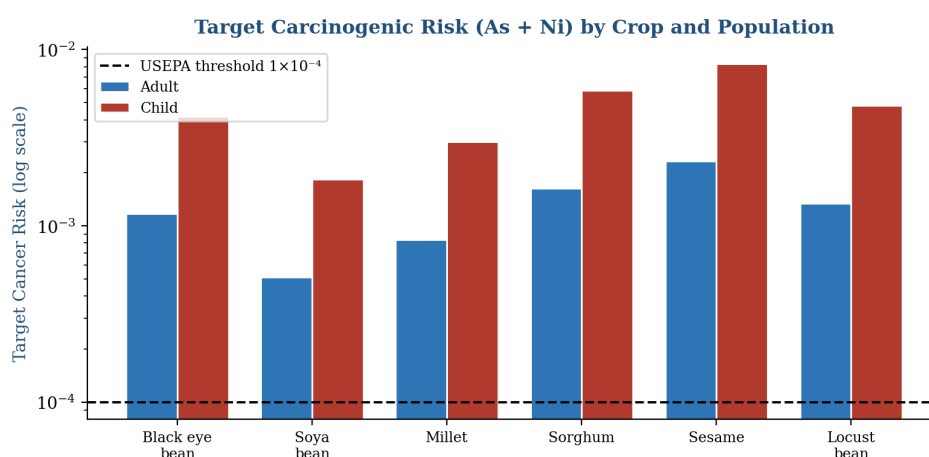


Figure 6: Target carcinogenic risk from combined arsenic and nickel exposure by crop and population, on a logarithmic scale, relative to the USEPA threshold of one in ten thousand. Source: Authors' analysis.

4. Conclusion

This study provides a systematic assessment of heavy metal contamination in six widely consumed food crops, namely black eye bean, soya bean, millet, sorghum, sesame, and locust bean, using inductively coupled plasma optical emission spectrometry and the risk assessment framework of the United States Environmental Protection Agency. Evaluating both essential macroelements and potentially toxic metals across ingestion and dermal exposure pathways, the study found that the non carcinogenic hazard indices for the potentially toxic metals remained below one for both adults and children, indicating no significant non carcinogenic risk through either pathway.

In contrast, the carcinogenic risk estimates for arsenic and nickel exceeded the recognised upper bound threshold of one in ten thousand across the entire study population, and sesame and sorghum emerged as priority crops for urgent regulatory and public health attention. These elevated values suggest that chronic dietary exposure to these crops, when consumed regularly over a lifetime, may constitute a meaningful carcinogenic risk. The multivariate analyses added an important interpretive dimension, since the observed correlations, principal component structure, and clustering pattern suggest that some metals behave similarly and may originate from related sources or follow comparable accumulation pathways, in particular the grouping of arsenic, nickel, copper, and aluminium and the association of magnesium, sodium, and calcium.

The authors recommend that food crops sold in Nasarawa markets be routinely monitored for heavy metals, with particular focus on nickel and arsenic given their carcinogenic relevance in this study. Agricultural interventions such as the use of a clean market environment, clean irrigation water, soil amendment, and cultivation in less contaminated areas should be encouraged to minimise metal uptake, and public awareness of the risks associated with chronic dietary exposure should be strengthened.

Declarations

Author Contributions Statement

Jude Ehwevwerhere Emurotu contributed to conceptualisation, methodology, supervision, validation, software, and the review and editing of the manuscript. Lydia Mariette Okorafor contributed to data curation, formal analysis, investigation, validation, and the writing of the original draft. Ephriam Musa Dallatu contributed to supervision and the review and editing of the manuscript. All authors read and approved the manuscript.

Conflict of Interest Statement

The authors declare that no potential conflict of interest exists.

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Data Availability Statement

All data generated or analysed during this work are included in this article.

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