Heavy Metal Contamination in Maize and Cowpea Flours: A Study of Awareness and Health Risks in Enugu State, Nigeria

Abstract

Aim: This study aimed to assess the awareness and implications of heavy metal contamination in cereal and legume flours among residents of Enugu State, Nigeria.

Study Design: The research employed a cross-sectional survey design combined with laboratory analysis to investigate public awareness and measure heavy metal concentrations in selected food samples.

Place and Duration: The study was conducted in Enugu State, Nigeria, focusing on three towns—Enugu, Nsukka, and Oji River—over a period of six months.

Methodology: A structured questionnaire was administered to 360 residents across the three towns to evaluate their awareness of heavy metals and their potential health implications. Additionally, maize and cowpea flour samples were collected from the three towns and analyzed in the laboratory for heavy metal concentrations. The results were compared against permissible limits set by FAO/WHO.

Results: The survey revealed a significant knowledge gap among respondents, with only a small percentage aware of heavy metals and their associated health risks. Laboratory analysis showed varying concentrations of heavy metals in maize and cowpea flours across the towns. Enugu recorded higher concentrations. Some heavy metals in Enugu exceeded FAO/WHO permissible limits, whereas Nsukka and Oji River had levels within acceptable limits.

Conclusion: The findings emphasize the urgent need for enhanced public education on food contamination risks, stricter food safety policies, and targeted interventions to address heavy metal exposure and improve environmental health monitoring in agricultural practices.

Keywords: Heavy metal contamination, Cereal, Legume, Awareness, Enugu State

1. Introduction

The classification of heavy metals has been a subject of debate within the scientific community, with the International Union of Pure and Applied Chemistry (IUPAC) highlighting its ambiguous nature and questioning its scientific basis [1]. This ambiguity has spurred the introduction of the term "toxic metals" as an alternative, yet a universally accepted definition remains elusive. Complicating matters further, these metals, such as Cu, Fe, Zn, Pb, As, Cd, and Cr, to name a few, resist degradation, persisting in the environment and accumulating where released [2].

With the rapid advancements in technology and industrialization, the dispersion of these metals has expanded, creating a wider array of metal compounds that can be found naturally in soil, air, and water—essential mediums for plant growth [1]. Cereals and legumes stand as staple foods for many Nigerians, particularly those residing in Enugu state. These grains and legumes are rich sources of fiber, trace minerals, and vitamins, making them vital for a balanced diet. However, their heavy metal content poses potential risks, as these metals are non-essential and potentially harmful to human health. Nutritionally, foods can be categorized as ready-to-eat or requiring further processing before consumption. These distinctions impact the exposure levels to heavy metals, given their prevalence in various natural cycles. For instance, rainwater can dissolve metals from soil, transporting them through water systems into oceans, or carrying them upwards to be deposited elsewhere [1].

The heterogeneous nature of heavy metals, with their diverse chemical properties and biological roles, presents a complex scenario. While some trace amounts of these metals are vital for human metabolism [3], elevated concentrations pose significant health risks, potentially leading to various diseases affecting cardiovascular, nervous, kidney, and bone health [4]. Moreover, certain heavy metals, including mercury, cadmium, and lead, are particularly toxic [1].

Root vegetables, due to their subterranean growth, are more susceptible to contamination, as they readily absorb these metals from the soil. However, effective washing can reduce heavy metal concentrations in these plants by up to 20-50%, though tubers remain a concern even post-washing [4-5].

Despite these known risks, there exists a considerable information gap in Nigeria regarding the prevalence and impact of heavy metals on dietary nutrition and overall health. This gap extends even to educated segments of the population. Contaminated agricultural soil from wastewater irrigation further exacerbates the issue, posing direct threats to human health [6].

Given these concerns, it becomes crucial to assess public awareness and understanding of heavy metal contamination in commonly consumed cereals and legumes in Enugu state. This study specifically evaluated the level of awareness regarding heavy metal presence in selected Nigerian food commodities, assessed the potential risks posed by heavy metals to food security in Enugu state, and identified the specific food commodities and locations most affected by heavy metal contamination in Enugu state.

2. Methodology

2.1 Study Area

Enugu Town

Enugu town is situated in the southeastern part of Nigeria. It is bordered by Udi to the west, Nkanu to the east, Awgu to the south, and Nsukka to the north. It lies within Latitude 6.4500° N, Longitude 7.5000° E, and approximately 223 meters (732 feet) above sea level.

Nsukka Town

Nsukka is located in the northern part of Enugu state. It is bordered by Igbo-Etiti to the west, Igbo-Eze South to the east, Enugu to the south, and Uzo-Uwani to the north. It lies within Latitude 6.8667° N, Longitude 7.3833° E, and approximately 430 meters (1,411 feet) above sea level.

Orji River Town

Orji River is situated in the southeastern part of Enugu state. It shares boundaries with Udi to the west, Awgu to the east, Enugu South to the south, and Nkanu East to the north. It lies within Latitude 6.0500° N, Longitude 7.7167° E, and approximately 160 meters (525 feet) above sea level.

2.2 Materials

Fresh maize grains and cowpea seeds were bought from farmers from each study town in Enugu state Nigeria. They were sorted of foreign bodies and subjected to dry milling into flours respectively, using the Hammer mill in the Department of Food Science and Technology Laboratory. The study sites were purposively selected for this study based on the availability and rate of usage of the two flours for the preparation of various meals in Enugu state.

2.3 Methods

Sample Collection

Enugu state is made up of three cultural zones, namely; Enugu, Nsukka, and Enugu West. Enugu, Nsukka, and Oji River towns were randomly selected from the three zones respectively for this research. Questionnaires were designed and administered to 360 respondents living in the three purposefully selected study towns. The questionnaire focused on the knowledge of the existence of heavy metals in foods, their health implications, and their threat to food security in Enugu state, Nigeria. A Chemist and a sociology and Anthropology graduate were integrated into the research team.

2.4 Laboratory Analysis

The following laboratory analyses were done in the Department of Food Science and Technology laboratories, University of Nigeria, Nsukka.

Determination of Proximate composition: The proximate composition of the flours was determined by [7] standard methods.

Determination of Heavy Metals: The Atomic Absorption Spectrophotometer (AAS), Shimadzu modelAA7000 with the monitor and printer at the National Centre for Energy Research and Development, University of Nigeria Nsukka, were used to determine the heavy metals in the flour samples(Plate 1).

Plate 1: Front view of the atomic absorption spectrophotometer with the monitor and printer.

model: Shimadzu modelAA7000

Digestion of the Samples

The samples were digested using the Aqua Regia digestion method as described by [7]. About 3 g of each of the samples was weighed into a digestion flask and 30 cm^3 of Aqua Regia (a mixture of HNO_3 and HCl in the ratio of 1:3) were added and digested in a fume-cupboard until a clear solution was obtained. They were cooled, filtered, and then made up to 50 ml mark in a standard volumetric flask with de-ionized water. A blank sample was prepared, to zero the

instrument AAS before running other series of samples. Standards (2 ppm, 4 ppm, and 6 ppm) were prepared from 1000 ppm stock solution of the metals and used to plot the calibration curve. The curve was plotted automatically by the instrument.

Preparation of Standard Concentration

The Standard solutions (2 ppm, 4 ppm, and 6 ppm) of the metals (Fe, Zn, Cr, Ni, Cd, Mn, Pb, and Cu) were prepared from 1000 ppm stock solution of each metal using the formula: C1*V1 = C2*V2

Where C1 = 1000 ppm and C2=2 ppm

V1=? V2 = 100 ml

V1 = (100 x 2) \ (1000) = 0.2ml

About 0.2 ml was pipetted from 1000 ppm into a 100 ml flask and was made to the mark with deionized water. This procedure was used in the preparation of 4 ppm and 6 ppm respectively. The high temperature was produced in the ignition chamber and provided enhanced reducing settings for the atomization of the respective heavy metals. Each standard was aspirated by a nebulizer, converted into an aerosol, mixed with the gases, and converted into atomic form. All the standard solutions were analyzed and the calibration curve was plotted automatically for the metal of interest. Each metal/mineral was analyzed using its respective wavelength after which its concentration was generated from the standard graph by the instrument.

2.5 Statistical Analysis

Data (triplicate measurements of values) generated from the analysis were subjected to a one-way analysis of variance (ANOVA) at a 0.05 probability level. Duncan's new multiple range test (DNMRT) was used to compare the treatment means using the statistical product for service solution (SPSS) version 23.0.

3. Results

Survey on the Awareness of the presence of Heavy Metals in Foods in Enugu state

A survey on the knowledge of heavy metals and their implications in the various foods within the Enugu state of the Eastern region of Nigeria was carried out. The survey was on 360 residents of Enugu state from various professions. The minimum academic qualification for each of the respondents in this survey was a Senior Secondary school certificate. The questionnaire covered information on their status ranging from sex, age, academic qualifications, marital status, occupation, different meals they prepare from maize grains and cowpea seeds, knowledge of heavy metals, identification and name of heavy metals, etc.

Out of the 120 questionnaires distributed in each study town, 114, 109, and 102 were returned from Enugu, Nsukka, and Oji River towns respectively.

Results from Enugu, the capital city of Enugu state showed that:

(i) 78% of the respondents were women while 22% were men

(ii) 55% of the respondents had a maximum of Senior School Certificate while 45 % had above Senior School Certificate.

53% of them were civil servants 22% were businessmen and women 25% were based on agro-ventures.

Only 4% of the respondents had pretty knowledge of the term “heavy metals”.

1% of the respondents could name at least 2 heavy metals they know

Results from Nsukka town showed that:

(i) 81% of the respondents were women while 19% were men

(ii) 71% of the respondents had a maximum of Senior School Certificate while 29% had above Senior School Certificate.

23% of them were civil servants while 35% were businessmen and women 42% were based on agro-ventures.

Only 1% of the respondents had pretty knowledge of the term “heavy metals”.

1% of the respondents could name at least 2 heavy metals they know

Results from Oji River town showed that:

(i) 92% of the respondents were women while 8% were men

(ii) 89% of the respondents had a maximum of Senior School Certificate while 11% had above Senior School Certificate.

13% of them were civil servants 24% were business men and women 63% were based on agro-ventures.

None of the respondents had pretty knowledge of the term “heavy metals”.

1% of the respondents could name at least 2 heavy metals they know

Proximate composition of Cowpea and maize flours (%) From Enugu Town, Nsukka Town, and Oji River Town

The results of the proximate compositions of the maize and cowpea flours are presented in Tables 1a, b, and c. The results from the Tables show that there was a significant ($p<0.05$) difference in moisture content among the three food samples. The highest moisture content of 13.64 percent was recorded in cowpea flour at Enugu (13.64 %) while Nsukka had 10.23% as the lowest. Enugu town also recorded the highest protein value of 14.47% while Oji River town had 10.15% as the lowest protein content.

Table 1a: Proximate composition of Cowpea and maize flours (%) From Enugu Town Nigeria

Parameters	Moisture	Protein	Fat	Crude fibre	Ash	Carbohydrate
Cowpea Flour	$13.64^{b}\pm0.05$	$14.47^{d}\pm0.02$	$2.63^{d}\pm0.03$	$3.32^{d}\pm0.08$	$3.10^{d}\pm0.03$	$62.84^{d}\pm0.03$
Maize flour	$12.30^{b}\pm0.02$	$12.25^{d}\pm0.07$	$4.32^{d}\pm0.07$	$1.12.05^{d}\pm0.01$	$1.92^{d}\pm0.05$	$68.09^{d}\pm0.07$

Table 1b: Proximate composition of Cowpea and maize flours (%) From Nsukka Town, Nigeria

Parameters	M0isture	Protein	Fat	Crude fibre	Ash	Carbohydrate
Cowpea Flour	$10.23^{b}\pm0.05$	13.22 ±0.02	$2.13^{d}\pm0.05$	$2.52^{d}\pm0.08$	$2.28^{d}\pm0.04$	$69.62^{d}\pm0.03$
Maize flour	$11.20^{b}\pm0.04$	$11.25^{d}\pm0.03$	$3.69^{d}\pm0.04$	$2.10^{d}\pm0.03$	$1.72^{d}\pm0.04$	$70.04^{d}\pm0.07$

Table 1c: Proximate composition of Cowpea and maize flours (%) From Oji River Town, Nigeria

Parameters	M0isture	Protein	Fat	Crude fibre	Ash	Carbohydrate
Cowpea Flour	$12.45^{b}\pm0.06$	$12.07^{d}\pm0.04$	$3.50^{d}\pm0.02$	$2.61^{d}\pm0.05$	$3.30^{d}\pm0.03$	$66.07^{d}\pm0.03$
Maize flour	$13.12^{b}\pm0.03$	$10.15^{d}\pm0.08$	$2.43^{d}\pm0.05$	$2.50^{d}\pm0.03$	$1.88^{d}\pm0.05$	$70.30^{d}\pm0.07$

Results of the heavy metal concentrations on the food commodities are presented in Tables 2a,b, and c.

The concentrations of six heavy metals Cadmium (Cd), Chromium (Cr), Lead (Pd), Arsenic (Ar), Copper (Cu), and manganese (Mn) were assessed in the two food commodities from the three survey sites (Enugu, Nsukka and Oji River towns. Samples of maize grains and cowpea seeds were randomly purchased from the farmers immediately after harvest from each study town and processed into flours respectively and used for heavy metal analysis. The heavy metal concentrations (mg/kg) were analyzed with an Atomic Absorption Spectrophotometer. The concentrations of the heavy metals in mg/kg dry weight are as presented in **Tables 2a b and C.**

Table 2a: Some Heavy metals (mg/kg) in Maize and cowpea flours from Enugu Town, Nigeria

Samples	Cadmium	Aluminium	Lead	Arsenic	Manganese	Copper
Maize flour	0.310	0.520	0.450	0.605	0.300	0.325
Cowpea flour	0.40	0.410	0.310	0.190	0.210	0.200

Table 2b: Some Heavy metals (mg/kg) in Maize and cowpea flours from Nsukka Town, Nigeria

Samples	Cadmium	Aluminium	Lead	Arsenic	Manganese	Copper
Maize flour	0.240	0.350	0.320	0.505	0.340	0.300
Cowpea flour	0.30 0	0.330	0.310	0.220	0.185	0.190

Table 2c: Some Heavy metals (mg/kg) in Maize and cowpea flours from Oji River Town Nigeria

Samples	Cadmium	Aluminium	Lead	Arsenic	Manganese	Copper
Maize flour	0.200	0.380	0.280	0.425	0.310	0.280
Cowpea flour	0.26 0	0.390	0.310	0.250	0.180	0.210

4. Discussion

From the above demographic data, it could be deduced that the capital city of Enugu had more educated residents who were predominantly civil servants with a small population engaged in agro-related industrial activities. Only 4% of this educated population were able to explain what heavy metals were. The rest (96%) however, were not able to understand what heavy metals were nor could they mention some heavy metals. The reverse was, however, the case in the remaining 2 towns of Nsukka and Oji towns where only 11 people knew what heavy metals were in Nsukka town and none in Oji town. This is apparently because of the poor educational qualifications of the residents of the 2 towns in comparison with the city of Enugu. The University of Nigeria, at Nsukka, must have contributed to the1% of the respondents that knew what heavy metals mean. Oji River is an agrarian town with a population massively engaged in agriculture with zero knowledge of what heavy metals mean. The inference from the above analysis is that there is a knowledge cap on what heavy metal means in Enugu state; thus, their health implications remain a mirage to the residents of Enugu state. The above findings are in consonant with [8-10].

There were remarkable variations in the remaining components of indices measured in the proximate composition of the food commodities within the 3 towns in Enugu state. The differences in the proximate composition of these food commodities could be attributed to the soil properties of the various towns in Enugu state. Enugu town with huge coal and other mineral deposits, expectedly, affected soil nutrients than Nsukka and Oji River areas. The differences in the proximate composition of the two food commodities could be attributed to the various soil factors, locations, and ecological factors that empirically affect crop yields. The above findings are in consonant with [11-12].

In Maize and cowpea flours from Enugu, only Aluminium and Arsenic exceeded the permissible limits set by [13] of 0.05 to 0.5 mg/kg. The levels of Cadmium, lead, Manganese, and Copper were below this critical permissible limit and were not detected. In Nsukka town, it was only in maize flour that the concentration of Arsenic slightly exceeded the permissible limit of [13]. The maize used in Nsukka town might have been sourced from parts where oil and Iron deposits had earlier been reported to be in abundance but not yet explored [14]. (Oji River town had no detectable heavy metal concentration in the maize and cowpea flours studied. The detection of Aluminium and Arsenic in the Enugu study site could be attributed to the huge coal deposits and other mineral deposits that are in abundance in the hilly city of Enugu and its environs. This is because Arsenic is known to be a notoriously toxic metalloid that occurs in many minerals. Nsukka and Oji River towns have no traces of heavy metal concentrations over the WHO/FAO limits for the heavy metals studied. This is apparently because the two towns are devoid of coal and other mineral mining activities that are likely to interfere with the soil profiles and properties that could deposit some extra heavy metals in the farms.

5. Conclusion

Findings from this research show that despite the academic status attained, a significant percentage population of the Enugu state residents do not know what heavy metals are, regardless of their impacts on their food commodities. It was also noted that even the elites in Enugu state confessed their ignorance of the term “heavy metals’ and their harmful effects and contamination of their food commodities. There is, therefore, an urgent need to create public awareness of the existence of heavy metals and their adverse effects on humans. From the result obtained, only Arsenic was implicated in the maize flour at Enugu town since other metals did not exceed their permissible limit by FAO/WHO. The results also indicated that agricultural products within coal and other mineral mining environments are more prone to heavy metal contamination.

6. Recommendations

Researchers in the area of Food Security must intensify efforts in investigating the contamination of other produce by heavy metals in Enugu State, particularly in those areas with coal and other mineral deposits. There is an urgent need for federal and State Ministries of Agriculture, other Agricultural Research Institutes as well and other tertiary institutions, to install Atomic Absorption Spectrophotometer for heavy metal detection.

7. Acknowledgments

The authors are grateful to the TETFund, Federal College of Education, Eha Amufu, for the financial support, the Head of the Department of Food Science and Technology, the University of Nigeria Nsukka for the use of their laboratory facilities, the National Centre for Energy Research and Development, University of Nigeria, Nsukka for the use of their Atomic Absorption Spectrometer (AAS) and students of College of Education Eha Amufu and some younger staff of the University of Nigeria, Nsukka who participated in the survey.

9. AUTHORS’ CONTRIBUTIONS

Both authors designed the study and participated in every other aspect of the study.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.
2.
3.

12. References

1. Ahmed ATA, Mandal S, Chowdhury DA, Tareq ARM, Rahman MM. Bioaccumulation of some heavy metals in Ayre Fish (Sperata Aor Hamilton, 1822), sediment, and water of Dhaleshwari River in the dry season. Bangladesh J Zool. 2019;40(1):147-53.
2. Bemph CI, Kwefie AP, Tut A, Denutsi N. Assessing potential dietary intake of heavy metals from selected fruits and vegetables from Ghanaian markets. Elixir Pollution. 2011; 39:4925-6.
3. Prescott LM, Harley JP, Klein OA. Microbial nutrition types media in microbiology. 6th ed. New York: McGraw Hill Publishers; 2005. p. 95-105.
4. Nwiniiwii JD. Heavy metal concentrations in cassava leaves and tubers harvested from some communities in Gokana, Rivers State, Southern Nigeria. 2022.
5. Sulaiman RF, Hamzah HA. Heavy metal accumulation in suburban roadside plants of a tropical area (Jenhka, Malaysia). Ecol Process. 2018; 7:78. doi:10.1186/S13717-018-0.9-3.

6. Suruchi, Pankaj K. Assessment of heavy metal contamination in different vegetables grown in and around urban areas. Res J Environ Toxicol. 2011; 5:162-79.
7. AOAC. Official methods of analysis. 18th ed. Washington, D.C.: Association of Official Analytical Chemists; 2010.
8. Madu DI, Anthonius AE, Vivian A, Nonso CE, Ikechukwu EE. Assessment of heavy metal contents and probable health risks of some staple vegetables in Enugu Metropolis. Eur J Nutr Food Saf [Internet]. 2021 Jan 10;13(1):1-14. Available from: https://doi.org/10.9734/ejnfs/2021/v13i130333
9. Ajibola FO, Onyeyili IN, Adabra MS, Obianyo CM, Ebubechukwu DJ, Auwal AM, Justina EC. Adverse health effects of heavy metal pollution in the Enugu area, Southeastern Nigeria. World J Biol Pharm Health Sci. 2024;20(3).
10. Al-Trbany A, Elsayed AH, Fawzy AEA, Khorshed MA. Health risk from heavy metal contamination in maize. J Angiother. 2024;8(5):1-12.
11. Onakpa MM, Njan AA, Kalu OC. A review of heavy metal contamination of food crops in Nigeria. Ann Glob Health. 2018;84(3):488-94.
12. Sharma D, Bisla G. Determination of heavy metals contamination in maize flour collected from local markets of Bareilly City, Uttar Pradesh. J Emerg Technol Innov Res. 2019;6(4):19-23.
13. WHO/FAO. Summary and conclusion, Joint FAO/WHO Expert Committee of Food Additives (JECFA/73) 73rd meeting. Geneva; 2010.
14. Obaje NG. Update on the geology and mineral resources of Nigeria. Abuja: Onaiyi Printing and Publishing Co. Ltd.; 2013. 215 p.