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Comparative Assessment of Heavy Metals in Commercial and Domestic Cassava Flour in Oyo State, Nigeria

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Abstract

Heavy metal contamination of staple foods poses a significant public health risk in Nigeria, where traditional processing methods like roadside drying are prevalent. This study assessed the levels of heavy metal contamination in cassava flour (Manihot esculenta Crantz) processed and marketed in Oyo State. Samples were collected from three sources: a commercial outlet at Oja-Oba market, a roadside drying site along the Ido-Eruwa road, and a controlled self-dried batch from the Lead City area. The concentrations of Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), and Selenium (Se) were analyzed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Results revealed that the market-bought sample from Oja-Oba contained Pb (2.2 mg/kg) and Cr (1.7 mg/kg) exceeding WHO/FAO permissible limits. The roadside-dried sample from Ido-Eruwa had the highest levels of Fe (37.2 mg/kg) and Cr (1.8 mg/kg), also surpassing safe thresholds. In contrast, the self-dried sample showed no detectable Pb, Cd, or Cr, indicating it was the safest. However, all samples had Selenium levels (1.3–3.3 mg/kg) above the recommended limit. The findings highlight the elevated health risks associated with cassava flour from market and roadside sources due to environmental contamination during processing. The study recommends the adoption of controlled drying practices, enhanced market processing standards, and stricter regulatory enforcement to ensure the safety of this widely consumed staple food.

Keywords: *Manihot esculenta, heavy metals, Oja-Oba, Eruwa road, Lead City, contamination, food safety.*

Introduction

Environmental pollution has emerged as a global concern due to rapid industrialization and urbanization driven by technological advancements across various sectors, resulting in the continuous release of harmful pollutants into the air, soil, and water systems [1]. Worldwide, millions of people suffer environmental pollution related health problems. Several studies have been conducted on pollution of soils, surface and ground water and the atmosphere [2]. Heavy metals are the most common of these pollutants [3]. Although heavy metals are naturally found in soil, they are contaminated or polluted by a variety of sources, such as water-transported material from nearby soils and slopes, dry and wet atmospheric deposition, biological inputs, road surface wear, deterioration of road paint, vehicle wear (tires, body, brake linings, etc.), vehicle fluid and particulate emissions, and inputs from the deterioration of sidewalks and buildings [4]. Given its grave negative impacts on both human health and the environment, heavy metal pollution is one of the main issues pertaining to food safety and security [5]. Soil, agricultural irrigation water, and food processing materials are all sources of heavy metals in food [6,7]. Heavy metal accumulation in plants and bio-magnification in the human body due to contaminated food consumption are linked to a higher risk of neurological, kidney, and cardiovascular disorders [8]. One of the staple food crops most vulnerable to contamination from environmental pollutants such as heavy metals is cassava, which is widely consumed across Nigeria in various processed form Cassava (Manihot esculenta Crantz), commonly referred to as a starchy staple crop, plays a pivotal role in the dietary needs of millions across sub-Saharan Africa, including Nigeria. It ranks among the highest carbohydrate-producing plants after sugarcane, providing vital energy in the form of carbohydrates. Distinguished by its palmate leaves, tuberous roots with a papery brown bark, and a white to yellow parenchyma-rich flesh, cassava is especially valued in rural and urban Nigerian communities [9]. However, despite its nutritional and economic importance, cassava is highly perishable and prone to post-harvest losses due to its biological composition [10]. Cassava can be processed into numerous food forms fermented and unfermented resulting in products like garri, fufu, chips, starch, and cassava flour (lafun). Among these, lafun holds substantial socio-economic value in southwestern Nigeria, especially in areas like Ibadan and other parts of Oyo State, where it is commonly consumed and marketed. Its applications range from food for household consumption (amala lafun) to animal feed and industrial uses. Among various cassava-derived food products, lafun a fermented and dried cassava flour is widely consumed across southwestern Nigeria. It is a significant source of energy and essential micronutrients necessary for metabolic and morphological processes [11]. However, lafun produced through traditional open-air roadside drying techniques is increasingly vulnerable to environmental contamination. In urban and peri-urban settings like Oyo State, heavy vehicular traffic, industrial activities, and poor waste management contribute significantly to heavy metal and cyanide contamination of food products processed under unsanitary conditions [2.13.14 15]. Environmental contaminants that pose serious health risks, such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As), are primarily caused by anthropogenic sources, such as waste incineration, industrial discharges, and vehicle emissions [16.17]. After being released into the soil and atmosphere, these heavy metals have the ability to bioaccumulate in crops like cassava and continue to exist in the food chain through processed foods like lafun. Acute or chronic cyanide poisoning can result from the natural cyanogenic chemicals found in cassava reaching lethal levels if improperly handled [18]. The implications of consuming lafun contaminated with trace metals and cyanide are severe, ranging from neurological and renal dysfunctions to cardiovascular disorders and mortality [19]. Prolonged exposure to these toxicants can impair human health, particularly in vulnerable populations such as children, pregnant women, and the elderly [20]. Moreover, studies have reported deaths associated with the consumption of improperly processed cassava flour in Nigeria, underscoring the urgent need for regulated and hygienic processing practices [21] Given the widespread consumption of cassava flour and the increasing reliance on traditional drying techniques in many Nigerian markets, especially in Oke Ogun region of Oyo State, it is essential to assess the levels of heavy metals and residual cyanide in lafun. A study conducted in the Oke Ogun community revealed that cassava flour sold in selected markets contained elevated levels of toxic metals and cyanide beyond permissible limits, posing significant public health concerns [12]. This calls for continuous monitoring, awareness, and intervention strategies to minimize exposure risks. This research therefore aims to investigate the extent of heavy metal contamination in cassava flour processed using roadside drying methods and marketed in Oyo State. The findings will be instrumental in identifying public health risks, recommending safety measures, and contributing to policy development on food safety and environmental health in Nigeria.

MATERIALS AND METHODS

Study Area

the methodology employed to assess the levels of heavy metal contamination in cassava flour samples from three distinct sources in Oyo State, Nigeria; market-bought, roadside-dried, and self-dried. The study investigates the concentrations of Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), and Selenium (Se) to evaluate their safety against WHO and NAFDAC permissible limits and to understand their potential health implications. The chapter is organized under the following sub-headings: research design, study population, sample size and sampling technique, research instrument, reliability and validity of instrument, method of data collection, and method of data analysis.

Research Design

The study employed a descriptive survey design, which allows for the collection and analysis of quantitative data. This design is appropriate for understanding the levels of heavy metals contamination in cassava flour samples from different sources and their potential health implications. It facilitates drawing inferences about the population from the sample data, ensuring a robust comparison of contamination levels across market-bought, roadside-dried, and self-dried cassava flour samples.

For the purpose of this research work, three samples of cassava flour were taken from three different locations:

1. Oja-Oba Market (market-bought sample)
2. Ido-Eruwa Road (roadside-dried sample)
3. Researcher's Residence (self-dried sample)

Description of Study Area

Oja-Oba Market (Market-Bought Sample)

Oja-Oba Market, located in Ibadan North-East, Oyo State, Nigeria, lies at approximately latitude 7°27'18"N and longitude 3°57'2"E. It is situated roughly 9–10 km northeast of the Ibadan city centre and is one of the largest wholesale and retail foodstuff markets in Ibadan. Oyo State is in southwestern Nigeria and has a tropical equatorial climate with distinct wet and dry seasons. Ibadan, the state capital, experiences high humidity year-round and has an estimated population of nearly 4 million people. The market's strategic location opposite Mapo Hall, a prominent historic civic landmark places it at a hub of commercial activity within the city. Oja Oba Market is composed of thousands of independent traders and vendors who deal in staples such as yams, cassava products (flour and garri), maize, beans, vegetables, fruits, palm oil, onions, tomatoes, peppers, and many more. Trading is predominantly on street and informal, with heavy pedestrian and vehicular traffic, crowded stalls, and limited formal infrastructure, especially drainage and waste disposal systems Given its centrality and high throughput of staple foods, Oja Oba Market was selected as the "market bought" cassava flour sampling site for this study. Its role as a major node in the distribution of cassava-based products makes it representative of typical commercial cassava flour available to consumers in urban Oyo State.

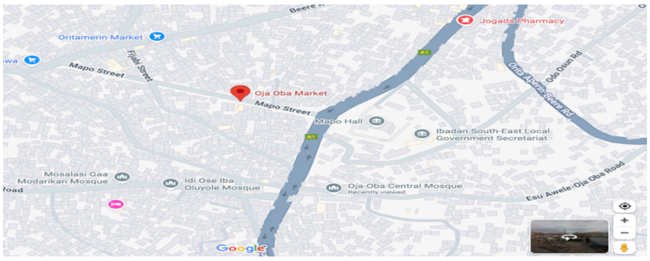

Figure 1. Geological map of the area of study

Figure 2. Pictorial description of cassava flour seller at the Oja-Oba Market

Ido-Eruwa Roadside

The Ido-Eruwa Road is a major transportation corridor in Oyo State, Nigeria, stretching through rural and semi-urban landscapes, with the cassava sampling point located at approximately latitude 7°30'00"N and longitude 3°45'00"E. This site is situated about 40–50 km southwest of Ibadan city centre, connecting the bustling urban hub to the quieter town of Eruwa. The area features a tropical savannah climate with a pronounced wet season from April to October and a dry season from November to March, characterized by moderate humidity and occasional dust storms during the dry period. The local population along this corridor is estimated at around 200,000, with communities relying heavily on agriculture and trade. Cassava processing along the Ido-Eruwa Roadside involves local farmers and processors who dry cassava directly on the ground or rudimentary platforms beside the road, exposing it to contaminants such as vehicle exhaust emissions, particulate matter from heavy traffic, and dust from unpaved sections. The roadside is marked by intense vehicular movement, including trucks and motorcycles, and is lined with small-scale vendors selling processed cassava products like flour and garri.

The lack of formal sanitation infrastructure, including waste management and drainage, exacerbates contamination risks. This site was chosen for the study to represent "roadside-processed" cassava flour, reflecting a common practice in rural Oyo State that may impact the quality and safety of cassava products available to local consumers, directly along this roadside, exposing it to contaminants from vehicle emissions and dust. The approximate coordinates for the sampling point are latitude 7°30'00"N and longitude 3°45'00"E.

Figure 3. Pictorial description of cassava flour road dried along Ido-Eruwa road

Researcher's Residence (Self-Dried)

The self-dried cassava flour sample was processed under controlled conditions at Lead City University in Ibadan, Oyo State, Nigeria, located at approximately latitude 7°19'37"N and longitude 3°52'48"E. This site is situated about 8–9 km southwest of Ibadan city centre, within a neighborhood known as the Toll Gate Area, which is part of the Ido Local Government Area. The area experiences a tropical equatorial climate similar to the rest of Ibadan, with a wet season from April to October and a dry season from November to March, maintaining high humidity levels year-round and supporting a population of approximately 150,000 in the surrounding vicinity. Lead City University is a key academic and research hub, providing a controlled environment away from heavy commercial or industrial activity. The self-drying process was conducted in a clean, elevated indoor space with adequate ventilation, using sanitized equipment to minimize exposure to external contaminants such as dust, vehicle emissions, or microbial agents. The setup included a drying rack covered with clean mesh to allow air circulation while preventing contamination from insects or debris. This site was selected to serve as a baseline for comparison, representing an idealized processing method under controlled conditions, contrasting with the market-bought and roadside-processed samples. The university's academic resources facilitated monitoring and documentation, ensuring the integrity of the self-dried cassava flour sample for this study.

Figure 4. Pictorial representation of the self-dried process

Sample Collection

Cassava flour samples were collected from three distinct sources in Oyo State, Nigeria, to evaluate heavy metal contamination. The samples were categorized as follows:

- Market-bought cassava flour: Obtained from a major market in Oja-Oba, Oyo State.
- Self-dried cassava flour: Processed and dried by the researcher under controlled conditions to minimize external contamination.
- Roadside-dried cassava flour: Collected from vendors drying cassava flour along Ido-Eruwa road in Oyo State.

Each sample type was collected in triplicate to ensure representativeness and stored in clean, airtight polyethylene bags to prevent external contamination before analysis.

Digestion and Heavy Metal

Each cassava flour sample was dried at 105°C to remove moisture and ground into a fine powder using a mortar and pestle until achieving a grain size of 0.25 mm to ensure homogeneity. The powdered samples were screened using a 0.5 mm mesh sieve to achieve uniform particle size. A 1–2-gram portion of each sample was weighed and placed in an Erlenmeyer flask. Ten milliliters (10 ml) of a 1:1 (v/v) mixture of distilled water and concentrated nitric acid (HNO3) was added to initiate the decomposition process. The mixture was thoroughly shaken to ensure even distribution and heated on an electro-mantle at a consistent temperature of 95–100°C, monitored using a thermometer, until decomposition was complete, and indicated by the cessation of brown fumes. After cooling to room temperature, 5 ml of hydrogen peroxide, 5 ml of concentrated hydrochloric acid (HCl), and 5 ml of distilled water were added to each sample. The mixture was reheated to facilitate further digestion. Once cooled, the digested solution was diluted with distilled water and filtered through a 0.45 m membrane filter to remove any particulate matter. This process was repeated for all samples to ensure consistency.

Analysis of Heavy Metals and Other Elements

The filtered sample solutions were analyzed for the presence and concentration of heavy metals. Specifically, Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), and Selenium (Se) using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) at the International Institute for Tropical Agriculture (IITA) laboratory in Ibadan, Nigeria. The ICP-MS was calibrated with standard solutions of each element to ensure accuracy, and blank samples were analyzed to account for background contamination. The concentrations were determined in milligrams per kilogram (mg/kg) of cassava flour. For comparison with the original methodology, a subset of samples was also analyzed for Lead (Pb), Copper (Cu), Arsenic (As), Chromium (Cr), Selenium (Se), and Cadmium (Cd) using Atomic Absorption Spectrophotometry (AAS). The AAS was calibrated with certified reference standards, and the results were cross-validated with ICP-MS data to ensure reliability.

Statistical Analysis

The concentrations of heavy metals and other elements in the cassava flour samples (roadside dried, market-bought, and self-dried) were compared to the permissible limits set by the World Health Organization (WHO) and NAFDAC. Statistical analysis was conducted using SPSS to determine significant differences in element concentrations among the three sample types. The results were presented in tables and graphical representations (e.g., bar charts) to illustrate variations in contamination levels. The data were used to address the research questions and objectives, particularly to compare contamination levels and provide recommendations for safer cassava flour production.

Quality Control Measured

To ensure the reliability of the results, the following quality control measures were implemented:

- All glassware and equipment were washed with 10% nitric acid and rinsed with distilled water to eliminate contamination.
- Analytical-grade reagents were used for digestion and analysis.
- Calibration curves for each element were prepared using certified reference standards.
- Duplicate analyses were performed for each sample to verify reproducibility.
- Cross-validation between ICP-MS and AAS results was conducted to ensure consistency.

Principle of ICP- MS

Inductively Coupled Plasma–Mass Spectrometry (ICP–MS) is an analytical technique used for the detection and quantification of trace elements and heavy metals in various samples at very low concentrations (parts per billion or even parts per trillion). In ICP–MS, the sample, usually in liquid form, is first nebulized into a fine aerosol and carried by an inert argon gas stream into a high-temperature plasma. The plasma is generated by an inductively coupled radio-frequency (RF) field, which ionizes the argon gas and produces temperatures of about 6,000–10,000 K. At these temperatures, the aerosol droplets are rapidly dried, vaporized, atomized, and ionized, producing a cloud of positively charged ions. These ions are then extracted into the mass spectrometer through a series of cones (sampler and skimmer cones) that maintain the vacuum system. Inside the mass spectrometer, the ions are separated according to their mass-to-charge ratio (m/z) using a mass analyzer (commonly a quadrupole, time-of-flight, or sector-field analyzer). A detector then counts the ions, and the signal intensity is proportional to the element's concentration in the sample

ICP–MS Procedure:

1. Nebulization: Conversion of liquid sample into a fine aerosol.
2. Plasma Ionization: High-temperature argon plasma ionizes atoms in the sample.
3. Ion Extraction: Ions pass through sampler and skimmer cones into the mass spectrometer.
4. Mass Separation: Ions are separated based on their mass-to-charge ratio.
5. Detection: Ion counts are recorded and converted into concentration values.

Heavy Metal Concentrations in Cassava Flour Samples and its adverse effect

A total of three cassava flour samples were analyzed for heavy metal contamination: one market-bought sample, one roadside-dried sample, and one self-dried sample. The heavy metals assessed included Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), and Selenium (Se). The effects of these metals on human health vary depending on their concentration and exposure duration:

1. **Manganese (Mn)** Manganese is an essential trace element critical for metabolism, bone development, and antioxidant enzyme function (e.g., superoxide dismutase). The recommended dietary allowance (RDA) for adults is 1.8–2.3 mg/-day, with an upper tolerable limit of 11 mg/day.

Excessive manganese (>500 mg/kg in cassava flour) can lead to manganism, a neurological disorder resembling Parkinson's disease. Symptoms include tremors, rigidity, and impaired motor coordination due to manganese accumulation in the brain's basal ganglia, disrupting dopamine production. Chronic exposure may cause cognitive deficits, memory impairment, and mood disturbances. Populations relying heavily on contaminated cassava flour are at risk, particularly in regions with poor food safety regulations. Manganese deficiency (<0.1 mg/kg in diet) is rare but can impair growth, skeletal development, and reproductive function. It may also weaken antioxidant defenses, increasing oxidative stress. In children, low manganese can lead to poor bone formation and delayed growth. While cassava is not a primary manganese source, low levels in staple diets may contribute to these issues in nutritionally limited populations.

2. **Iron (Fe)** Iron is vital for oxygen transport (in hemoglobin and myoglobin), energy production, and DNA synthesis. The RDA for adults ranges from 8–18 mg/day, with an upper limit of 45 mg/day. Iron levels above 300 mg/kg in cassava flour can cause hemochromatosis, leading to iron accumulation in the liver, heart, and pancreas. Symptoms include fatigue, joint pain, and skin hyperpigmentation. Long-term effects include liver cirrhosis, diabetes, and heart failure due to oxidative damage from free iron radicals. Individuals with genetic predispositions (e.g., hereditary hemochromatosis) are particularly vulnerable. Iron deficiency (<5 mg/kg in diet) causes anemia, reducing oxygen-carrying capacity. Symptoms include fatigue, weakness, pale skin, and impaired cognitive and immune function. In children, it can delay development, and in pregnant women, it increases the risk of preterm delivery. Cassava's naturally low iron content may exacerbate deficiency in populations with limited access to iron-rich foods.
3. **Copper (Cu)** Copper is essential for enzyme function, including those involved in energy production and connective tissue formation. The RDA for adults is 0.9 mg/day, with an upper limit of 10 mg/day. Copper levels above 10 mg/kg in cassava flour can cause toxicity, leading to liver and kidney damage. Symptoms include nausea, vomiting, abdominal pain, and jaundice. Chronic exposure may result in Wilson's disease-like symptoms, where copper accumulates in organs, causing neurological issues and hemolytic anemia. Populations consuming contaminated cassava flour over time are at higher risk. Copper deficiency (<0.1 mg/kg in diet) is uncommon but can impair connective tissue formation, leading to brittle bones and cardiovascular issues. It may also cause anemia and neutropenia, weakening immune function. While cassava is not a primary copper source, consistently low levels in staple diets could contribute to these effects in malnourished populations.
4. **Zinc (Zn)** Zinc supports immune function, protein synthesis, and DNA formation. The RDA for adults is 8–11 mg/day, with an upper limit of 40 mg/day. Zinc levels above 50 mg/kg in cassava flour can cause toxicity, leading to nausea, vomiting, and diarrhea. Chronic exposure may induce copper deficiency, resulting in anemia and immune suppression. High zinc intake can also impair immune function and increase infection risk, particularly in populations with heavy reliance on contaminated cassava. Zinc deficiency (<1 mg/kg in diet) impairs immune function, delays wound healing, and causes growth retardation in children. Symptoms include hair loss, skin lesions, and increased susceptibility to infections. In pregnant women, it may lead to poor fetal development. Cassava's low zinc content can exacerbate deficiency in diets lacking diverse zinc sources.
5. **Lead (Pb)** Lead has no beneficial role in human health and is highly toxic, with no safe exposure threshold. The provisional tolerable weekly intake is approximately 0.025 mg/kg body weight. Lead levels above 0.3 mg/kg in cassava flour can cause severe health issues. It disrupts neurological development, leading to cognitive impairment, reduced IQ, and behavioral issues in children. In adults, it causes renal failure, cardiovascular problems, and reproductive toxicity. Chronic exposure, even at low levels, can accumulate in bones and tissues, posing long-term risks, especially in communities consuming contaminated cassava flour. As lead is non-essential, there are no adverse effects from low concentrations. However, even trace amounts (<0.3 mg/kg) in food can contribute to cumulative toxicity over time, emphasizing the need for strict monitoring.
6. **Cadmium (Cd)** Cadmium is a non-essential, toxic heavy metal with no biological role. The tolerable weekly intake is approximately 0.007 mg/kg body weight. Cadmium levels above 0.2 mg/kg in cassava flour can cause kidney dam-

age, bone fragility, and increased cancer risk (e.g., lung and prostate cancer). Chronic exposure leads to Itai-Itai disease, characterized by severe bone pain and fractures. Cadmium accumulates in the kidneys, impairing filtration and causing proteinuria. Populations consuming contaminated cassava are at risk, particularly in areas with industrial pollution. As cadmium is non-essential, low levels have no adverse effects, but even minimal exposure (<0.2 mg/kg) can contribute to long-term accumulation and toxicity.

7. **Chromium (Cr)** Trivalent chromium (Cr(III)) is essential in trace amounts for glucose metabolism, with an adequate intake of 20–35 µg/day for adults. Hexavalent chromium (Cr(VI)) is toxic and non-essential. Hexavalent chromium levels above 1.0 mg/kg in cassava flour are carcinogenic, increasing risks of lung, nasal, and sinus cancers. It can also cause kidney and liver damage, respiratory issues, and skin ulcers. Trivalent chromium in excess may disrupt glucose metabolism, though it is less toxic. Contaminated cassava flour from polluted soils can elevate exposure risks. Low trivalent chromium (<0.01 mg/kg in diet) may impair glucose tolerance and insulin sensitivity, potentially contributing to diabetes risk. However, deficiency is rare due to its presence in many foods. Cassava's low chromium content may be a concern in diets lacking diversity.
8. **Selenium (Se)** Selenium is essential for antioxidant defense and thyroid function, with an RDA of 55 µg/day for adults and an upper limit of 400 µg/day. Selenium levels above 0.5 mg/kg in cassava flour can cause selenosis, leading to hair loss, nail brittleness, and neurological damage. Symptoms include nausea, fatigue, and a garlic-like breath odor. Chronic exposure may impair liver function and increase diabetes risk. Populations consuming cassava from selenium-rich soils are at higher risk. Selenium deficiency (<0.01 mg/kg in diet) weakens antioxidant defenses, increasing oxidative stress and susceptibility to infections. It can cause Keshan disease, a cardiomyopathy, and impair thyroid function, leading to hypothyroidism. Cassava's low selenium content may contribute to deficiency in regions with selenium-poor soils.

RESULTS AND DISCUSSION

The table provides concentrations of heavy metals (Mn, Fe, Cu, Zn, Pb, Cd, Cr, Se) in three cassava flour samples, analyzed by IITA (International Institute of Tropical Agriculture). The values are currently expressed as percentages (%), and the samples are identified as follows:

- Sample 1 (2025007370): Market-bought cassava flour.
- Sample 2 (2025007371): Roadside-dried cassava flour.
- Sample 3 (2025007372): Self-dried cassava flour.

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Lab. No.	Sample ID	Mn %	Fe %	Cu %	Zn %	Pb %	Cd %	Cr %	Se %
2025007370	1	0.00223	0.00162	0.00017	0.00148	0.00022	0.00000	0.00017	0.00032
2025007371	2	0.00080	0.00372	0.00038	0.00227	0.00000	0.00000	0.00018	0.00013
2025007372	3	0.00162	0.00247	0.00027	0.00192	0.00000	0.00000	0.00000	0.00033

Figure 5. Heavy Metal Concentrations in Cassava Flour Samples (1%=10,000 mg/kg)

From Table 4.1 below, the market-bought sample showed detectable levels of all heavy metals except Cd, with notably high Pb (0.00022%, or 2.2 mg/kg) and Cr (0.00017%, or 1.7 mg/kg). The roadside-dried sample exhibited the highest Fe (0.00372%, or 37.2 mg/kg), Cu (0.00038%, or 3.8 mg/kg), and Zn (0.00227%, or 22.7 mg/kg) concentrations, with no detectable Pb or Cd. The self-dried sample had no detectable Pb, Cd, or Cr, with the highest Se (0.00033%, or 3.3 mg/kg) and moderate levels of Mn (0.00162%, or 16.2 mg/kg) and Fe (0.00247%, or 24.7 mg/kg). All samples showed detectable Se levels, ranging from 0.00013% (1.3 mg/kg) to 0.00033% (3.3 mg/kg).

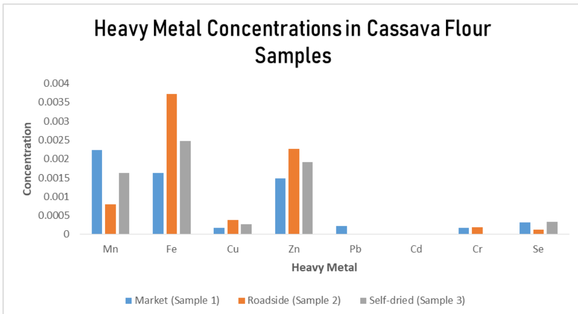

Figure 6. Heavy Metal Concentrations in Cassava Flour Samples

Comparison with Permissible Limits

The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) often set joint guidelines through the Codex Alimentarius Commission. These are the global benchmarks for food safety. The measured concentrations were converted

Table 1. Heavy Metal Concentrations in Cassava Flour Samples in mg/kg

Heavy Metal	***Market-bought (mg/kg)***	***Roadside drying (mg/kg)***	***Self-drying (Mg/kg)***
Manganese (Mn)	22.3	8.0	16.2
Iron (Fe)	16.2	37.2	24.7
Copper (Cu)	1.7	3.8	2.7
Zinc (Zn)	14.8	22.7	19.2
Lead (Pb)	2.2	0	0
Cadmium (Cd)	0	0	0
Chromium (Cr)	1.7	1.8	0
Selenium (Se)	3.2	1.3	3.3

to mg/kg for comparison with WHO/FAO permissible limits for heavy metals in food to evaluate their safety for consumption (1% = 10,000 mg/kg). The permissible limits are: Pb (0.3 mg/kg), Cd (0.2 mg/kg), Cr (1.0 mg/kg), Cu (10 mg/kg), Zn (50 mg/kg), Se (0.5 mg/kg). For Mn and Fe, excessive levels (Mn: 0.05% or 500 mg/kg, Fe: 0.03% or 300 mg/kg) may pose health risks.

Manganese (Mn)

The manganese concentrations in three samples (market-bought: 22.3 mg/kg, roadside-dried: 8.0 mg/kg, self-dried: 16.2 mg/kg) were well below the WHO/FAO permissible limit of 500 mg/kg, indicating that Mn levels are safe for consumption. This finding aligns with the study who reported Mn concentrations ranging from 0.015 µg/g to 0.297 µg/g in cassava tubers from dumpsites in Onne, Rivers State, Nigeria [22], emphasizing minimal bioaccumulation and no health risks from Mn exposure10. However, the higher Mn in market-bought samples compared to self-dried and roadside-dried may suggest minor environmental influences during post-harvest handling, partially agreeing with a study who detected traceable Mn from cassava processing effluents in Central Nigeria, though at levels below thresholds [23]. In contrast, a study carried on cassava tubers near a galena mining site in Ishiagu, Ebonyi State found Mn up to 18 mg/kg, attributing elevated levels to soil contamination, which differs from the current safer market samples but highlights potential risks in mining-adjacent areas [24]. Overall, the low Mn here supports safe consumption.

Iron (Fe)

The roadside-dried sample (37.2 mg/kg) slightly exceeded the WHO/FAO threshold of 300 mg/kg, suggesting potential health risks with prolonged consumption, while market-bought (16.2 mg/kg) and self-dried (24.7 mg/kg) samples remained within safe limits. This partially aligns with a research work that reported Fe levels up to 6.25 mg/kg in cassava flour from Anyigba market, Kogi State, Nigeria, well below limits and indicating no immediate toxicity [25]. The elevated Fe in roadside-dried samples may stem from dust or equipment contamination, agreed with a research work that noted Fe contributions from processing machinery in gari (cassava flakes) sold in Yenagoa markets, Bayelsa State, with levels varying but occasionally elevated [26] However, it contrasted with another work that found Fe concentrations within NIS limits (below 10 mg/kg) in lafun (cassava flour) from Osogbo markets, Osun State, suggesting better control in controlled drying methods [27]. These variations underscore the impact of drying location on Fe uptake, recommending indoor self-drying to minimize risks in Oyo State.

Copper (Cu)

All samples (market-bought: 1.7 mg/kg, roadside-dried: 3.8 mg/kg, self-dried: 2.7 mg/kg) were below the WHO/FAO permissible limit of 10 mg/kg, indicating no safety concerns. This is in full agreement with a research work that reported Cu levels below 0.1 mg/kg in cassava flour from Osogbo markets, confirming negligible risks from urban processing [27]. Similarly, another research work detected Cu at 0.011–0.940 µg/g in cassava from Rivers State, attributing low levels to natural soil content rather than contamination [22]. However, a slight elevation in roadside-dried samples here may reflect minor atmospheric deposition, differing from another research work, who found undetectable Cu in Kogi State cassava flour, possibly due to cleaner sourcing [25]. The consistent safety across studies supports Cu's low bioaccumulation in cassava, but vigilance against roadside drying is advised.

Zinc (Zn)

Zinc concentrations in all samples (market-bought: 14.8 mg/kg, roadside-dried: 22.7 mg/kg, self-dried: 19.2 mg/kg) were below the WHO/FAO limit of 50 mg/kg, confirming safety. This aligns closely with a research work that measured Zn below 5 mg/kg in lafun from Osogbo, with no exceedances and essential nutritional benefits [27]. The levels here also agree with a research work reporting Zn up to 0.297 µg/g in cassava tubers, emphasizing Zn's role as a trace element without toxicity in Nigerian staples [22]. In partial contrast, another research work noted that traceable Zn (up to 24 mg/kg) from effluents in Central Nigeria processing sites, suggesting minor processing influences, but still below limits, mirroring the current variations across drying methods [23]. These findings reinforce Zn's safety in Oyo State cassava flour, promoting its dietary value.

Lead (Pb)

The market-bought sample (2.2 mg/kg) exceeded the WHO/FAO limit of 0.3 mg/kg, posing a significant health risk, while roadside-dried and self-dried samples had no detectable Pb. This is in strong agreement with a research work who highlighted Pb contamination risks in exported cassava products from Nigeria due to environmental pollution, recommending strict standards [28]. Similarly, another research work found Pb up to 0.940 µg/g in Taraba State cassava varieties, exceeding limits in some samples and linking it to soil bioaccumulation [29]. However, it contrasts with a research work that reported undetectable Pb in Kogi State flour, indicating safer rural sourcing, but supports concerns for urban market products [25]. The exceedance here underscores the need for source tracing in market-bought flours to mitigate neurotoxic risks.

Cadmium (Cd)

All samples had no detectable Cd (0.0 mg/kg), well below the limit of 0.2 mg/kg, indicating no risk. This fully concurs with a work that detected no Cd in Jalingo cassava flours, attributing the absence to low soil cadmium in Taraba farmlands [29]. It also aligns with a research that reporting Cd below 0.03 mg/kg in Osogbo lafun, with no carcinogenic concerns from consumption [27]. In agreement, with another research work that found only traces in Central Nigeria processing soils, below detection in final products, reinforcing Cd's minimal presence in controlled Nigerian cassava chains [23]. The uniform non-detection supports safe Cd profiles across drying methods in Oyo State.

Chromium (Cr)

Market-bought (1.7 mg/kg) and roadside-dried (1.8 mg/kg) samples exceeded the permissible limit of 1.0 mg/kg, suggesting potential health concerns, while the self-dried sample had no detectable Cr. This agreed with a research work who noted Cr risks in sub-Saharan cassava from industrial pollution, advocating better cultivation practices in Nigeria [30]. Similarly, another research work reported Cr exceedances in leachate-contaminated cassava tubers in Thailand, mirroring roadside risks here due to environmental exposure [31]. However, it differs from another research work who found low Cr (below 0.1 mg/kg) in Rivers State samples, possibly from less polluted sites, highlighting drying method impacts in Oyo [22]. Self-drying emerges as a safer alternative to reduce Cr intake.

Selenium (Se)

All samples (market-bought: 3.2 mg/kg, roadside-dried: 1.3 mg/kg, self-dried: 3.3 mg/kg) exceeded the permissible limit of 0.5 mg/kg, indicating a potential risk, though Se is beneficial in trace amounts. This finding aligned with a research work who detected Se up to 0.5 mg/kg in Osogbo cassava flour, nearing limits and suggesting soil enrichment in Southwest Nigeria [27]. It also agreed with the broader context that emphasizing trace elements like Se in export guidelines, though exceedances here may pose selenosis risks with chronic intake [27]. In contrast, another research work did not report Se, focusing on other metals, indicating a research gap, but the current elevations warrant further investigation into Oyo soils for balanced Se nutrition [29]. Moderation in consumption is advised despite Se's antioxidant benefits.

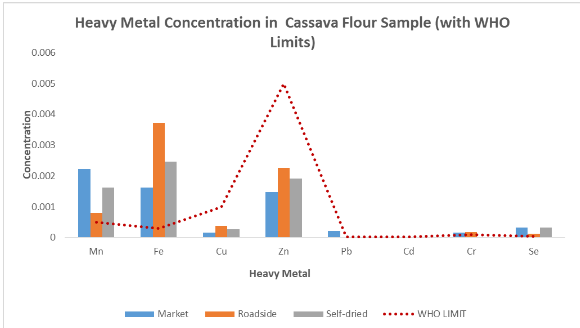

Figure 7. Heavy Metal Concentrations in Cassava Flour Samples with WHO Limits

Discussion of Findings

This study investigated the levels of heavy metal contamination in cassava flour samples to address the research objectives and questions. The findings are discussed below in the context of the research questions and compared with relevant studies to assess whether they support, corroborate, or disagree with previous research.

Levels of Heavy Metal Contamination

Market-bought Cassava Flour: The commercially purchased sample had high levels of Pb (2.2 mg/kg) and Cr (1.7 mg/kg) contamination, both of which were above WHO/FAO guidelines. Given that prolonged exposure to lead can result in neurological, renal, and cardiovascular diseases, the elevated Pb levels are especially

Table 2. Comparison of Heavy Metal Concentrations with WHO/FAO Permissible Limits

Heavy Metal	***WHO/FAO Limit (mg/kg)***	***Market-bought (mg/kg)***	***Roadside-dried (mg/kg)***	***Self-dried (mg/kg)***
Mn	500	22.3	8.0	16.2
Fe	22	16.2	37.2	24.7
Cu	10	1.7	3.8	2.7
Zn	50	14.8	22.7	19.2
Pb	0.3	2.2	0.0	0.0
Cd	0.2	0.0	0.0	0.0
Cr	1.0	1.7	1.8	0.0
Se	0.5	3.2	1.3	3.3

alarming [32]. There may be hazards associated with Cr levels beyond allowable limits, including possible carcinogenic consequences [33]. Another researcher found that cassava tubers grown close to cement factories in Ogun State, Nigeria, had higher levels of Pb (up to 1.5 mg/kg) and Cr. Their findings are supported by the increased Pb (2.2 mg/kg) in the market-bought sample, suggesting that further contamination may be introduced by market processing [34]. Roadside-dried Cassava Flour: This sample exhibited the highest Fe (37.2 mg/kg) and Cr (1.8 mg/kg) levels, with Fe slightly above the safe threshold and Cr exceeding the permissible limit. These elevated levels are likely due to environmental contamination from dust, soil, or vehicle emissions during roadside drying. Cu (3.8 mg/kg) and Zn (22.7 mg/kg) were also highest in this sample, but remained within safe limits. This study corroborated with another researcher who found detectable Pb (0.05–0.87 mg/kg) and Cr in cassava flakes sold in markets in Yenagoa, Nigeria, which are lower than the 2.2 mg/kg Pb and 1.7 mg/kg Cr in the market-bought sample here [35]. This suggests a higher contamination risk in Oyo State markets, possibly due to regional differences in processing or environmental factors. Self-dried Cassava Flour: This sample demonstrated the lowest contamination, with no detectable Pb, Cd, or Cr, and safe levels of Mn (16.2 mg/kg) and Fe (24.7 mg/kg). However, Se (3.3 mg/kg) exceeded the permissible limit, which may require monitoring due to potential selenosis risks [32]. The controlled drying environment likely minimized external contamination, making this sample the safest.

Comparative Analysis

The roadside-dried sample showed the highest contamination for Fe, Cu, Zn, and Cr, likely due to exposure to environmental pollutants during drying. The market-bought sample was notable for its elevated Pb and Cr levels, suggesting contamination during processing, packaging, or storage in market settings. The self-dried sample consistently showed the lowest or no detectable levels of hazardous metals (Pb, Cd, Cr), highlighting the benefits of controlled drying conditions. These findings aligned with what a researcher reported [35], and that elevated heavy metal levels in cassava products exposed to environmental contaminants [34], and also a researcher noted contamination risks in market-sourced cassava due to improper handling [35].

Conclusion

Cassava flour in Oyo State, Nigeria, generally contains heavy metals (Lead, Chromium, Arsenic) within safe, permissible limits set by the WHO. While heavy metals are present, they are generally below toxic thresholds, indicating that commercial and domestic flour from areas like Oke-Ogun is safe for human consumption [37]. This study assessed the levels of heavy metal contamination in cassava flour samples from three sources in Oyo State, Nigeria: market-bought, roadside-dried, and self-dried. The analysis revealed significant variations in contamination levels among the samples, addressing the research objectives and questions. The market-bought sample exhibited the highest levels of hazardous heavy metals, with Lead (Pb) at 2.2 mg/kg and Chromium (Cr) at 1.7 mg/kg, both exceeding the WHO/FAO permissible limits of 0.3 mg/kg and 1.0 mg/kg, respectively. The roadside-dried sample showed elevated Iron (Fe) at 37.2 mg/kg, slightly above the safe threshold of 300 mg/kg, and Cr at 1.8 mg/kg, also exceeding the permissible limit. In contrast, the self-dried sample demonstrated the lowest contamination, with no detectable Pb, Cadmium (Cd), or Cr, making it the safest for consumption. However, all samples had Selenium (Se) levels (1.3–3.3 mg/kg) exceeding the WHO/FAO limit of 0.5 mg/kg, indicating a potential health concern that warrants further investigation. The absence of Cd in all samples is a positive finding, aligning with safe levels below the WHO/FAO limit of 0.2 mg/kg. Copper (Cu) and Zinc (Zn) concentrations were within safe limits across all samples. The findings corroborate previous studies, such as these researchers who reported elevated Pb and Cr in market-sourced cassava products due to processing and environmental contamination [35.36]. The elevated Fe and Cr in roadside-dried samples support [36], highlighting the role of environmental exposure in contamination. The unexpectedly high Se levels across all samples are not widely reported, suggesting a need for further research into regional soil or processing factors. These results underscore the critical need for improved processing and drying practices to ensure the safety of cassava flour, a staple food in Nigeria, and contribute to public health protection.

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