HEALTH RISK IMPLICATIONS OF HEAVY METALS INTRODUCED DURING FOOD GRINDING

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN ANIMAL AND ENVIRONMENTAL BIOLOGY(BSCAEB)

OCTOBER, 2025.

CERTIFICATION

This is to certify that this project was carried out by **ORDAH JESSE ORUME** of the Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, Benin City.

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DEDICATION

This work is dedicated to God Almighty.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Food processing methods, particularly mechanical grinding, have been identified as potential sources of heavy metal contamination in daily diets. This study assessed the concentrations and health risks of heavy metals introduced into common Nigerian food items (tomato, pepper, melon, beans, groundnut, white and yellow corn, and crayfish) during grinding with various equipment types including blenders, milling machines, hand-crank grinders, mortars, and grinding stones. Heavy metals (Fe, Mn, Zn, Ni, Cd, and Pb) were analyzed using Atomic Absorption Spectrophotometry (AAS), and potential health risks were evaluated using Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) models. Results revealed elevated levels of essential metals such as Fe, Mn, and Zn, with concentrations highest in foods ground with older milling machines and mechanical grinders, reflecting increased leaching due to metallic wear. Toxic metals (Pb and Cd) were mostly below detection limits, indicating minimal immediate toxicity but potential for chronic accumulation. Fe showed the highest EDI (up to 5.35 mg/kg/day in hand-crank grinder samples), while THQ values exceeded 1.0 in several processed beans samples, suggesting possible non-carcinogenic risk upon prolonged exposure. Traditional grinding methods (mortar and pestle) exhibited significantly lower contamination levels compared to mechanical ones. These findings highlight that metal leaching from food processing equipment constitutes a significant but often overlooked route of dietary exposure to heavy metals in Nigeria.

CHAPTER ONE

INTRODUCTION

Food is vital for human survival, supplying necessary nutrients for growth, maintenance, and overall well-being. Typically sourced from plants and animals, it is the main contributor of proteins, vitamins, carbohydrates, and essential micronutrients like iron and zinc, all crucial for health (Aquilera et al., 1999; Wang et al., 2005). Beyond its biological roles, food is deeply embedded in cultural traditions, livelihoods, and economic stability. Globally, around 2.5 billion people depend on street food for their daily nutrition, especially in densely populated urban areas. This reliance underscores food's importance in community sustenance but also raises concerns about vulnerability to contamination, particularly regarding food safety (Wu et al., 2017; Liu et al., 2016).

While food delivers essential nutrients, it can also harbor harmful contaminants, especially heavy metals. The presence of heavy metals in food is a significant public health concern in both developed and developing countries, with alarming cases reported from nations like Nigeria and Ghana. Heavy metals such as iron (Fe), lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), cobalt (Co), mercury (Hg), and arsenic (As) can infiltrate the food supply through various means, including environmental pollution (affecting soil, air, and water), agricultural practices like irrigation with wastewater, industrial operations, and food processing (Pennington, 2000; Jigam et al., 2011; Ehiri et al., 2010; Elekofehinti et al., 2012; Dabonne, 2010). Once introduced, heavy metals persist in the environment due to their non-biodegradable nature and can accumulate in biological systems, amplifying their toxic effects (Chan et al., 2003).

The toxicity of heavy metals adversely affects vital organs and glands such as the heart, brain, kidneys, liver, and bones. They can disrupt the absorption of essential minerals, impairing their biological functions. For example, aluminum can bind to nutrients like calcium, zinc, and copper, interfering with their use in the body, which may contribute to conditions such as Alzheimer's disease (Dabonne et al., 2010; Miu & Beng, 2006; Bharathi et al., 2008).

Some metals, such as iron and zinc, are necessary in small quantities but can be harmful in high concentrations. In contrast, metals like lead, cadmium, mercury, and arsenic serve no beneficial purpose in the body and are toxic even in trace amounts (Li et al., 2014). The health effects of heavy metals can lead to both non-carcinogenic and carcinogenic outcomes. Non-carcinogenic impacts include acute and chronic damage to the central nervous, cardiovascular, gastrointestinal, and endocrine systems, along with respiratory problems. Lead toxicity is especially concerning for children due to their higher absorption rates, often resulting in irreversible neurobehavioral disorders and decreased IQ (Bronstein et al., 2011). Long-term exposure to cadmium can result in kidney dysfunction and skeletal issues, while prolonged arsenic exposure is linked to skin lesions and cardiovascular diseases (Sigel et al., 2013; Thevenod et al., 2013; Sinicropti et al., 2010). Moreover, the International Agency for Research on Cancer (IARC) has classified several metals, including arsenic, cadmium, cobalt, and nickel compounds, as human carcinogens (Sinicropti et al., 2010; Galanis et al., 2009).

This issue is of particular concern for populations that heavily depend on staple foods, as children are especially susceptible to the toxic effects of heavy metals. Although the implications are serious, few studies have specifically examined dietary exposure to heavy metals from grinding equipment. Most research has focused on environmental contamination, leaving a critical gap in understanding the risks associated with food processing methods.

1.1 Aim of Study

This study aims to address the gap by investigating the role of mechanical grinding in contributing to heavy metal contamination in staple foods. It seeks to quantify contamination levels and evaluate related health risks for the general population. By highlighting this often-overlooked pathway, the research contributes to broader efforts to improve food safety and protect public health in regions where these food processing methods are common. Furthermore, it emphasizes the need for further research to fully understand and mitigate the associated risks.

CHAPTER TWO

LITERATURE REVIEW

2.1 Heavy Metal Contamination in Food

Heavy metals are naturally occurring metallic elements that have high atomic weights and densities, typically exceeding five times that of water. They are widely distributed in the Earth's crust and occur in various concentrations depending on geological and environmental conditions. Essential micronutrients are required by the human body in minute amounts for proper functioning. Conversely, substances such as lead, cadmium, and arsenic are highly toxic, even at trace levels. When these toxic elements accumulate in food and subsequently in the body, they can lead to bioaccumulation and cause serious health problems, including kidney failure, anemia, neurological impairment, and various cancers.

Food can become contaminated with heavy metals at almost any point in its production chain. Contamination may begin in the field during cultivation and extend through harvesting, processing, storage, and preparation. Among these stages, food processing, especially milling and grinding using metallic machinery, has been identified as one of the most critical points where heavy metals are introduced into food products.

2.1.1 Food Milling as a Source of Contamination

Milling is one of the most essential and widely practiced food processing operations. It reduces the size of solid materials, making them easier to digest, cook, and consume (Kwofie et al., 2006). Around the world, milling is indispensable of preparing staple foods, converting grains such as maize, millet, and wheat into flour suitable for human and animal diets. However, during this process, metal parts from grinding plates and other mechanical components can wear down.

The resulting friction and abrasion release trace amounts of metals into the food, contributing to contamination that may accumulate over time.

2.2 Classification and Characteristics of Heavy Metals

2.2.1 Essential and Non-Essential Metals

Trace metals are generally classified as either essential or non-essential. Essential metals, such as iron, copper, and zinc, are required in small quantities to support biological functions, including enzyme activation, tissue repair, and metabolic regulation. Both insufficient and excessive levels of these elements can disturb normal physiological balance and lead to health complications. Non-essential metals, including lead, cadmium, and mercury, serve no known biological purpose and are toxic even at very low concentrations. Other examples of essential and non-essential metals include manganese and arsenic, respectively (Bamuwamye et al., 2015; Nnaji et al., 2016).

2.2.2 Persistence, Non-Biodegradability, and Bioaccumulation

Unlike organic pollutants, heavy metals do not decompose or degrade over time. They persist in the environment and tend to accumulate in living organisms through a process known as bioaccumulation. Bioaccumulation is the gradual build-up of a substance in an organism over time, often reaching higher concentrations than in the surrounding environment. Once absorbed, these metals concentrate in tissues and organs and can move up the food chain, increasing in concentration with each trophic level. This persistence and cumulative behavior make heavy metals a long-term threat to both environmental and human health (Vogt et al., 2012; Zukowska & Biziuk, 2008).

22.2.3 Commonly Detected Metals in Food Processing

A wide range of trace metals, including arsenic, mercury, chromium, iron, lead, cadmium, cobalt, copper, manganese, nickel, and zinc, have been detected in various food systems. Investigations focusing on grinding and milling operations have shown that contamination frequently involves iron (Fe), zinc (Zn), chromium (Cr), nickel (Ni), lead (Pb), and cadmium (Cd) (Nnaji & Emmanuel et al., 2016; Nnaji et al., 2020).

2.3 Heavy Metal Toxicity

Heavy metals are recognized as persistent environmental pollutants capable of accumulating in the tissues of humans and animals. Dietary intake is regarded as the primary route of exposure for the general population. The degree of toxicity is influenced by several factors beyond mere concentration, including the chemical form and interactions with other metals or nutrients.

2.3.1 Chemical Speciation

The toxicity of a metal is primarily determined by the form in which it exists (chemical speciation). Chemical speciation refers to the distribution of an element among its various chemical forms in a sample. For instance, inorganic arsenic (As^{3+}) and organic mercury compounds such as methylmercury are far more toxic than their elemental or other inorganic counterparts (Zukowska & Biziuk, 2008).

2.3.2 Element Interactions

Interactions between metals can significantly influence their absorption and toxicity. A deficiency in essential trace elements, such as zinc or iron, can enhance the absorption of toxic metals, such as cadmium. Conversely, selenium has been shown to reduce the toxic effects of mercury and lead by forming inert complexes (Sigel et al., 2013; Thevenod et al., 2013).

2.4 Risk Assessment of Heavy Metals

2.4.1 Exposure Variables

The health effects of heavy metals depend on the duration, route, and frequency of exposure. Acute toxicity occurs following short-term exposure to high concentrations, while chronic toxicity arises from long-term, low-level exposure (Bjermo et al., 2013).

2.4.2 Individual Susceptibility

Individual susceptibility to heavy metal toxicity is influenced by several factors, including age, nutritional condition, and genetic background. Two central toxicological mechanisms are commonly observed: oxidative stress and molecular mimicry. In oxidative stress, metals such as mercury, cadmium, and lead generate reactive oxygen species that damage cell membranes and deplete antioxidants, such as glutathione. Through molecular mimicry, toxic metals can replace essential ones; lead can substitute for calcium in bone tissue, while cadmium can replace zinc in enzymes, disrupting biological functions and metabolic processes.

2.5 Heavy Metal Exposure and Risks in Milled Foods

Risk assessment studies conducted across different regions have revealed significant levels of heavy metal contamination in milled foods. In Umuahia, Nigeria, mean lead (Pb) levels in food products processed with metallic disc grinders exceeded the WHO/FAO safety limit of 0.2 mg/kg. The Health Risk Index (HRI) for lead exceeded 1 in several foods, including beans, maize, bambara nuts, and soybeans, suggesting that consumers may be exposed to potentially harmful levels of lead. Iron (Fe) concentrations were also reported to be high, reaching 646.67 mg/kg in soybeans, with corresponding HRI values above 1.

A similar pattern was observed in Kampala, Uganda, where lead concentrations in roasted pork and beef exceeded the tolerable daily intake (TDI) for both adults and children. The target hazard quotient (THQ) for lead surpassed 1, particularly among children, indicating a potential health risk.

In Ghana, a comparative study on milled maize processed using grinding plates from Ghana, India, and Nigeria showed that copper (Cu), chromium (Cr), and nickel (Ni) levels often exceeded FAO/WHO permissible limits. The HRI values for chromium and nickel were highest when newly sharpened local grinding plates were used, suggesting contamination from equipment wear.

In Bangladesh, assessments of vegetables and fruits revealed that the incremental lifetime cancer risk (ILCR) for cadmium (Cd) exceeded the U.S. Environmental Protection Agency (EPA) threshold of 10^{-4}. The cumulative cancer risk from arsenic, cadmium, and lead also surpassed acceptable limits, with cadmium identified as the most significant contributor to total cancer risk.

2.6 Health Implications of Dietary Heavy Metal Exposure

2.6.1 Non-Carcinogenic Effects

Exposure to heavy metals can cause both acute and chronic health problems, including nausea, abdominal pain, vomiting, anemia, cardiovascular issues, and neurological impairment (Adal et al., 2013). Acute poisoning generally occurs after short-term exposure to high doses and can affect multiple organ systems, particularly the gastrointestinal tract and central nervous system. Chronic toxicity develops gradually due to long-term, low-level exposure and often mimics other diseases, making it difficult to diagnose (Galanis et al., 2009).

2.6.2 Carcinogenic Risks

Chronic exposure to certain heavy metals has been linked to cancer development. The International Agency for Research on Cancer (IARC) classifies arsenic and its compounds, cadmium, and nickel compounds as Group 1 carcinogens, meaning they are carcinogenic to humans. Cobalt and its compounds are classified as Group 2B, indicating possible carcinogenicity (Sultana et al., 2017).

2.6.3 Organ Damage

Heavy metals tend to accumulate in specific organs where they interfere with normal function. Mercury often concentrates in the brain and kidneys (ATSDR, 2001), while lead is stored primarily in bones (ATSDR, 2007b). Cadmium accumulates in the liver and kidneys, leading to renal dysfunction and reduced bone mineral density during long-term exposure (Kirberger et al., 2013).

2.6.4 Nutrient Displacement and Chelation Effects

Toxic metals can imitate essential elements and displace them from their biological binding sites. Lead behaves similarly to calcium and can substitute for it in bone tissue. Cadmium is known to replace zinc in thousands of enzymes and structural proteins, disrupting their regular activity. Thallium mimics potassium within the nervous and cardiovascular systems. These substitutions compromise enzyme function and nutrient balance. In addition, metals such as mercury, cadmium, and lead promote oxidative stress by generating free radicals and depleting antioxidant reserves, including glutathione (Adeti, 2012).

2.6.5 Links to Specific Diseases

Elevated aluminum levels have been detected in the brains of some Alzheimer's patients, although a causal link remains unconfirmed. Lead poisoning is one of the most common forms of single-metal toxicity, especially in children. Even low-level exposure below 10 μg/dL has been associated with cognitive deficits, developmental delays, and reductions in IQ. Chronic cadmium exposure leads to its accumulation in kidney tissue, resulting in renal failure and bone demineralization (Vogt et al., 2012; Adeti, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at New Benin Market. This market is located at the intersection of New Benin–Mission Road and New Lagos Road in Oredo Local Government Area, Edo State, Nigeria. New Benin Market is one of the largest and busiest markets in Benin City. It experiences intense commercial activity, high human traffic, and considerable organizational challenges. The market is divided into distinct sections. These include areas for clothing (both imported and locally produced), Ankara fabrics, tailoring materials, curtains, bedding, household utensils, and a wide variety of fresh and packaged food items. In addition to the main market stalls, numerous informal vendors operate along the roadside and within the market premises. They contribute to the market's vibrant and bustling atmosphere. Commodities are generally sold at lower prices than in other markets within the city. This makes New Benin Market a major shopping destination for residents from various parts of Benin City and neighboring communities. The market's central location and accessibility by major roads further enhance its appeal to both buyers and sellers.

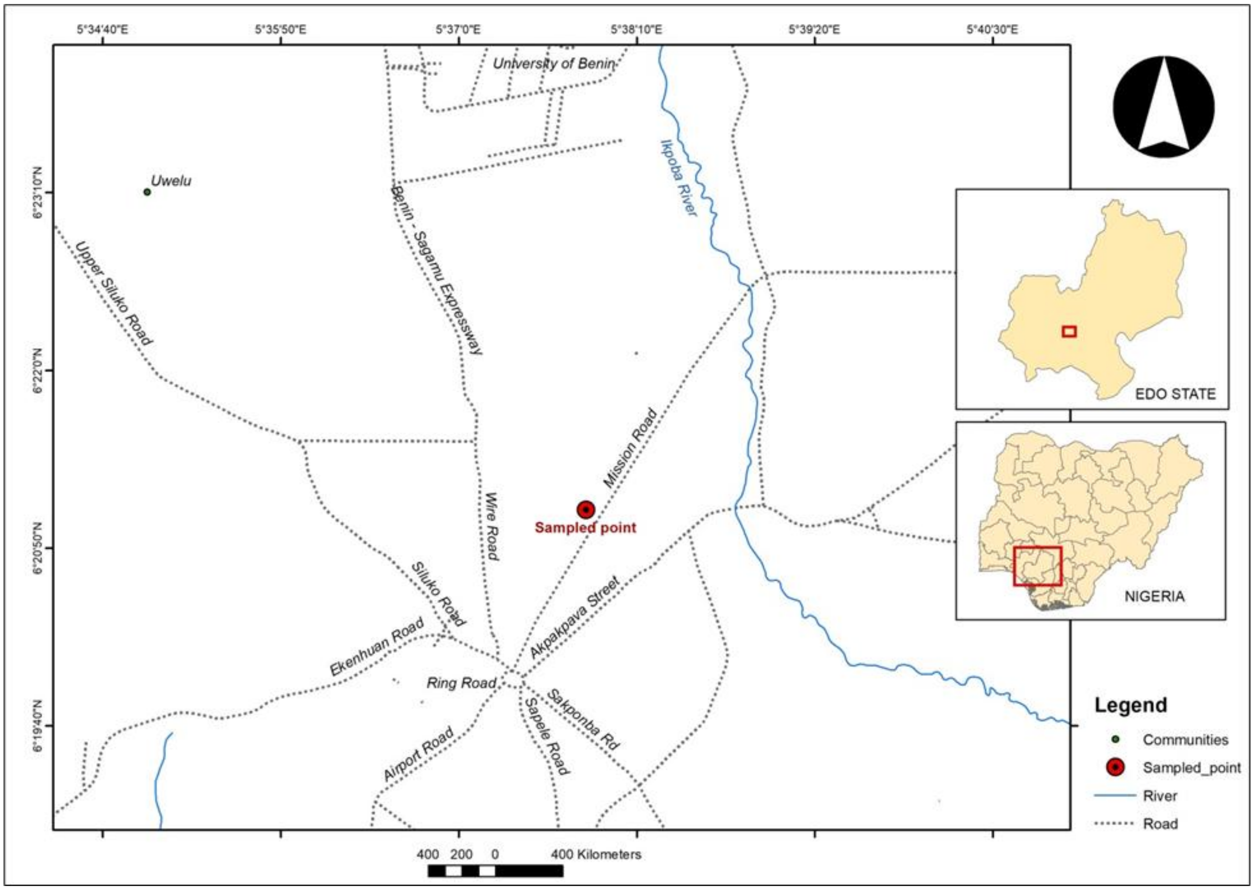

FIGURE 3.1 (Map showing study area)

3.2 Sampling Methods

Sample Collection

3.2.1 Sample Collection and Identification

Eight different food items were purchased from New Benin Market and transported to the laboratory for identification and preparation.

1. **Preparation**: In the laboratory, samples were separated into smaller portions according to grinding method and texture. These portions were then prepared for further processing and analysis.

PLATE 1: Tomato
(Solanum lycopersicum)

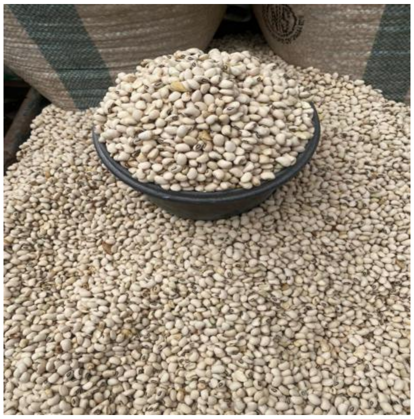

PLATE 2: Beans
(Phaseolus vulgaris)

PLATE 3: Melon
Citrullus colocynthis

PLATE 4: Crayfish
Procambarus clarkii

PLATE 5: Milling machine

PLATE 6: Hand cranker grinder

3.3 Sample Labeling and Storage

Each container was marked with a unique identifier, including sample type, date of collection, and processing method.

3.3.1 Sample Storage

The samples were stored in airtight, contamination-free containers before digestion, while the digested samples were stored in clean, labeled 25 ml plastic volumetric flasks. All samples were kept in a cool, dry environment to prevent degradation or contamination before analysis.

3.4 Quality Assurance and Quality Control

To ensure the reliability and validity of results, appropriate quality control measures were implemented throughout the study. We employed analytical-grade reagents for calibrating the instruments, and reagent blanks were included in each digestion batch to detect potential contamination. Additionally, all samples were analyzed in duplicates, and results were accepted only when the variation was less than 10%.

3.5 Sample Analysis

The sample digests were analyzed for heavy metals, including Iron (Fe), Zinc (Zn), Manganese (Mn), Nickel (Ni), Lead (Pb), and Cadmium (Cd), using a Buck Scientific AAS Model 205A.

3.5.1 Processing of Samples: A portion of each food item was subjected to different grinding methods:

i. **Market processing**: Mechanical grinders and hand-blending machines.

ii. **Laboratory processing**: Household blender, grinding stone, and mortar.

The processed samples were placed in clean crucibles, labeled, and oven-dried at 105°C until constant weight was achieved. The dried samples were ground into fine powder using a clean mortar and pestle.

3.5.2 Digestion Process: Each 1.0 g portion of the sample was accurately weighed into a clean beaker and digested with 10 ml of perchloric acid. The mixture was subsequently filtered into a 250 ml digestion tube and subjected to heating until a clear solution was obtained. After cooling to room temperature, a small volume of distilled water was added to prevent scorching of the filter paper during subsequent filtration. The digest was then carefully filtered through Whatman No. 42 filter paper into a 25 ml volumetric flask and diluted to the calibration mark with distilled water. All volumetric flasks were clearly labeled and stored for subsequent determination of metal concentrations using Atomic Absorption Spectrophotometry (AAS).

Apparatus used includes:

i. 250 ml digestion tubes

ii. Hot plate/heater

iii. Funnels

iv. 25 ml volumetric flasks

v. Beakers

vi. Filter paper (Whatman No. 42)

vii. Reagent

viii. Perchloric acid ($HClO_4$)

3.5.3 Determination of Heavy Metals

The Buck Scientific VGP 210 Atomic Absorption Spectrophotometer (AAS) was calibrated with Buck-certified atomic absorption standards for the respective metals of choice to obtain a calibration curve. Standard solutions used for the calibration of the machine were prepared using the following procedure;

A 10ml portion of the stock solution (1000 ppm) was transferred into a 100ml volumetric flask and diluted to the mark with deionized water, yielding a solution of 100 ppm metal concentration. From this solution, 10ml was pipetted into another 100ml volumetric flask and diluted to the mark, giving a 10-ppm solution. From the 10-ppm solution, aliquots of 2.5, 5, 7.5, and 10 ml were each pipetted into separate 50 ml volumetric flasks and diluted to volume with distilled water. These final solutions had metal concentrations of 0.5, 1.0, 1.5, and 2.0 ppm, respectively. They were then used to calibrate the machine. For each element, the respective hollow cathode lamp was installed in the AAS. Sample digests were aspirated into the flame, with periodic blanking using distilled water to minimize instrumental drift. Heavy metal concentrations were quantified, and all samples were analyzed in duplicates to ensure reproductibility, accuracy, and precision.

3.6 Statistical Analysis

Data analysis was performed using the computer software Microsoft Excel and Statistical Package for Social Sciences (SPSS) version 20. One-way analysis of variance (ANOVA) was employed to test significant differences ($p < 0.05$) between groups. Mean and standard deviation were computed for heavy metal concentrations in each food sample.

3.7 Risk Assessment

3.7.1 Estimation of daily heavy metal intake

The health hazards faced by residents were assessed based on their dietary intake of heavy metals and compared with the maximum allowable risk level for humans. The estimated daily intake (EDI) of heavy metals from eating vegetables and fruits was determined using the following formula.

$$\mathrm{EDI} = \mathrm{VDIRx} \times \mathrm{CV} \div \mathrm{BW}$$

Where x = the daily food consumption rate.

EDI represents the estimated daily consumption of heavy metals (mg/kg/day). CV indicates the mean concentration of heavy metals found in the analyzed food samples (mg/kg, fresh weight), and V_{DIRx} denotes the rate of daily food intake. The total daily food intake (VDIRtotal) for Nigerians differed according to the food type, and the average adult body weight in this population was taken to be 63.4 kg.

3.7.2 Health Risk Assessment

The target hazard quotient (THQ) was used to evaluate the non-carcinogenic risks associated with consuming food contaminated by heavy metals.

$$THQ = [EFxEDxFIRxC / RfDxBWxAT] x 10-3$$

EF is the exposure frequency, ED is the exposure duration, half-life of the population, C is the concentration if heavy metals found in the food, *RfD* is the oral reference dose (mg/kg/day), BW is the average body weight of the population, and AT is the averaging time (EF × 70). (Charleine et al., 2024; Mahfuza et al., 2017).

Table 3.1: Input parameters to characterize CDI values

Parameter	Symbol	Units	Risk Assessment
Estimated daily intake	EDI	g/day	Varied per food item
Exposure frequency	EF_r	Days/year	365
Exposure duration	ED_{tot}	Years	63.4
Averaging time	AT	Days	25,550 (70×365)
Body Weight	Bw	Kg	65

Table 3.2: Oral reference dose (R_fD) for heavy metals.

Metal	R_fD (mg/kg/day)
Iron (Fe)	0.007
Manganese (Mn)	0.14
Zinc (Zn)	0.3
Nickel (Ni)	0.02
Cadmium (Cd)	0.001
Lead (Pb)	0.0035

Table 3.3: Ingestion rate of food item by consumers.

Food item	Ingestion Rate(g/day)
Tomato	110
Pepper	110
Crayfish	24
Beans	455.4
White corn	350
Yellow corn	350
Groundnut	30
Melon	107

(Melesse et al., 2023; Byrd et al., 2022; Yahaya et al., 2020)

CHAPTER FOUR

RESULTS

4.1 Metal Concentration in Processed Food

The concentrations of heavy metals assessed in the processed food samples are presented in Table 4.1 below as Mean/average, standard deviation (SD) and Minimum-Maximum range.

4.1.1. Concentration of Iron (Fe) in Food.

Iron (Fe) concentrations varied widely among the samples. The highest mean concentrations were observed in Beans (5.01-3.63mg/kg), Crayfish (1.10205-3.6825 mg/kg), and Pepper (0.28-2.11mg/kg). Intermediate levels of 0.94-1.68 mg/kg were found in Tomato, 1.327-1.62 mg/kg in White corn, and 0.655-1.338 mg/kg in yellow corn. The lowest mean concentrations were recorded in Melon (0.770-1.137mg/kg) and Groundnut (0.7521-1.0008 mg/kg).

4.1.2. Concentration of Manganese (Mn) in Food

Manganese (Mn) concentrations varied significantly among the food samples analyzed. The highest mean concentrations were found in Beans, ranging from 0.086 to 0.411 mg/kg, followed closely by Melon (0.102–0.401 mg/kg) and White corn (0.140–0.399 mg/kg). Intermediate levels were detected in Groundnut (0.0922–0.355 mg/kg), Yellow corn (0.1263–0.339 mg/kg), Pepper (0.149–0.335 mg/kg), and Crayfish (0.1341–0.3167 mg/kg). The lowest mean concentration was observed in Tomato, ranging from 0.129 to 0.25 mg/kg.

4.1.3. Concentration of Zinc (Zn) in Food

Zinc (Zn) concentrations varied significantly across the food samples. The highest mean concentration was identified in Crayfish, ranging from 0.1860 to 0.829167 mg/kg. Moderate levels were observed in White corn (0.071–0.548 mg/kg), Yellow corn (0.0696–0.537 mg/kg), Beans (0.096–0.505 mg/kg), Melon (0.077–0.499 mg/kg), and Groundnut (0.1351–0.4725 mg/kg). The lowest mean levels were found in Pepper (0.175–0.309 mg/kg) and Tomato (0.18–0.23 mg/kg).

4.1.4. Concentration of Nickel (Ni) in Food

Nickel (Ni) concentrations were generally very low across all food samples. Levels were below the detection limit (BDL) in Pepper, White corn, and Beans. Among the detectable samples, yellow corn showed the highest mean concentration, ranging from 0.0072 to 0.0026 mg/kg, followed by Groundnut (0.0052–0.0015 mg/kg), Crayfish (0.00346–0.001 mg/kg), Melon (0.0020–0.0009 mg/kg), and Tomato (0.0015–0.0005 mg/kg).

4.1.5. Concentration of Cadmium (Cd) in Food

Cadmium (Cd) levels were mainly below the detection limit (BDL) in most food samples, including Pepper, Crayfish, White corn, yellow corn, Groundnut, and Beans. Detectable concentrations were only found in Melon (0.0032–0.001 mg/kg) and Tomato (0.0037–0.00083 mg/kg).

4.1.6. Concentration of Lead (Pb) in Food

Lead (Pb) was largely undetected across the food samples. Concentrations were below the detection limit (BDL) in Melon, Crayfish, White corn, yellow corn, Groundnut, and Beans. Trace amounts were observed in Pepper (0.000084–0.00004 mg/kg) and Tomato (0.000047–0.00001 mg/kg).

Table 4.1: Heavy metal concentration in grinded food.

Parameters	Tomato Mean ± SD (Min and Max)	Pepper Mean ± SD (Min and Max)	Melon Mean ± SD (Min and Max)	Crayfish Mean ± SD (Min and Max)	White corn Mean ± SD (Min and Max)	Yellow corn Mean ± SD (Min and Max)	Groundnut Mean ± SD (Min and Max)	Beans Mean ± SD (Min and Max)	Control Mean ± SD (Min and Max)
Fe	1.68±0.94 (0.48-2.96)	2.11±0.28 (1.56-2.54)	1.137±0.770 (0.50-3.22)	3.6825±1.10205 (2.56-6.46)	1.62±1.327 (0.52-4.63)	1.338±0.655 (0.68-2.52)	1.0008±0.7521 (0.35-3.03)	5.01±3.63 (1.59-10.9)	1.37625±0.44785 (0.61-1.92)
Mn	0.25±0.129 (0.30-0.56)	0.335±0.149 (0.04-0.57)	0.401±0.102 (0.260-0.59)	0.3167±0.1341 (0.10-0.51)	0.399±0.140 (0.21-0.71)	0.339±0.1263 (0.20-0.61)	0.355±0.0922 (0.25-0.50)	0.411±0.086 0.21-0.48	0.3075±0.094378 (0.18-0.43)
Zn	0.23±0.18 (0.06-0.79)	0.309±0.175 (0.80-0.54)	0.499±0.077 (0.40-0.65)	0.829167±0.1860 (0.5-1.1)	0.548±0.071 (0.39-0.61)	0.537±0.0696 (0.43-0.65)	0.4725±0.1351 (0.39-0.81)	0.505±0.096 (0.40-0.69)	0.45±0.15427 (0.29-0.76)
Ni	0.0005±0.0015 (0.00-0.006)	BDL	0.0009±0.0020 (0.000-0.006)	0.001±0.00346 (0.000-0.0120	BDL	0.0026±0.0072 (0.00-0.23)	0.0015±0.0052 (0.000-0.0180)	BDL	BDL
Cd	0.00083±0.0037 (0.000-0.02)	BDL	0.001±0.0032 (0.00-0.01)	BDL	BDL	BDL	BDL	BDL	BDL
Pb	0.00001±0.000047 (0.000-0.0002)	0.00004±0.000084 (0.0000-0.0002)	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table 4.2: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated Tomatoes for Adults.

Grinding method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	4.122397476	0.371293375	0.301892744	0.002082019	0.003470032	0
Mortar	2.342271293	0.475394322	0.211671924	0	0	0
Grinding stone	3.341640379	0.395583596	0.96466877	0	0	0.000138801
Milling machine	2.920609884	0.560988433	0.179284963	0	0	0
Control	1.761041009	0.190851735	0.30362776	0	0	0

Table 4.2 shows the EDI values of Fe, Mn, Zn, Ni, Cd, Cr, and Pb in tomatoes processed by different grinding methods. Iron ranged from 1.7601 mg/kg/day (control) to 4.4239 mg/kg/day (blender), while manganese varied from 0.1958 to 0.4175 mg/kg/day, highest in the natural method, likely due to metal leaching. Zinc ranged from 0.1730 (milling machine) to 0.3161 mg/kg/day (natural method), suggesting greater contamination from traditional tools. Nickel and cadmium were undetected. Chromium ranged from 0.0020 to 0.0034 mg/kg/day, and lead from 0.0000138 to 0.00047 mg/kg/day, both slightly elevated in blender-processed samples. Overall, blender and natural grinding methods showed higher EDI values, while the control and milling machine samples had lower contamination risks.

Table 4.3: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated Pepper for Adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	4.424290221	0.425078864	0.954258675	0	0	0.000433754
Mortar	3.89511041	0.060725552	0.130126183	0	0	0
Grinding stone	3.695583596	0.589905363	0.720031546	0	0	0
6months Hand crank grinder	0	0	0	0	0	0
1 year hand crank grinder	3.764984227	0.589905363	0.84148265	0	0	0.000433754
4-year milling machine	3.044952681	0.954258675	0.294952681	0	0	0
Control	1.752365931	0.511829653	0.494479495	0	0	0

Among all methods, iron (Fe) showed the highest EDI values, 4.24 mg/kg/day in blender-processed samples and 1.75 mg/kg/day in the control, indicating that friction from metal surfaces increases iron contamination. Manganese (Mn) ranged from 0.51 to 0.95 mg/kg/day, highest in the hand-crank grinder, likely due to surface erosion. Zinc (Zn) values (0.29–0.95 mg/kg/day) also peaked in blended samples, reflecting the effect of high-speed metallic contact. Nickel (Ni) and cadmium (Cd) were undetected, while lead (Pb) appeared in trace amounts (0.00002–0.00043 mg/kg/day), suggesting minor background contamination. Overall, blending and manual grinding methods produced higher metal intakes than controlled or non-metallic techniques, emphasizing the need to assess processing equipment as a source of heavy metal exposure.

Table 4.4: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated Beans for Adults.

Among all methods, iron (Fe) showed the highest Estimated Daily Intake (EDI) values, 108.70 mg/kg/day in the 1-year hand crank grinder and 11.11 mg/kg/day in the control, indicating that friction and wear from mechanical grinding surfaces significantly increase iron contamination. Manganese (Mn) ranged from 1.77 mg/kg/day (Control) to 4.30 mg/kg/day (9-year milling machine), with the highest values seen in the mechanical milling machines, likely due to surface erosion from older or more frequently used equipment. Zinc (Zn) values (2.62–4.31 mg/kg/day) peaked in the 9-year milling machine samples, reflecting the potential leaching of Zn from galvanized machine parts during processing. Nickel (Ni), cadmium (Cd), and lead (Pb) were undetected (0) across all samples, suggesting no contamination from these specific metals from the grinding processes or the beans themselves. Overall, the mechanical grinding methods (hand crank and milling machines) produced substantially higher metal intakes than the control or traditional methods like the mortar and grinding stone, emphasizing the need to assess processing equipment as a major source of heavy metal exposure.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Mortar	0.214	0.003057143	2.945015773	0	0	0
Grinding stone	0.208540816	0.004203571	2.945015773	0	0	0
9year Milling machine	0.253306122	0.006332653	4.30977918	0	0	0
1 year hand crank grinder	0.211816327	0.00414898	3.878801262	0	0	0
4-year milling machine	0.69222449	0.005022449	3.842886435	0	0	0
Control	0.131020408	0.003493878	2.621782334	0	0	0

Table 4.5: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated white corn for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Grinding stone	15.5126183	2.346214511	2.815457413	0	0	0
Mortar	3.422712934	1.242113565	2.097791798	0	0	0
6-year Milling machine	10.15772871	2.042586751	2.925867508	0	0	0
3-year Milling machine	4.444006309	2.843059937	3.450315457	0	0	0
9-year Milling machine	4.52681388	1.738958991	2.981072555	0	0	0
Control	5.686119874	1.13170347	2.014984227	0	0	0

Iron (Fe) showed the highest EDI, ranging from 5.686 mg/kg/day in the control to 15.513 mg/kg/day in samples ground with the grinding stone, indicating that abrasive surfaces contribute to Fe leaching. Manganese (Mn) values (1.132–2.843 mg/kg/day) were highest in the 3-year milling machine, while zinc (Zn) levels (2.015–3.450 mg/kg/day) peaked in the 6-year milling machine, reflecting contamination from metallic wear. Ni, Cd, and Pb were not detected. Mechanical and abrasive methods exhibited higher EDI values than the control or mortar, highlighting processing equipment as a contamination source.

Table 4.6: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated yellow corn for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Grinding stone	13.93927445	2.484227129	2.456624606	0	0	0
Mortar	4.195583596	2.014984227	2.815457413	0	0	0
6-year Milling machine	11.75867508	1.932176656	3.09148265	0	0	0
3-year Milling machine	4.996056782	1.242113565	3.146687697	0	0	0
9-year Milling machine	9.605678233	1.462933754	3.643533123	0	0	0
Control	3.671135647	2.318611987	2.622239748	0	0	0

Among all methods, iron (Fe) showed the highest EDI, 3.671 mg/kg/day in the control and 13.939 mg/kg/day in grinding stone samples, indicating that both abrasive and mechanical processes increase Fe contamination. Manganese (Mn) ranged from 1.242 to 2.484 mg/kg/day, highest in the grinding stone, suggesting surface wear. Zinc (Zn) levels (2.457–3.644 mg/kg/day) were highest in the 9-year milling machine, likely due to degradation of metallic components. Ni, Cd, and Pb were undetected. The grinding stone and mechanical milling machines produced greater EDI values, particularly for Fe and Zn, than the control or mortar.

Table 4.7: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated groundnut for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	0.414037855	0.123028391	0.212933754	0.00804	0	0
Mortar	0.449526814	0.132492114	0.179810726	0	0	0
Grinding stone	0.291009464	0.208201893	0.205835962	0	0	0
6months Hand crank grinder	0.241324921	0.19873817	0.179810726	0	0	0
1 year hand crank grinder	0.35488959	0.227129338	0.229495268	0	0	0
4-year milling machine	1.438485804	0.123028391	0.203470032	0	0	0
Control	0.149053628	0.123028391	0.194006309	0	0	0

Iron (Fe) exhibited the highest EDI values, 0.149 mg/kg/day in the control and 1.438 mg/kg/day in the 4-year milling machine, indicating contamination from aged mechanical parts. Manganese (Mn) ranged from 0.123 to 0.227 mg/kg/day, highest in the 1-year hand-crank grinder, while zinc (Zn) (0.180–0.229 mg/kg/day) also peaked in the same grinder. Cadmium (Cd) and lead (Pb) were undetected, whereas nickel (Ni) appeared in a trace amount (0.008 mg/kg/day) in the blender sample. Mechanical grinders yielded higher metal intake than traditional methods, confirming the influence of equipment wear.

Table 4.8: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated Melon for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	1.653943218	0.472555205	0.877602524	0.010970032	0	0
Grinding stone	1.611750789	0.649763407	1.122318612	0	0	0
Mortar	1.957728707	0.978864353	0.759463722	0.005147476	0	0
6months Hand crank grinder	1.637066246	0.641324921	0.978864353	0	0	0
1 year hand crank grinder	5.35	0.776340694	1.097003155	0	0	0
4-year milling machine	1.012618297	0.540063091	1.122318612	0	0	0
Control	1.021056782	0.616009464	0.911356467	0	0	0

The highest EDI values were observed for iron (Fe), with 5.35 mg/kg/day in the 1-year hand-crank grinder and 1.021 mg/kg/day in the control. This pattern suggests significant metal transfer from grinding surfaces during processing. Manganese (Mn) concentrations ranged from 0.016 to 0.979 mg/kg/day, highest in the mortar, possibly due to its material composition. Zinc (Zn) values varied from 0.759 to 1.127 mg/kg/day, peaking in samples processed with the 4-year milling machine. Cadmium (Cd) and lead (Pb) were not detected, while nickel (Ni) appeared only in trace amounts (≤ 0.011 mg/kg/day). The elevated EDI values from mechanical grinders indicate that metal leaching from equipment is a probable source of contamination.

Table 4.9: Estimated Daily Intake (EDI) Values of Heavy Metals Via Consumption of Contaminated Crayfish for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	1.042902208	0.170347003	0.43533123	0	0	0
Mortar	0.965299685	0.045425868	0.194952681	0	0	0
Grinding stone	1.372239748	0.196845426	0.323659306	0	0	0
6months Hand crank grinder	1.597476341	0.177917981	0.32555205	0	0	0
1 year hand crank grinder	1.796214511	0.141955836	0.312302839	0	0	0
4-year milling machine	0.518611987	0.060567823	0.388012618	0	0	0
Control	0.518611987	0.060567823	0.280126183	0	0	0

The EDI values for iron (Fe) ranged from 0.5186 mg/kg/day in the control sample to 1.5974 mg/kg/day in crayfish processed with a 6-month-old hand-crank grinder, indicating a higher level of iron contamination associated with manual grinding.

For manganese (Mn), values varied between 0.0605 mg/kg/day in the control and 0.1779 mg/kg/day in the 1-year hand-crank grinder sample, suggesting a gradual increase in manganese content with prolonged manual grinding.

The zinc (Zn) concentration ranged from 0.2301 mg/kg/day in the control to 0.3880 mg/kg/day in the 4-year milling machine sample, implying that prolonged mechanical use may enhance zinc leaching from metallic components.

Nickel (Ni), cadmium (Cd), and lead (Pb) were not detected across all samples, indicating minimal or no contamination from these metals.

Table 4.10: Target Hazard Quotient (THQ) Values of Heavy Metals Via Consumption of Contaminated Tomatoes for adults.

Grinding method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	0.52025821	0.002342914	0.000888993	6.13099E-06	1.02183E-05	0
Mortar	0.295601256	0.002999805	0.000623317	0	0	0
Grinding stone	0.421724458	0.002496188	0.002840692	0	0	4.08733E-07
Milling machine	0.36858922	0.003539916	0.000527946	0	0	0
Control	0.222248352	0.001204301	0.000894103	0	0	0

Iron (Fe) recorded the highest THQ values, from 0.222248352 in the control to 0.52025821 in the blender, indicating elevated risk from mechanical processing. Manganese (Mn) ranged from 0.001204301 to 0.003539916, highest in the milling machine. Zinc (Zn) values (0.000894103 - 0.002840692) peaked in the grinding stone. Cadmium (Cd), nickel (Ni) and lead (Pb) were present in traces. The grinding stone and milling machine presented higher hazard quotients than the control, underscoring the risk from equipment wear.

Table 4.11: Target Hazard Quotient (THQ) Values of Heavy Metals Via Consumption of Contaminated Pepper for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	0.558357928	0.002682308	0.002810037	0	0	0.000109482
Mortar	0.49157394	0.000383187	0.000383187	0	0	0
Grinding stone	0.466393093	0.003722386	0.0021203	0	0	0
6months Hand crank grinder	0	0	0	0	0	0
1 year hand crank grinder	0.475151648	0.003722386	0.002477941	0	0	0.000109482
4-year milling machine	0.384281633	0.006021507	0.000868557	0	0	0
Control	0.221153532	0.003229717	0.00145611	0	0	0

Iron (Fe) exhibited the highest THQ, ranging from 0.221153532 in the control to 0.558357928 in the blender-processed sample, suggesting that friction from high-speed blades significantly increases hazard risk. Manganese (Mn) ranged from 0 to 0.006021507, highest in the 4-year milling machine. Zinc (Zn) values ranged from 0–0.002810037, peaked in the blender. Nickel (Ni) and cadmium (Cd) were undetected, while lead (Pb) occurred only in trace amounts (≤0.112). Mechanical grinders generated higher hazard quotients than traditional methods, confirming equipment as a contamination source.

Table 4.12: Target Hazard Quotient (THQ) Values of Heavy Metals Via Consumption of Contaminated Crayfish for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	0.131617206	0.001074914	0.001281934	0	0	0
Mortar	0.121823548	0.000286644	0.000574084	0	0	0
Grinding stone	0.173180534	0.001242122	0.00095309	0	0	0
6months Hand crank grinder	0.201606028	0.001122688	0.000958664	0	0	0
1 year hand crank grinder	0.226687347	0.000895761	0.000919648	0	0	0
4-year milling machine	0.309097394	0.00051357	0.001142593	0	0	0
Control	0.065450298	0.000382192	0.000824897	0	0	0

Iron (Fe) recorded the highest THQ, from 0.065450298 in the control to 0.309097394 in the 4-year milling machine, indicating elevated risk from metallic wear. Manganese (Mn) ranged from 0.000286644 to 0.001242122, highest in the grinding stone, while zinc (Zn) values (0.000824897–0.001281934) peaked in the blender. Ni, Cd, and Pb were undetected. Mechanical grinding equipment and the grinding stone produced greater hazard quotients than the control, emphasizing the risk associated with equipment degradation.

Table 4.13: Target Hazard Quotient (THQ) Values of Heavy Metals Via Consumption of Contaminated Beans for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Mortar	2.098571849	0.021529625	8.891142857	0	0	0
Grinding stone	3.857202254	0.022209508	8.891142857	0	0	0
9year Milling machine	9.944420383	0.020849742	13.01142857	0	0	0
1 year hand crank grinder	8.670773105	0.016317189	11.71028571	0	0	0
4-year milling machine	3.340491259	0.016770445	11.60185714	0	0	0
Control	1.409623856	0.010878126	7.915285714	0	0	0

Iron (Fe) exhibited exceptionally high THQ values, from 1.409623856 in the control to 8.670773105 in the 1-year hand-crank grinder, demonstrating significant risk from mechanical abrasion. Manganese (Mn) ranged between 0.010878126 and 0.022209508, peaking in grinding stone, while zinc (Zn) values (7.915–13.013) were highest in the 9-year milling machine. Nickel (Ni), cadmium (Cd), and lead (Pb) were undetected.

Table 4.14: Target Hazard Quotient (THQ) Values of Heavy Metals Via Consumption of Contaminated white corn for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Grinding stone	2.007142857	0.015178571	0.0085	0	0	0
Mortar	0.442857143	0.008035714	0.006333333	0	0	0
6-year Milling machine	1.314285714	0.013214286	0.008833333	0	0	0
3-year Milling machine	0.575	0.018392857	0.010416667	0	0	0
9-year Milling machine	0.585714286	0.01125	0.009	0	0	0
Control	0.735714286	0.007321429	0.006083333	0	0	0

Iron (Fe) showed the highest THQ, ranging from 0.735714286 in the control to 2.007142857 in the grinding stone samples, indicating substantial risk from abrasive surfaces. Manganese (Mn) values (0.007321429–0.018392857) and zinc (Zn) values (0.006333333–0.010416667) were both highest in the 3-year milling machine, reflecting metallic wear. Ni, Cd, and Pb were undetected. Both the grinding stone and mechanical milling machines produced higher hazard quotients than the control, identifying them as significant contamination sources.

Table 4.15: Target Hazard Quotient (THQ), Values of Heavy Metals Via Consumption of Contaminated Yellow corn for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Grinding stone	1.803571429	0.016071429	0.007416667	0	0	0
Mortar	0.542857143	0.013035714	0.0085	0	0	0
6-year Milling machine	1.521428571	0.0125	0.009333333	0	0	0
3-year Milling machine	0.646428571	0.008035714	0.0095	0	0	0
9-year Milling machine	1.242857143	0.009464286	0.011	0	0	0
Control	0.475	0.015	0.007916667	0	0	0

Iron (Fe) had THQ values ranging from 0.475 in the control to 1.803571429 in the grinding stone, indicating substantial contamination from abrasive processing. Manganese (Mn) ranged from 0.009464286 to 0.016071429, highest in the grinding stone, while zinc (Zn) (0.007416667–0.011) peaked in the 9-year milling machine. Ni, Cd, and Pb were undetected. Grinding stones and aged milling machines posed the highest hazard risk relative to the control.

Table 4.16: Target Hazard Quotient (THQ), Values of Heavy Metals Via Consumption of Contaminated Groundnut for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	0.053571429	0.000795918	0.000642857	0.000364286	0	0
Grinding stone	0.058163265	0.000857143	0.000592857	0	0	0
Mortar	0.037653061	0.001346939	0.000621429	0	0	0
6months Hand crank grinder	0.03122449	0.001285714	0.000542857	0	0	0
1 year hand crank grinder	0.045918367	0.001469388	0.000692857	0	0	0
4-year milling machine	0.186122449	0.000795918	0.000614286	0	0	0
Control	0.019285714	0.000795918	0.000585714	0	0	0

Iron (Fe) recorded the highest THQ, ranging from 0.019285714 in the control to 0.186122449 in the 4-year milling machine, showing significant risk from metallic wear. Manganese (Mn) values ranged from 0.00085714 to 0.000795918, with the value been the same for the blender, 4-year milling machine, and blender. In zinc (Zn), the values ranged from 0.000585714 in the control to0.000692857 in the 1-year hand crank grinder samples. Cadmium (Cd) and lead (Pb) were not detected, whereas nickel (Ni) appeared in trace amounts (≤0.164). Mechanical grinders exhibited higher Fe and Zn hazard quotients than traditional methods, linking metal contamination to equipment contact.

Table 4.17: Target Hazard Quotient (THQ) Values of Heavy Metals Via Consumption of Contaminated Melon for adults.

Grinding Method	Fe	Mn	Zn	Ni	Cd	Pb
Blender	0.214	0.004657143	0.002849524	0.000496786	0	0
Grinding stone	0.208540816	0.004203571	0.003388333	0	0	0
Mortar	0.253306122	0.006332653	0.002892857	0.000233107	0	0
6months Hand crank grinder	0.211816327	0.00414898	0.002955238	0	0	0
1 year hand crank grinder	0.69222449	0.005022449	0.003311905	0	0	0
4-year milling machine	0.137020408	0.004093878	0.003388333	0	0	0
Control	0.132112245	0.003985204	0.002751429	0	0	0

Iron (Fe) showed the highest THQ, ranging from 0.132112245 in the control to 0.69222449 in the 1-year hand-crank grinder, indicating significant contamination due to mechanical abrasion. Manganese (Mn) ranged between 0.003985204 and 0.005022449, highest in the same grinder, while zinc (Zn) ranged between 0.002751429–0.003388333, with its peak in the 4-year milling machine and grinding stone. Cadmium (Cd) and lead (Pb) were undetected, and nickel (Ni) appeared in trace levels (≤0.000233).

CHAPTER FIVE

DISCUSSION

The findings of this study show that mechanical grinding significantly contributes to the introduction of heavy metals into food items. As presented in Chapter Four, the concentrations of essential metals such as iron (Fe), manganese (Mn), and zinc (Zn) were consistently higher in foods processed with metallic grinding equipment, particularly older milling machines, grinding stones, and hand crank grinders. These results support earlier studies, which reported that food processing, especially grinding and milling, is a major entry point for heavy metals into food materials (Kwofie et al., 2006; Nnaji et al., 2020). The mechanism is explained in previous literature. When metal surfaces undergo friction and abrasion, particles that contain Fe, Mn, Zn, and other elements detach from the surface and mix with food (Nnaji and Emmanuel, 2016).

The high Estimated Daily Intake (EDI) values observed for Fe, Mn, and Zn further confirm the effect of metal leaching. For example, Fe reached 5.35 mg/kg/day in melon processed with the one-year hand crank grinder. Pepper processed with a blender recorded 4.42 mg/kg/day. These values were much higher than those from the control samples, which indicates that the equipment is the main source of contamination, not the food itself. This observation agrees with reports on the persistence and non-biodegradability of heavy metals (Vogt et al., 2012; Zukowska and Biziuk, 2008). Once introduced, these metals accumulate in food systems and contribute to dietary exposure.

The Target Hazard Quotient (THQ) values also showed that Fe contributed the highest non-carcinogenic risk across the food items. In white corn processed with a grinding stone, Fe produced a THQ of 2.007. This value is above the safe limit of 1.0 and indicates possible long-term health effects. Beans processed with older milling machines recorded THQ values above

8.0 for Fe, which suggests a very high level of risk. Mn and Zn also recorded THQ values above acceptable limits in several food samples. Although these elements are essential nutrients, many studies have confirmed that excessive intake may result in oxidative stress, enzyme interference, organ damage, and metabolic disruptions (Adeti, 2012; Sigel et al., 2013; Thevenod et al., 2013). These outcomes are consistent with the results obtained here.

The concentrations of toxic metals such as lead (Pb) and cadmium (Cd) were mostly below detection limits. This differs from previous reports from Umuahia, Nigeria, where Pb levels in milled foods exceeded WHO and FAO limits (Nnaji et al., 2016). The lower Pb and Cd values in this study may reflect differences in grinding plate composition or improved maintenance of grinding equipment in the study area. Nevertheless, the consistently high levels of Fe, Mn, and Zn remain a concern. Long-term exposure to these elements has been associated with disruptions in the central nervous system, the cardiovascular system, and the renal system (Chan et al., 2003; Dabonne et al., 2010; Kirberger et al., 2013).

Nickel (Ni) appeared in trace amounts in only a few samples, such as blender-processed groundnut. Although these values were low, they are still relevant because nickel compounds are classified by IARC as possible or confirmed carcinogens (Sinicropti et al., 2010; Sultana et al., 2017). Even though carcinogenic risk was not assessed in this study, the literature suggests that continuous low-dose exposure may still contribute to long-term health effects.

The pattern of contamination found in this research agrees with studies from other regions. For example, work done in Uganda and Ghana reported high contamination of processed foods with chromium, nickel, and lead due to grinding equipment wear (Bamuwamye et al., 2015; Melesse et al., 2023). Similar findings from Bangladesh also show that vegetables and fruits exposed to heavy metals may pose cancer and non-cancer-related risks (Mahfuza et al., 2017). Although the present study did not report high levels of toxic metals, the elevated concentrations of Fe, Mn, and Zn reveal that metal transfer from grinding equipment is a serious issue that requires attention.

Overall, this study supports the viewpoint that food processing methods are a major but often neglected pathway for heavy metal exposure. The widespread use of metal-based grinding equipment in Nigerian markets increases the possibility of long-term accumulation of Fe, Mn, and Zn in consumers. Considering that previous works have linked heavy metal exposure to cognitive impairment, oxidative stress, and chronic diseases (Galanis et al., 2009; Adal et al., 2013), the contamination levels recorded here raise important public health concerns.

In conclusion, the results confirm that mechanical grinding introduces measurable levels of heavy metals into food items. Older equipment and abrasive surfaces make the problem more severe. The high EDI and THQ values recorded for Fe, Mn, and Zn show that these metals pose a significant non-carcinogenic risk. There is a clear need for better regulation of grinding equipment, replacement of worn grinding plates, and promotion of safe alternatives such as stainless steel or ceramic grinding tools. Public awareness campaigns are also needed to reduce long-term exposure and protect consumer health.

CONCLUSION

These findings emphasize the need for stronger policies and regulations to control the quality of materials used in manufacturing food-processing equipment. Authorities should encourage the production and use of grinders made from safer materials, such as stainless steel or coated alloys, that are less likely to corrode. Public enlightenment programs should also be introduced to educate food processors and consumers about the health implications of prolonged exposure to heavy metals and the importance of regular machine maintenance. By implementing these measures, it will be possible to significantly reduce contamination levels, improve the quality of processed food, and protect public health. In the long term, reducing the burden of heavy metal exposure will not only benefit individual well-being but will also contribute to national food safety goals and sustainable development.

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