COMPARATIVE ASSESSMENT OF GRINDING FINENESS ON HEAVY METAL LEACHING ACROSS SELECTED FOOD MATRICES

BY

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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 FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN ANIMAL AND ENVIRONMENTAL BIOLOGY (BSCAEB)

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CERTIFICATION

This is to certify that this project was carried out by AIGBEDO JULIET NOGHAYIN 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 Almighty God.

ACKNOWLEDGEMENT

My profound gratitude goes to Almighty God, for His unfailing love, and grace, in the course of this project. Without His support and guidance, this journey would not have been possible.

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ABSTRACT

This study investigated the influence of grinding fineness on heavy metal leaching across seven common food matrices-melon, tomatoes, pepper, white and yellow corn, beans, groundnut, and crayfish-using both household and industrial tools. Samples were processed at two fineness levels (coarse and smooth), and analyzed for iron (Fe), manganese (Mn), zinc (Zn), nickel (Ni), cadmium (Cd), and lead (Pb). Results showed that smooth grinding consistently produced higher Fe and Zn concentrations than coarse grinding, indicating that finer particle exposure and increased friction enhance metal transfer from processing tools. Iron levels were highest in beans (10.97 mg/kg), followed by crayfish (6.47 mg/kg) and white corn (4.64 mg/kg), while zinc peaked in crayfish (1.15 mg/kg) and groundnut (0.82 mg/kg). Manganese were moderate, with the highest levels in pepper (0.71 mg/kg) and melon (0.58 mg/kg). Nickel appeared only in isolated smooth-ground samples, while cadmium and lead were largely undetected, except for trace levels in melon (0.015 mg/kg) and tomatoes (0.00008 mg/kg). Blenders, hand crank grinders, and aged milling machines contributed most to metal leaching, whereas traditional tools such as mortars and grinding stones showed comparatively lower contamination. Although detected metal levels generally fell within international food safety limits, cumulative exposure may pose long-term health risks. The study concludes that grinding fineness, tool type, and age are key factors influencing heavy metal migration during food processing. Routine equipment maintenance, use of food-grade materials, and greater public awareness are recommended to minimize contamination and ensure safer household and industrial food processing practices.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Food processing is a fundamental and essential aspect of modern food systems, as most staples are rarely consumed in their raw form. To render them suitable for consumption or commercial use, these staples typically undergo treatments such as cleaning, drying, and grinding. These processes enhance food safety, extend shelf life, and improve palatability (Amirah *et al*., 2013). Among these techniques, grinding holds particular significance. It is widely employed to convert staple foods into flours, pastes, or powders, facilitating cooking and improving digestibility. However, grinding also presents a potential health hazard due to the release of heavy metals from grinding machine surfaces (Odusote *et al*., 2016). In Nigeria, cast iron disc-equipped grinding machines are commonly used in both domestic and commercial settings. These discs, often manufactured with minimal quality control, exhibit poor resistance to wear and corrosion. During grinding, shear forces cause surface abrasion, leading to the release of metallic particles into food items (Ogunlalu *et al*., 2017). This phenomenon is a primary source of contamination in ground foods.

Grinding is an ancient method of particle size reduction, relying on mechanical forces such as impact, compression, shear, and cutting to produce fine powders. It is an energy-intensive process that breaks down solid food substances into smaller particles (Oniya *et al*., 2018). While the general risk of contamination is acknowledged, a critical variable called grinding fineness remains underexplored in relation to heavy metal leaching.

This study addresses that gap by investigating how the degree of grinding, whether coarse or fine affects heavy metal leaching across a range of staple food matrices. The focus is strictly on grinding fineness, excluding any physico-chemical analysis. Seven commonly consumed food types are selected for this investigation: melon, tomatoes, peppers, corn, groundnut, beans, and crayfish.

Grinding fineness influences the duration of contact between food and grinding surfaces, as well as the friction and heat generated during processing (Ilie *et al*., 2023). It is hypothesized that finer grinding requires longer processing time and higher energy input, thereby increasing the likelihood of heavy metal leaching due to prolonged and intimate contact with metallic surfaces (Gomez *et al*., 2025).

Despite its widespread use, grinding may not be entirely safe. The energized rubbing of grinding discs can introduce metallic and non-metallic contaminants into food, including heavy metals that pose serious health risks (Silva *et al*., 2019). Toxic elements such as lead, chromium, and cadmium are non-biodegradable and can accumulate in the human body over time. Chronic exposure to these metals is associated with neurological disorders, organ damage, and increased cancer risk (Balali *et al*., 2021).

Contaminants in ground food typically originate from the grinding machine's metal components, deteriorating discs, and coating materials. Once ingested, these contaminants disrupt metabolic functions in two major ways: Firstly, they impair the functioning of vital organs such as the heart, brain, kidneys, bones, and liver. Secondly, they inhibit the absorption of essential nutrients, preventing them from fulfilling their biological roles.

Given the growing global concern over heavy metal contamination in food, most existing studies have focused on isolated food types. To address this limitation, the present study adopts a comparative approach, evaluating how grinding fineness influences heavy metal leaching across multiple food matrices.

Central to this investigation is the use of Atomic Absorption Spectroscopy (AAS) a technique widely recognized for its precision and reliability in detecting trace metal contaminants in food. AAS has been extensively applied in food safety studies due to its sensitivity and accuracy in quantifying heavy metals such as lead, cadmium, and chromium (Hamzat *et al*., 2018).

1.2 AIM AND OBJECTIVES

Aim

To comparatively evaluate the effect of grinding fineness on heavy metal leaching across selected food matrices.

Objectives

1. To determine and compare the heavy metal concentrations in coarsely and finely ground samples of melon, tomatoes, peppers, corn, beans, groundnut, and crayfish prepared using a milling machine.
2. To determine and compare the heavy metal concentrations in coarsely and finely ground samples of melon, tomatoes, peppers, corn, beans, groundnut, and crayfish prepared using a hand crank grinder.
3. To determine and compare the heavy metal concentrations in coarsely and finely ground samples of melon, tomatoes, peppers, corn, beans, groundnut, and crayfish prepared using a mortar and pestle.
4. To determine and compare the heavy metal concentrations in coarsely and finely ground samples of melon, tomatoes, peppers, corn, beans, groundnut, and crayfish prepared using a grinding stone.
5. To determine and compare the heavy metal concentrations in coarsely and finely ground samples of melon, tomatoes, peppers, corn, beans, groundnut, and crayfish prepared using an electric blender.

CHAPTER TWO

LITERATURE REVIEW

2.1 FUNDAMENTALS AND IMPORTANCES OF GRINDING IN FOOD PROCESSING

Grinding is a fundamental mechanical process in food processing that involves reducing the particle size of raw materials. This operation improves the texture, solubility, and mixing behaviour of food ingredients, making them more suitable for further processing such as cooking, drying, and packaging. Grinding is a necessary step for proper nutrient analysis and can play a role in extending shelf life and making food more convenient. In cereal grains, legumes, and seafood (crayfish), grinding facilitates the release of nutrients and bio-active compounds, improves digestibility, and enhances microbial safety by increasing the surface area for thermal treatments. Moreover, grinding also contributes to product uniformity and palatability, especially in powdered and paste-based foods. (Singh *et al*.,2021).

Importances:

1. **Improves texture and flavour**: Grinding creates a smoother, more consistent product and allows for better flavour distribution in items like sauces and pastes.
2. **Increases digestibility and nutrient availability**: By breaking down a food's structure, grinding makes it easier to digest and can increase the solubility of nutrients, improving their bio-availability.
3. **Facilitates further processing**: Many food products require grinding as a first step. For example, grinding grains into flour is essential for baking bread. Grinding also increases the surface area, which improves the efficiency of subsequent processes.
4. **Increases convenience**: Grinding can make food more convenient for consumers, such as by creating instant mixes or products that require less preparation time.

5. **Assists in analysis**: To accurately test the heavy metal concentration like iron (Fe), manganese (Mn), and nickel (Ni) in a food, it must first be ground into a homogeneous powder or paste for analysis.
6. **Aids in food preservation**: Grinding, as a form of processing, can help in preserving food. By creating powders, for instance, it can help extend the shelf life of products.

2.2 GRINDING FINENESS AND ITS ROLE

The degree of fineness ranging from coarse to smooth directly affects the surface area, porosity, and structural integrity of the food matrix. (Elemo *et al.*, 2021). In informal food markets, grinding is typically performed using locally fabricated machines, often without consideration for how particle size may influence contaminant behaviour (Ogunlalu *et al.*, 2017). Finer grinding increases the surface area of food particles and disrupts cellular structures, exposing more of the matrix to solvents such as water or digestive fluids. This enhanced exposure facilitates solvent penetration and accelerates the release of heavy metals like lead (Pb), cadmium (Cd), and mercury (Hg). The intense mechanical action required to break down the exoskeleton can release metals bound to the shell's chitin and mineral structure, a process distinct from the cellular disruption seen in plant matrices.

A higher liquid-to-solid ratio increases solvent availability, promoting greater migration of metals. Prolonged contact time further accelerate leaching rates. Additionally, particle size remains a key contributor whereby smaller particles offer greater surface exposure, resulting in faster and more complete release of heavy metals (Kulkarni *et al.,*2015).

2.3. HEAVY METAL CONTAMINATION IN FOOD

Heavy metals are naturally occurring elements characterized by high atomic mass and density, known for their persistence and toxicity in biological systems. While some, such as iron (Fe), copper (Cu), and zinc (Zn), are essential micronutrients required in trace amounts, others including lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr) are toxic and pose serious health risks when ingested (Gupta *et al*., 2019). The presence of heavy metals in food is often attributed to environmental exposure; however, a less frequently discussed yet equally significant source is direct contamination through food processing tools, particularly grinding implements (Aremo *et al*., 2020).

2.4. HEAVY METAL CONTAMINATION IN FOOD FROM METAL GRINDING MACHINES

Heavy metal contamination in food can result from the wear and tear of grinding machine components, leading to the introduction of metallic particles into food during processing. The extent of metal leaching is influenced by several factors, including the type of grinding tool, its material composition, and the mechanical stress exerted during use (Omobowale *et al*., 2022). Traditional grinding implements such as grinding stone, mortal and pestles, and manually operated mills are commonly used in many communities. These tools are often fabricated from locally sourced materials, which may contain trace metals depending on their geological origin. Studies have shown that grinding stones can release toxic metals like lead and cadmium into food, particularly when used frequently or when their surfaces become worn (Sobukola *et al*., 2010). Modern mechanical grinders, including electric blenders and industrial milling machines, are typically constructed from stainless steel. When corroded or damaged, these machines may leach chromium and nickel into food. Additionally, aluminium-based grinders have been found to release aluminium ions, which are associated with neurological disorders when consumed in excess (Yang *et al*., 2014)

Causes of contamination from grinding machines include:

- **Wear and tear:** The abrasive process of grinding food, especially with cast-iron discs, causes the discs to wear down and shed metal particles into the food.
- **Abrasion of parts:** Other parts of the machine, such as beaters, bushings, and bearings, can also contribute to contamination as they degrade over time.
- **Corrosion:** Corrosion of the machine parts can release metallic contaminants, not just from physical wear.
- **Machine age and paint:** Older machines or those with degrading paint coatings can introduce metals and other toxins into the food.
- **Poor quality equipment**: The use of low-quality or scrap metal in fabrication can increase the risk of heavy metals leaching into the processed food.

2.5. PUBLIC HEALTH IMPLICATIONS OF HEAVY METAL CONTAMINATION IN FOOD

Heavy metal contamination in food presents a serious public health challenge, particularly in regions where food processing infrastructure is poorly regulated. Toxic metals such as lead (Pb), cadmium (Cd), and chromium (Cr) are non-biodegradable and can accumulate in human tissues over time, leading to chronic health conditions including neurological disorders, renal impairment, and increased cancer risk (Mititelu et al., 2023). These risks are exacerbated by the widespread use of substandard grinding equipment, which contributes to metal leaching during food preparation.

The health burden is especially pronounced in vulnerable populations such as children and pregnant women, where exposure can disrupt essential biochemical functions and impair organ development. Mitigating these risks requires a multifaceted approach involving regulatory oversight, routine monitoring of contamination levels, and public education on safe food handling practices. The current study contributes to this discourse by examining grinding fineness as a potential pathway for heavy metal exposure in commonly consumed staples (Alberto, 2023).

2.6. TOXILOGICAL PROFILE OF SELECTED HEAVY METALS IN RELATION TO GRINDING-INDUCED LEACHING

The presence of heavy metals in food is a growing concern due to their potential to leach into food matrices during processing, particularly grinding. The seven metals under investigation cadmium (Cd), chromium (Cr), lead (Pb), iron (Fe), zinc (Zn), nickel (Ni), copper (Cu), and manganese (Mn) are commonly detected in food systems and have varying degrees of toxicity and health implications. Their behavior during grinding is influenced by factors such as equipment composition, particle surface area, and matrix-metal interactions.

Cadmium (Cd)

Cadmium is a non-essential metal known for its high toxicity and long biological half-life. It can leach into food during grinding, especially when equipment surfaces are contaminated or degraded. Studies have shown that cadmium levels increase in finely ground food due to enhanced surface contact and absorption (Aliyu *et al.*, 2023). Chronic exposure through contaminated food is linked to kidney damage, skeletal disorders, and carcinogenic effects.

Chromium (Cr)

Chromium contamination in food is often associated with metallic processing tools. The hexavalent form, Cr (VI), is particularly dangerous and has been classified as carcinogenic by the IARC (2012). Grinding equipment made from stainless steel alloys may release trace amounts of chromium, especially under high friction or wear. Finer grinding increases the likelihood of chromium leaching due to prolonged contact and increased particle reactivity.

Lead (Pb)

Lead is one of the most studied toxic metals in food safety research. It can be introduced during grinding through worn-out metallic surfaces or environmental dust. Finer grinding enhances lead leaching by increasing the food's exposure to contaminated surfaces and airborne particles (Nnaji *et al*., 2020). Lead exposure is particularly harmful to children, causing neurodevelopmental delays and reduced cognitive function (Bellinger, 2008).

Iron (Fe)

Iron is essential for human health but can become problematic when introduced in excess through processing. Grinding tools made of iron or steel can shed particles into food, especially under intense mechanical stress. While iron toxicity is rare, excessive intake from contaminated sources may lead to gastrointestinal distress and oxidative stress (Goyer, 1997). Grinding fineness plays a role in iron leaching, with finer particles absorbing more iron due to increased surface area.

Zinc (Zn)

Zinc is vital for immune function and enzymatic activity. However, contamination during grinding particularly from galvanized surfaces can lead to elevated levels in food. Finer grinding may facilitate zinc leaching, especially in acidic or moist food matrices. Excessive zinc intake can interfere with copper metabolism and cause nausea and immune suppression (Tchounwou *et al*., 2012).

Nickel (Ni)

Nickel contamination is common in food processed with stainless steel equipment. Grinding-induced friction can release nickel particles, which are then absorbed by food matrices. Finer grinding increases nickel leaching due to prolonged contact and enhanced particle interaction.

Chronic exposure to nickel is associated with allergic reactions, respiratory issues, and potential carcinogenicity (Das *et al*., 2008).

Manganese (Mn)

Manganese is required for metabolic functions but can be neurotoxic at elevated levels. Grinding equipment and environmental dust are potential sources of manganese contamination. Finer grinding enhances manganese leaching by increasing food surface exposure and absorption potential. Chronic exposure may result in motor dysfunction and cognitive impairment (Chen *et al*., 2014).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at New Benin Market, located at the intersection of Mission Road and New Lagos Road in the Oredo Local Government Area of Edo State, Nigeria. Geographically, the market spans approximately from 6°19′36″ N to 6°20′12″ N latitude and 5°37′36″ E to 5°37′58″ E longitude, placing it centrally within Benin City. Figure 1 illustrates the location and spatial extent of the market within the city.

New Benin Market was selected as the study site due to its role as a major distribution point for the food items under investigation, which are: melon, tomatoes, peppers, corn, beans, groundnut, and crayfish. These items are commonly processed using local grinding machines within the market, making it a suitable location for assessing the effect of grinding fineness on heavy metal leaching across different food matrices.

The market is one of the largest and most active commercial centers in Benin City. It is characterized by high volume of human and vehicular traffic, limited spatial organization, and a vibrant mix of economic activities. The market operates daily from early morning until late evening, with peak activity observed during weekends and festive periods. It is segmented into various sections that cater to diverse consumer needs, including stalls for imported and locally produced clothing, Ankara fabrics, tailoring accessories, curtains, bedding materials, household utensils, food items, traditional beads, and electronics.

Benin City experiences a tropical rainforest climate with two distinct seasons: the wet season (April to October) and the dry season (November to March). The average annual temperature ranges from 22°C to 31°C, with high humidity levels during the rainy months (Nigerian

Meteorological Agency, 2023). This climatic pattern may influence market operations but is not directly related to the focus of this study.

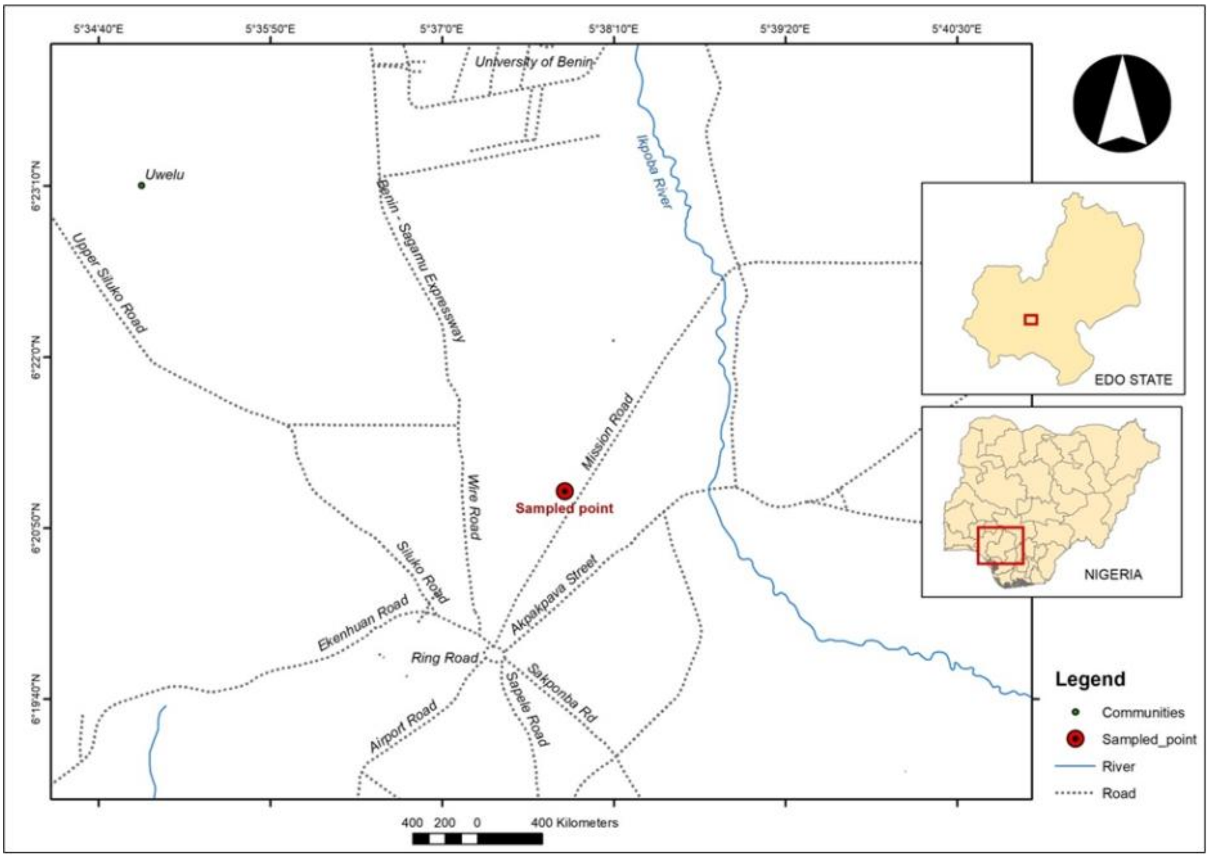

Figure 3.1: Map Showing the Location of New Benin Market

3.2 Study Location

The study was conducted in August 2025 at New Benin Market, located in Benin City, Edo State, Nigeria. To ensure sample diversity and representatives, seven food items such as melon, tomatoes, peppers, corn, groundnut, beans, and crayfish, were collected from different vendors located at distinct points within the market. Each sampling point was georeferenced using GPS, and the coordinates were recorded as shown below:

Sampling Station 1: Melon (6°21'6" N 5°37'49" E)

Plate 1: Melon

Sampling Station 2: Tomatoes (6°21'8" N 5°37'47" E)

Plate 2: Tomatoes

Sampling Station 3: Pepper (6°21'8" N 5°37'47" E)

Plate 3: Pepper

Sampling Station 4: White Corn (6°21'4" N 5°37'51" E)

Plate 4: White Corn

Sampling Station 5: Yellow Corn (6°21'5" N 5°37'50" E)

Plate 5: Yellow Corn

Sampling Station 6: Groundnut (6°21'4" N 5°37'51" E)

Plate 6: Groundnut

Sampling Station 7: Beans (6°21'4" N 5°37'51" E)

Plate 7: Beans

Sampling Station 8: Crayfish (6°217" N 5°37'48" E)

Plate 8: Crayfish

Each item was photographed at the point of purchase to document its physical condition.

To facilitate comparative analysis, the food items were processed using five distinct grinding tools:

Plate 9: Milling machine

Plate 10: Hand Crank grinder

Plate 11: Grinding stone

Plate 12: Mortar and pestle

Plate 13: Electric grinder

While some of these tools such as the milling machine and manual grinder were observed and documented within the market, others (including the electric grinder, mortal and pestle, and grinding stone) were sourced externally from associated residential or community settings in Benin City. This sampling strategy ensured the assessment covered grinding practices relevant to various user scales and techniques.

3.3 Sampling Methods

Sample Collection

3.3.1 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.

3.4 Sample Labelling and Storage

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

3.4.1 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.

3.5 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 analysed in duplicates, and results were accepted only when variation was less than 10%.

3.6 Sample Analysis

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

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

i. **Market processing**: Mechanical grinders and hand crank grinder.

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.

3.6.2 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 include:

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 ($HClO_4$)

3.6.3 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 distilled 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 10ppm solution. From the 10ppm solution, aliquots of 2.5, 5.0, 7.5, and 10ml were each pipetted into separate 50ml 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 analysed in duplicates to ensure reproducibility, accuracy, and precision.

3.7 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.

CHAPTER FOUR

RESULT

In this chapter, grinding fineness is categorized as coarse (c) and smooth (s), and these abbreviations are used consistently across all sample descriptions.

4.1 Comparative Analysis of Grinding Fineness in Melon

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in mortar S (3.235 mg/kg) and 1-year hand crank grinder S (3.17 mg/kg), followed by blender S (1.335 mg/kg). Coarse samples such as mortar C (1.16 mg/kg) and blender C (0.98 mg/kg) showed moderate levels. The control sample recorded the lowest Fe concentration (0.515 mg/kg). (Figure 4.1).

Manganese (Mn)

Manganese levels were highest in mortar S (0.58 mg/kg), followed by 6-year and 1-year hand crank grinder S (0.46 mg/kg each). Coarse samples such as mortar C (0.44 mg/kg) and 6-year hand crank grinder C (0.38 mg/kg) also showed elevated Mn levels. The control sample recorded the lowest Mn concentration (0.27 mg/kg). (Figure 4.1).

Nickel (Ni)

Nickel was detected only in blender S (0.0065 mg/kg), and blender C (0.00305 mg/kg) while all other samples including the control showed no Ni presence. (Figure 4.1).

Zinc (Zn)

Zinc concentrations were highest in smooth samples, particularly in grinding stone S and 4-year hand crank grinder S (0.665 mg/kg each), followed by 1-year hand crank grinder S (0.65 mg/kg) and 6-year hand crank grinder S (0.58 mg/kg). Coarse samples such as 6-year hand crank grinder C (0.54 mg/kg) and grinding stone C (0.5 mg/kg) also showed elevated levels. The control sample recorded the lowest Zn concentration (0.405 mg/kg). (Figure 4.1).

Cadmium (Cd)

Cadmium was detected only in 6-year hand crank grinder S (0.015 mg/kg). All other samples, including coarse grinds and the control, showed no Cd presence. (Figure 4.1).

Lead (Pb)

Lead was not detected in any of the melon samples, including all processed and control groups. (Figure 4.1).

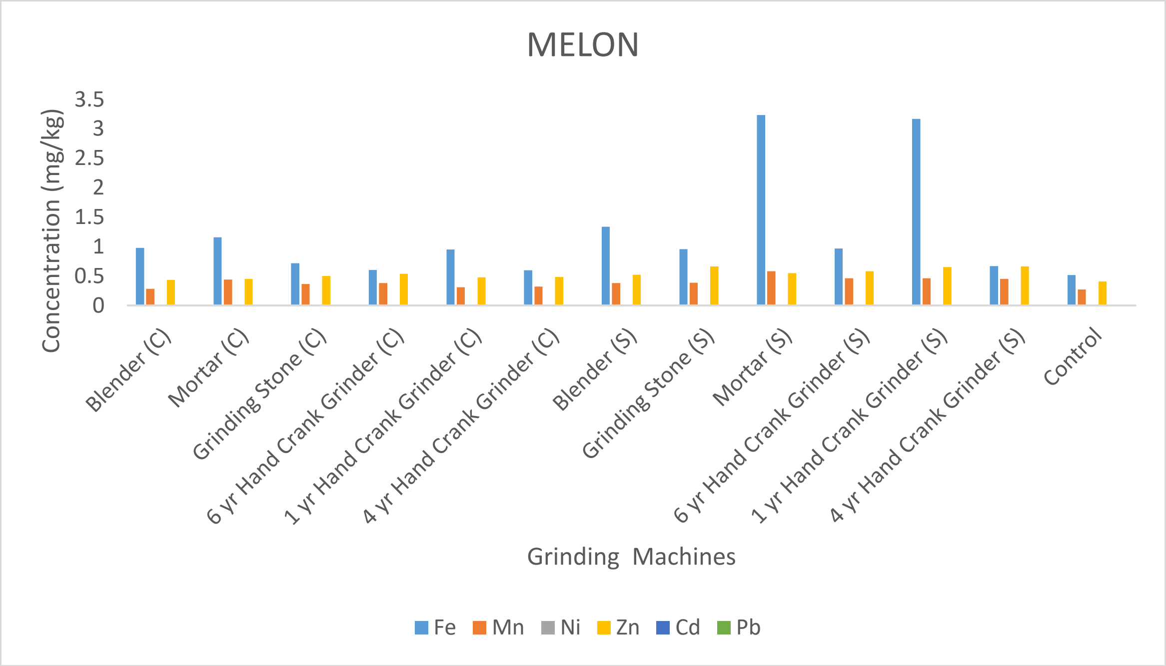

Figure 4.1: Comparative Analysis of Heavy Metals Concentrations in Melon

4.2 Comparative Analysis of Grinding Fineness in Tomatoes

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in blender S (2.376 mg/kg) and milling machine S (2.0267 mg/kg). Coarse samples such as blender C (1.966 mg/kg) and grinding stone C (1.926 mg/kg) also showed elevated levels. Traditional tools like mortar C (1.302 mg/kg) and mortar S (1.35 mg/kg) recorded moderate values. The control sample had the lowest Fe concentration (0.914 mg/kg). (Figure 4.2).

Manganese (Mn)

Manganese levels were highest in milling machine S (0.4 mg/kg), followed by mortar S (0.274 mg/kg) and mortar C (0.258 mg/kg). Coarse samples such as grinding stone C (0.228 mg/kg) and blender C (0.15 mg/kg) showed lower Mn levels. The control sample recorded the lowest Mn concentration (0.11 mg/kg). (Figure 4.2).

Nickel (Ni)

Nickel was detected in a few samples, with the highest concentration in mortar S (0.0018 mg/kg), followed by blender C (0.0012 mg/kg) and blender S (0.0006 mg/kg). All other samples, including the control, showed no detectable Ni levels. (Figure 4.2).

Zinc (Zn)

Zinc concentrations were highest in grinding stone S (0.556 mg/kg), followed by 4-year milling machine C (0.2 mg/kg) and blender C (0.174 mg/kg). Smooth samples such as blender S and milling machine S recorded similar values (0.174 mg/kg and 0.175 mg/kg respectively). The control sample had the lowest Zn concentration (0.1033 mg/kg). (Figure 4.2).

Cadmium (Cd)

Cadmium was detected only in blender C (0.002 mg/kg) and blender S (0.0004 mg/kg). All other samples, including the control, showed no Cd presence. (Figure 4.2).

Lead (Pb)

Lead was detected only in grinding stone S (0.00008 mg/kg), while all other samples including coarse and smooth grinds and the control showed no Pb detection. (Figure 4.2).

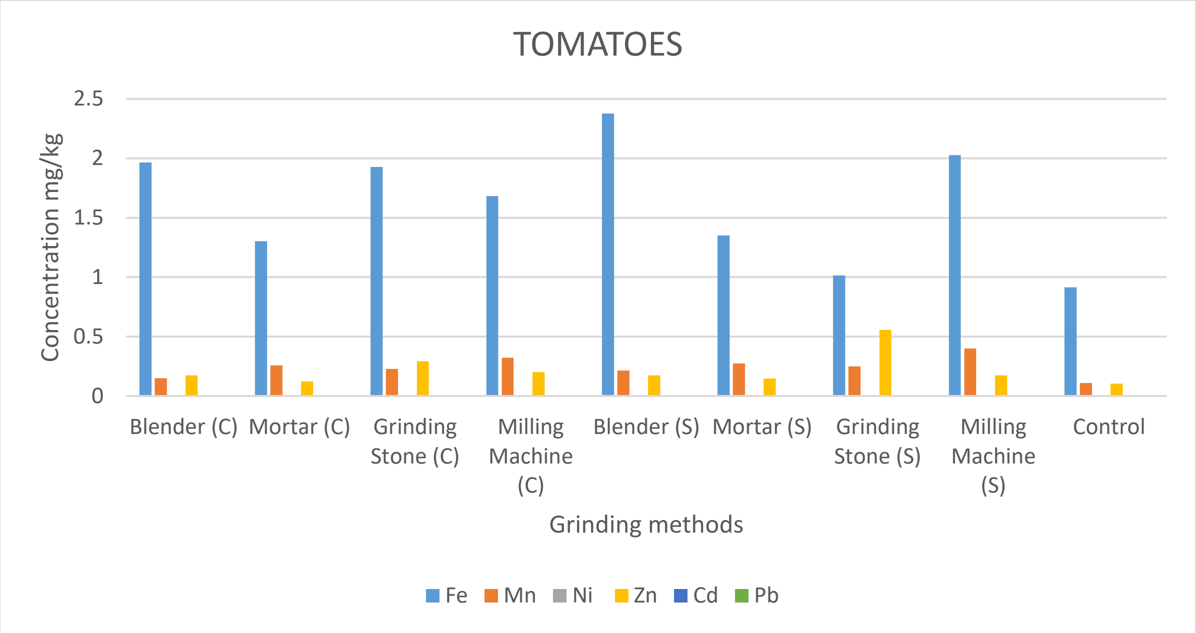

Figure 4.2: Comparative Analysis of Heavy Metals Concentrations in Tomatoes

4.3 Comparative Analysis of Grinding Fineness in Pepper

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in blender S (2.55 mg/kg), 1-year hand crank grinder S (2.345 mg/kg), and mortar S (2.245 mg/kg). Coarse samples such as blender C (2.235 mg/kg), 1-year hand crank grinder C (2.17 mg/kg), and grinding stone C (2.13 mg/kg) showed slightly lower levels. The control sample recorded the lowest Fe concentration (1.01 mg/kg). (Figure 4.3).

Manganese (Mn)

Manganese levels were highest in smooth samples, especially in 4-year milling machine S (0.55 mg/kg), 1-year hand crank grinder S (0.455 mg/kg), and mortar S (0.43 mg/kg). Coarse samples such as 1-year hand crank grinder C and 4-year milling machine C both recorded 0.34 mg/kg, while the control sample showed the lowest Mn concentration (0.035 mg/kg). (Figure 4.3).

Nickel (Ni)

Nickel was not detected in any of the pepper samples, including both coarse and smooth grinds and the control. (Figure 4.3).

Zinc (Zn)

Zinc concentrations were highest in smooth samples, particularly in blender S (0.55 mg/kg), 1-year hand crank grinder S (0.485 mg/kg), and grinding stone S (0.47 mg/kg). Coarse samples such as grinding stone C and blender C recorded 0.415 mg/kg, while the control sample showed the lowest Zn concentration (0.12 mg/kg). (Figure 4.3).

Cadmium (Cd)

Cadmium was not detected in any of the bean samples, including both coarse and smooth grinds as well as the control. This suggests that cadmium is either absent in the pepper matrix or present at concentrations below the detection limit. (Figure 4.3).

Lead (Pb)

Lead was detected only in smooth samples, specifically in blender S and 1-year hand crank grinder S, both recording a concentration of 0.00025 mg/kg. All coarse samples and the control showed no detectable levels of lead. (Figure 4.3).

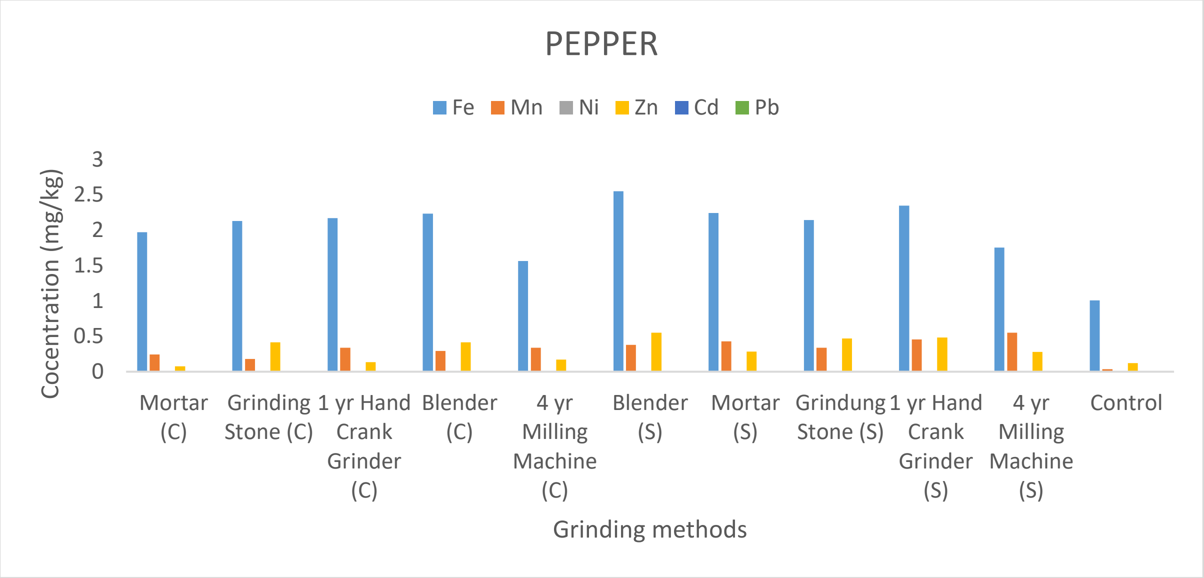

Figure 4.3: Comparative Analysis of Heavy Metals Concentrations in Pepper

4.4 Comparative Analysis of Grinding Fineness in White Corn

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in grinding stone S (4.64 mg/kg) and 6-year milling machine S (2.42 mg/kg). Coarse samples such as grinding stone C (2.81 mg/kg) and 6-year milling machine C (1.84 mg/kg) showed moderate levels. The lowest Fe concentrations were observed in 3-year milling machine C (0.53 mg/kg), mortar C (0.66 mg/kg), and the control sample (0.62 mg/kg). (Figure 4.4).

Manganese (Mn)

Manganese levels were highest in mortar S (0.72 mg/kg), followed by 3-year milling machine S (0.515 mg/kg) and grinding stone S (0.425 mg/kg). Coarse samples such as 6-year milling machine C (0.37 mg/kg) and grinding stone C (0.325 mg/kg) showed moderate Mn release. The control sample recorded the lowest Mn concentration (0.205 mg/kg). (Figure 4.4).

Nickel (Ni)

Nickel was not detected in any of the white corn samples, including both coarse and smooth grinds and the control. This indicates either its absence in the matrix or concentrations below detection limits. (Figure 4.4).

Zinc (Zn)

Zinc concentrations were highest in smooth samples, particularly in 6-year milling machine S and 3-year milling machine S (0.625 mg/kg each), followed by grinding stone S (0.575 mg/kg). Coarse samples such as 3-year milling machine C (0.61 mg/kg) and 9-year milling machine C (0.54 mg/kg) also showed elevated levels. The control sample recorded the lowest Zn concentration (0.365 mg/kg). (Figure 4.4).

Cadmium (Cd)

Cadmium was not detected in any of the white corn samples, including all coarse and smooth grinds and the control. (Figure 4.4).

Lead (Pb)

Lead was not detected in any of the white corn samples, including both coarse and smooth grinds and the control. (Figure 4.4).

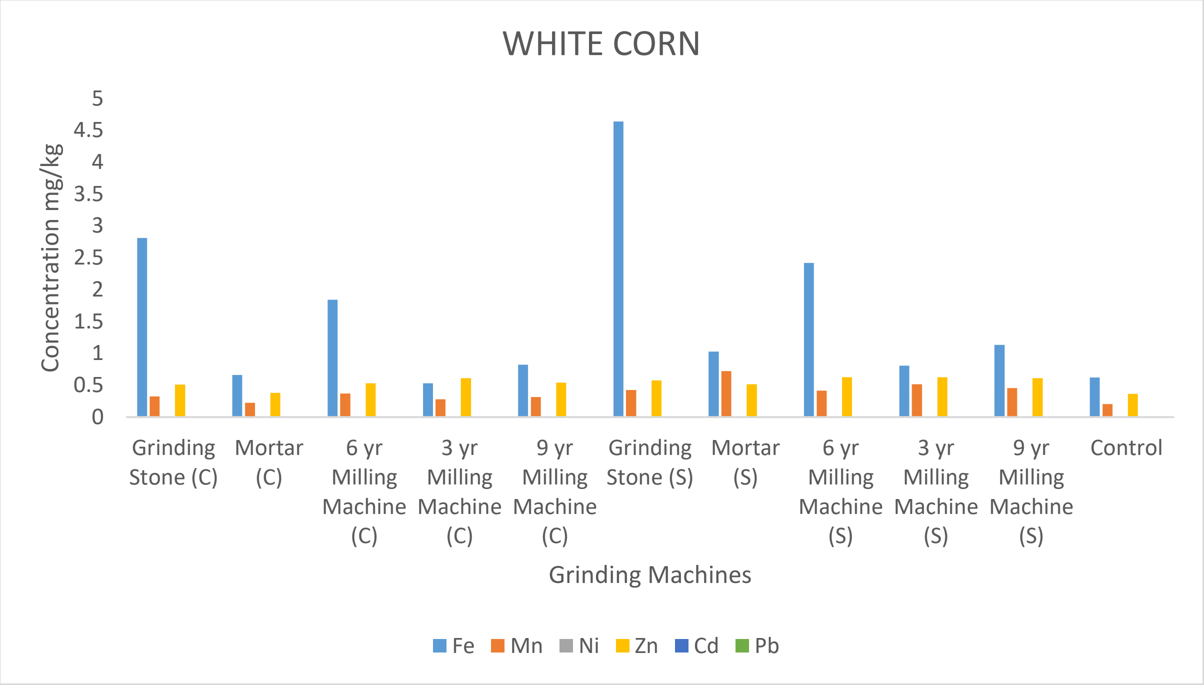

Figure 4.4: Comparative Analysis of Heavy Metals Concentrations in White Corn

4.5 Comparative Analysis of Grinding Fineness in Yellow Corn

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in grinding stone S (2.525 mg/kg) and 6-year milling machine S (2.13 mg/kg). Coarse samples such as 6-year milling machine C (1.83 mg/kg) and 9-year milling machine C (1.145 mg/kg) showed moderate levels. Traditional tools like mortar C (0.675 mg/kg) and grinding stone C (0.87 mg/kg) recorded lower values. The control sample had the lowest Fe concentration (0.665 mg/kg). (Figure 4.5).

Manganese (Mn)

Manganese levels were highest in mortar C (0.62 mg/kg), followed by grinding stone C (0.44 mg/kg) and grinding stone S (0.45 mg/kg). Smooth samples such as 6-year milling machine S (0.35 mg/kg) and mortar S (0.365 mg/kg) showed moderate Mn levels. The control sample recorded the lowest Mn concentration (0.205 mg/kg). (Figure 4.5).

Nickel (Ni)

Nickel was absent in all coarse samples and the control, but detected in smooth milling machine samples. The highest Ni concentration was found in 6-year milling machine S (0.024 mg/kg), followed by 9-year milling machine S (0.0035 mg/kg). (Figure 4.5).

Zinc (Zn)

Zinc concentrations were highest in smooth samples, particularly in 9-year milling machine S (0.66 mg/kg), 6-year milling machine S (0.585 mg/kg), and grinding stone S (0.58 mg/kg). Coarse samples such as 6-year milling machine C (0.56 mg/kg) and 3-year milling machine C (0.55 mg/kg) also showed elevated levels. The control sample recorded the lowest Zn concentration (0.44 mg/kg). (Figure 4.5).

Cadmium (Cd)

Cadmium was not detected in any of the yellow corn samples, including both coarse and smooth grinds and the control. (Figure 4.5).

Lead (Pb)

Lead was not detected in any of the yellow corn samples, including both coarse and smooth grinds and the control. (Figure 4.5).

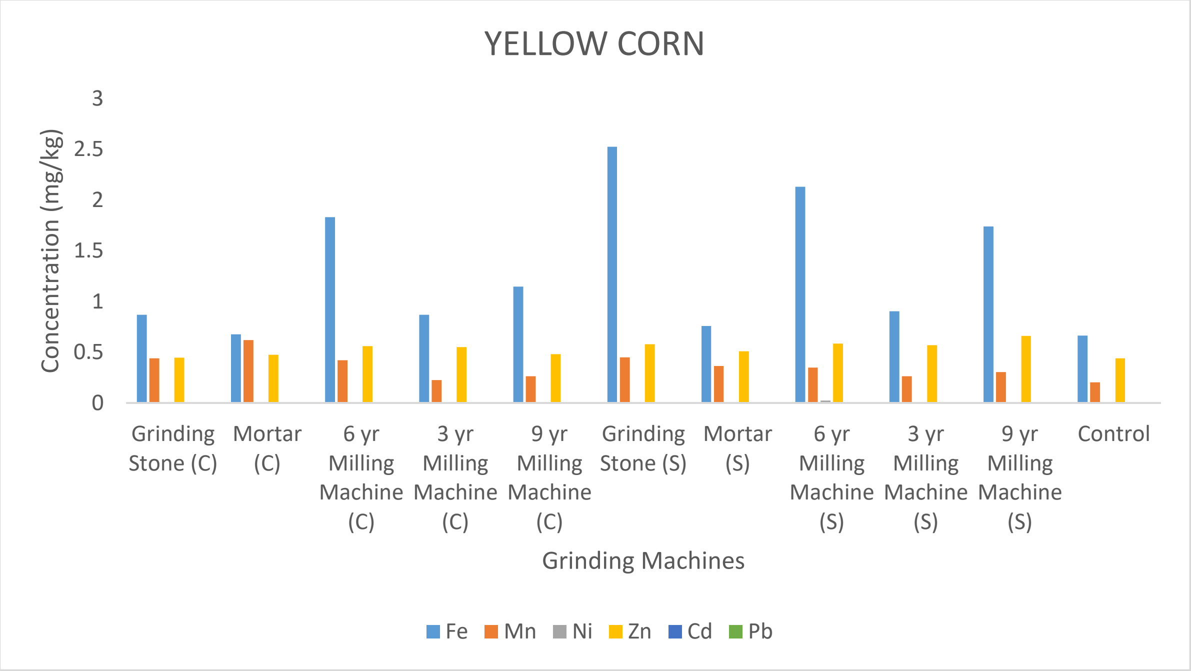

Figure 4.5: Comparative Analysis of Heavy Metals Concentrations in Yellow Corn

4.6 Comparative Analysis of Grinding Fineness in Groundnut

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in 4-year hand crank grinder S (3.04 mg/kg), blender S (1.72 mg/kg), and 6-year hand crank grinder S (1.075 mg/kg). Coarse samples such as 4-year hand crank grinder C (1.255 mg/kg) and blender C (0.875 mg/kg) showed moderate levels. Traditional tools like mortar C (0.36 mg/kg) and grinding stone C (0.55 mg/kg) recorded lower values. The control sample had the lowest Fe concentration (0.315 mg/kg). (Figure 4.6).

Manganese (Mn)

Manganese levels were highest in blender C (0.51 mg/kg), followed by 1-year hand crank grinder C (0.385 mg/kg) and 6-year hand crank grinder C (0.34 mg/kg). Smooth samples such as 1-year hand crank grinder S (0.48 mg/kg) and grinding stone S (0.44 mg/kg) also showed elevated Mn levels. The control sample recorded the lowest Mn concentration (0.26 mg/kg) (Figure 4.6).

Nickel (Ni)

Nickel was detected only in blender S (0.017 mg/kg), while all other samples including coarse grinds and the control showed no Ni presence. (Figure 4.6)

Zinc (Zn)

Zinc concentrations were highest in smooth samples, particularly in 4-year hand crank grinder S (0.82 mg/kg), blender S (0.685 mg/kg), and 1-year hand crank grinder S (0.485 mg/kg). Coarse samples such as grinding stone C (0.435 mg/kg) and blender C (0.45 mg/kg) showed moderate levels. The control sample recorded a lower Zn concentration (0.38 mg/kg). (Figure 4.6).

Cadmium (Cd)

Cadmium was not detected in any of the groundnut samples, including both coarse and smooth grinds and the control. This suggests that cadmium is either absent in the matrix or present at concentrations below detection limits. (Figure 4.6).

Lead (Pb)

Lead was not detected in any of the groundnut samples, including all processed and control groups. (Figure 4.6).

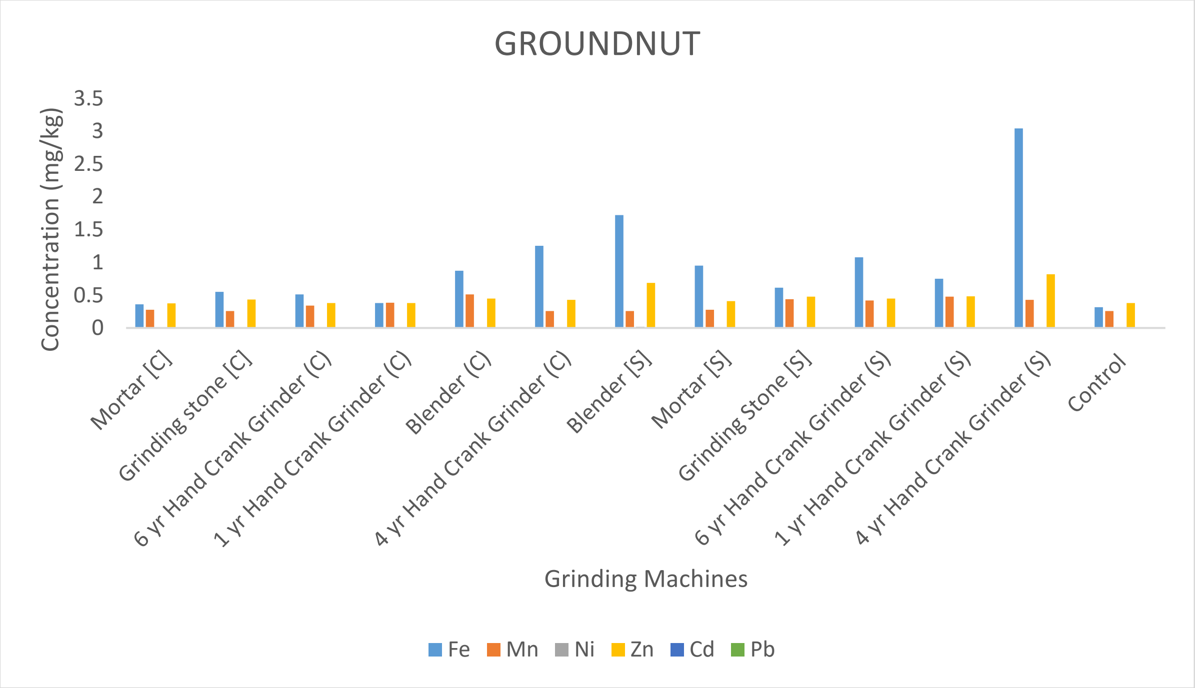

Figure 4.6: Comparative Analysis of Heavy Metals Concentrations in Groundnut

4.7 Comparative Analysis of Grinding Fineness in Beans

Iron (Fe)

Iron concentrations were markedly elevated in smooth samples, with 9-year milling machine S (10.97 mg/kg), 4-year milling machine S (9.685 mg/kg), and 1-year hand crank grinder S (9.565 mg/kg) showing the highest levels. Coarse samples such as 9-year milling machine C (4.32 mg/kg) and 4-year milling machine C (3.685 mg/kg) exhibited moderate iron release. Traditional tools like mortar C (1.57 mg/kg) and grinding stone C (1.68 mg/kg) recorded the lowest among processed samples. The control sample (1.555 mg/kg) had the least iron content overall. (Figure 4.7).

Manganese (Mn)

Manganese levels were highest in grinding stone S (0.49 mg/kg), followed closely by mortar S and grinding stone C (0.475 mg/kg each). Coarse samples such as 1-year hand crank grinder C

(0.47 mg/kg) and 9-year milling machine C (0.4 mg/kg) also showed elevated Mn content. The control sample (0.22 mg/kg) had the lowest concentration. (Figure 4.7).

Nickel (Ni)

Nickel was not detected in any of the bean samples, including all coarse and smooth grinds and the control. This suggests either a complete absence of nickel in the beans matrix or concentrations below analytical detection limits. (Figure 4.7).

Zinc (Zn)

Zinc concentrations peaked in coarse samples, particularly in 4-year milling machine C (0.68 mg/kg), 9-year milling machine C (0.555 mg/kg), and 1-year hand crank grinder C (0.54 mg/kg). Smooth samples such as 9-year milling machine S (0.6 mg/kg) and 1-year hand crank grinder S (0.57 mg/kg) also showed substantial Zn release. (Figure 4.7).

Cadmium (Cd)

Cadmium was not detected in any bean samples, including all processed and control groups. This absence suggests that cadmium is either not present in the beans matrix or exists below detection thresholds. (Figure 4.7).

Lead (Pb)

Lead was also undetected across all bean samples, regardless of grinding fineness or tool type. The control sample similarly showed no Pb presence. This uniform absence indicates minimal risk of lead contamination from the grinding tools used. (Figure 4.7).

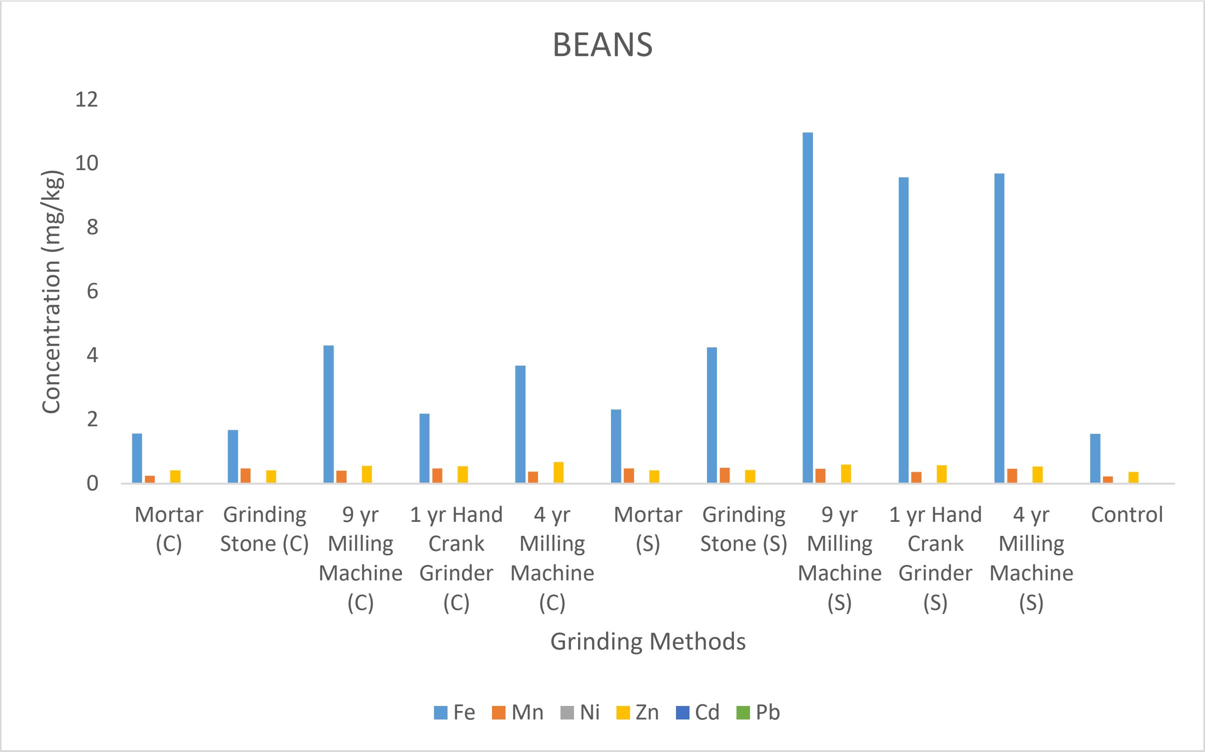

Figure 4.7: Comparative Analysis of Heavy Metals Concentrations in Beans

4.8 Comparative Analysis of Grinding Fineness in Crayfish

Iron (Fe)

Iron concentrations were highest in smooth samples, particularly in 4-year hand crank grinder S (6.47 mg/kg), 1-year hand crank grinder S (4.745 mg/kg), and 6-year hand crank grinder S (4.22 mg/kg). Coarse samples such as 1-year hand crank grinder C (4.14 mg/kg) and 4-year hand crank grinder C (3.675 mg/kg) also showed elevated levels. The control sample recorded the lowest Fe concentration (1.37 mg/kg). (Figure 4.8).

Manganese (Mn)

Manganese levels were highest in grinding stone S (0.52 mg/kg), blender S (0.45 mg/kg), and 6-year hand crank grinder S (0.47 mg/kg). Coarse samples such as 1-year hand crank grinder

C (0.375 mg/kg) and grinding stone C (0.33 mg/kg) showed moderate Mn release. The control sample recorded the lowest Mn concentration (0.1 mg/kg). (Figure 4.8).

Nickel (Ni)

Nickel was detected only in mortar S (0.0135 mg/kg), while all other samples including coarse grinds and the control showed no Ni presence. (Figure 4.8).

Zinc (Zn)

Zinc concentrations were highest in blender S (1.15 mg/kg), followed by 4-year hand crank grinder C (0.935 mg/kg), grinding stone S (0.855 mg/kg), and 6-year hand crank grinder S (0.86 mg/kg). Coarse samples such as 1-year hand crank grinder C (0.83 mg/kg) and grinding stone C (0.77 mg/kg) also showed elevated levels. The control sample recorded the lowest Zn concentration (0.515 mg/kg), indicating that both coarse and smooth grinding significantly increase zinc leaching in crayfish. (Figure 4.8).

Cadmium (Cd)

Cadmium was not detected in any of the crayfish samples, including both coarse and smooth grinds and the control. This suggests that cadmium is either absent in the matrix or present at concentrations below detection limits. (Figure 4.8).

Lead (Pb)

Lead was not detected in any of the crayfish samples, including all processed and control groups. (Figure 4.8).

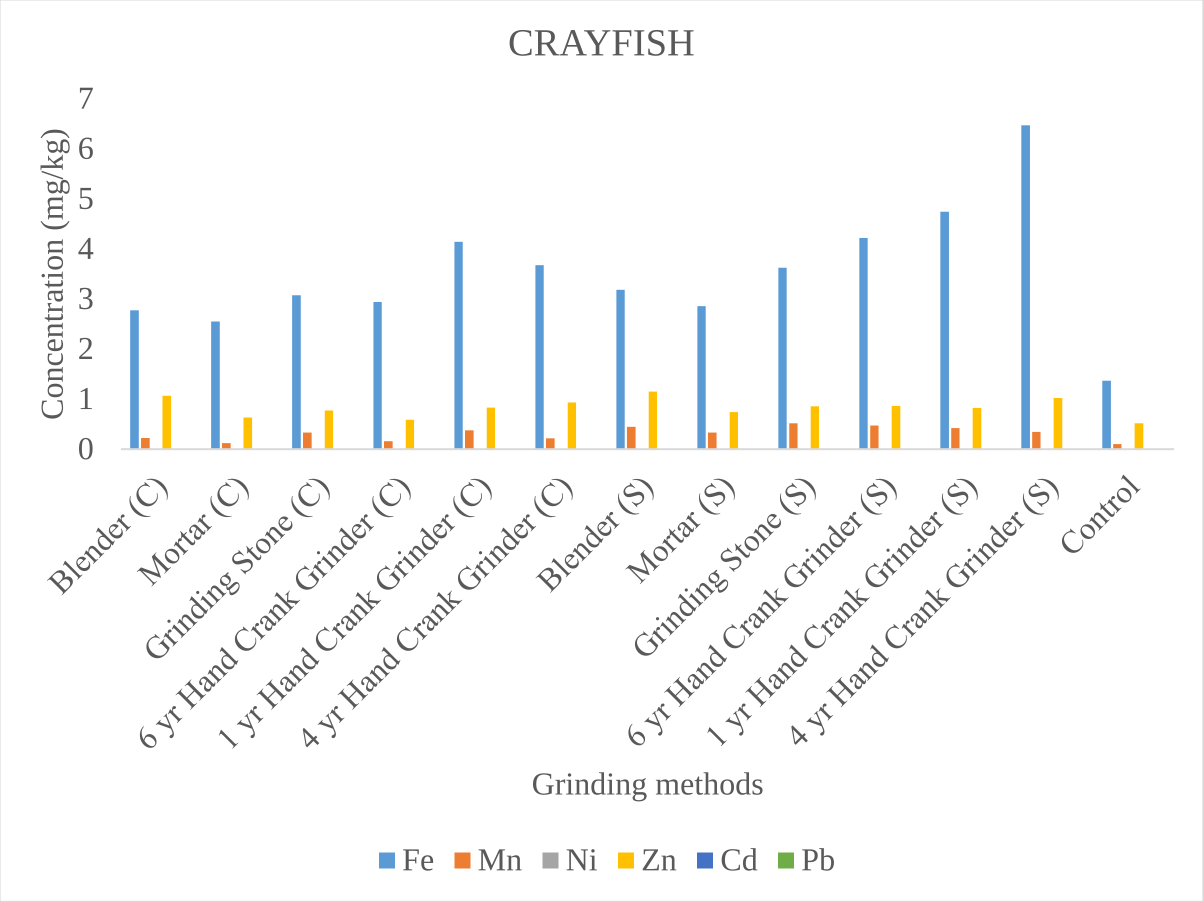

Figure 4.8: Comparative Analysis of Heavy Metals Concentrations in Crayfish

CHAPTER FIVE

DISCUSSION

Grinding fineness significantly influences the extent of heavy metal leaching across food matrices. Smooth grinding consistently yielded higher concentrations of iron and zinc, with notable variations across food types. Iron concentrations were highest in beans (10.97 mg/kg), followed by crayfish (6.47 mg/kg), white corn (4.64 mg/kg), melon (3.235 mg/kg), groundnut (3.04 mg/kg), pepper (2.55 mg/kg), yellow corn (2.525 mg/kg), and tomatoes (2.376 mg/kg). Control samples across all matrices recorded the lowest iron levels, ranging from 0.315 mg/kg in groundnut to 1.555 mg/kg in beans. These results affirm that finer particle exposure and prolonged contact with metallic surfaces intensify iron release (Elemo *et al*., 2021).

Zinc concentrations followed a similar trajectory. Crayfish recorded the highest zinc level (1.15 mg/kg), followed by groundnut (0.82mg/kg), beans (0.68 mg/kg), melon (0.665 mg/kg), yellow corn (0.66 mg/kg), white corn (0.625 mg/kg) tomatoes (0.556 mg/kg), and pepper (0.55 mg/kg). Control values remained significantly lower, with the lowest observed in tomatoes (0.103 mg/kg). The consistent elevation in zinc across matrices confirms that grinding, especially with blenders and aged hand crank grinders facilitates zinc mobilization (Lee *et al*., 2019).

Manganese leaching showed matrix-specific variability. Pepper exhibited the highest Mn concentration (0.71 mg/kg), followed by yellow corn (0.62 mg/kg), melon (0.58 mg/kg), crayfish (0.52 mg/kg), tomatoes (0.51 mg/kg), groundnut (0.51mg/kg), beans (0.49 mg/kg), and white corn (0.455 mg/kg) . Control samples ranged from 0.1 mg/kg in crayfish to 0.22 mg/kg in beans. Grinding stone and mortar tools contributed notably to manganese release, suggesting that tool composition and surface abrasion play a role in metal transfer (Balasubramaniyan *et al*., 2025). Nickel was largely undetected across matrices, appearing only in smooth-ground samples. The highest concentration was found in melon (0.0135 mg/kg), followed by yellow corn (0.024 mg/kg), groundnut (0.0018 mg/kg), and tomatoes (0.0006 mg/kg) . Crayfish, beans, pepper and white corn showed no detectable nickel. These isolated detections suggest that nickel leaching is tool-specific, likely originating from internal wear or alloy components in metallic grinders. Cadmium was virtually absent across all matrices, with only one trace detection in melon (0.015 mg/kg). All other samples, including coarse and smooth grinds, recorded cadmium levels below detection thresholds. This suggests minimal contamination risk from the tools used, aligning with international safety standards that recommend cadmium levels not exceeding 0.05-2 ppm in food products (FAO/WHO, 2002). Lead was similarly undetected in nearly all samples, with a single trace found in tomatoes (0.00008 mg/kg). This value falls well below the recommended maximum of 0.01-3 ppm, indicating negligible migration of lead during food processing unless tools are severely degraded or composed of unsafe alloys (Lee *et al*., 2019). Crayfish, beans, and melon exhibited the highest overall susceptibility to heavy metal leaching, particularly for iron and zinc. Tomatoes and peppers showed lower concentrations overall, though blenders and milling machines still contributed to measurable increases. This variation highlights the importance of food-specific assessments when evaluating processing safety (Balasubramaniyan *et al*., 2025). Tool type and duration were critical determinants of leaching intensity. Blenders and hand crank grinders used over multiple years consistently produced higher metal concentrations, especially in smooth samples. Milling machines also showed elevated leaching, while mortars and grinding stones yielded comparatively lower levels. Tool age and surface integrity directly influence metal migration during food processing (Elemo *et al*., 2021). Smooth grinding enhances texture and yield but may inadvertently increase exposure to heavy metals. Regular maintenance, tool replacement, and informed material selection are essential to minimize contamination. Matrix-specific responses should guide processing choices, particularly in high-risk foods like crayfish and beans (Lee *et al*., 2019). Iron and zinc were the most responsive to grinding fineness, with smooth-ground samples consistently showing elevated levels. Manganese followed a matrix-dependent pattern, while nickel, cadmium, and lead remained largely undetectable. Crayfish, beans, and melon were the most sensitive matrices, and traditional tools posed lower contamination risks compared to aged mechanical devices (Balasubramaniyan *et al*., 2025; Elemo *et al*., 2021).

RECOMMENDATIONS

In light of the findings from this study, it is imperative to adopt strategic measures aimed at minimizing heavy metal contamination during food processing. The observed increase in metal leaching particularly iron and zinc associated with smooth grinding techniques underscores the need for more cautious selection and maintenance of grinding tools. Food processors, especially at the household and small-scale commercial levels, should be encouraged to adopt safer grinding practices. This is particularly important for food matrices such as beans, crayfish, and melon, which demonstrated higher susceptibility to contamination.

Traditional grinding implements, such as mortars and grinding stones, have shown comparatively lower risks of metal leaching and should be promoted for use, especially when processing sensitive food items. While mechanical grinders offer convenience and efficiency, their prolonged use without proper maintenance significantly contributes to contamination. Therefore, it is recommended that such equipment be routinely inspected and replaced once signs of wear, corrosion, or degradation are evident.

Furthermore, public health authorities and food safety agencies should consider expanding existing guidelines to include the regulation and monitoring of household-level food processing tools. This would ensure a more comprehensive approach to food safety that addresses not only industrial practices but also domestic and informal sector activities. Educational campaigns and community outreach programs should be developed to raise awareness among local food processors and consumers about the potential health risks associated with metal contamination and the importance of adopting safe handling and processing techniques.

Finally, all food processing methods should aim to maintain heavy metal concentrations well below the permissible limits established by international bodies such as the Food and

Agriculture Organization (FAO) and the World Health Organization (WHO). Ensuring that exposure remains as low as reasonably achievable is essential for protecting public health, particularly among vulnerable populations such as children and individuals with compromised metabolic functions.

CONCLUSION

This study demonstrated that smooth grinding significantly increases the leaching of heavy metals particularly iron and zinc in various food matrices, with beans, crayfish, and melon being the most affected. Mechanical grinders, especially those used over time, contributed more to contamination than traditional tools. Although most metal levels remained within safety limits, prolonged exposure may pose health risks. These findings highlight the need for safer grinding practices to protect public health.

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