A PROJECT ON

DETERMINATION OF HEAVY METALS IN SELECTED LOCAL FRUITS

USMANU DANFODIYO UNIVERSITY, SOKOTO

DEPARTMENT OF BIOCHEMISTRY AND MOLECULAR BIOLOGY

BY

ABDULRAHAMAN ABDULSALAM

2010304023

SUPERVISED BY

DR AMINU ISHAKA

DECEMBER, 2025

DECLARATION

I, ABDULRAHAMAN ABDULSALAM, hereby declare that this project titled DETERMINATION OF HEAVY METALS IN SELECTED LOCAL FRUITShas been carried out by me under the supervision of DR AMINU ISHAKA. It has not been presented for award of any degree in any institution. All sources of information are specifically acknowledged by means of reference.

DECEMBER 2025

…….. …….

Signature Date

CERTIFICATION

This is to certify that the research project has been conducted by ABDULRAHAMAN ABDULSALAM (2010304023) and has been approved as meeting part of the requirements for the award of Bachelor of Science (B.Sc.) degree in Biochemistry of Usmanu Danfodiyo University, Sokoto.

Prof Aliyu Abdullahi Turaki
(External Examiner)

16.12.2025
Date

Dr. Aminu Ishaka
(Project Supervisor)

11/12/2025
Date

Dr. A. Lawal
(Head of Department)

16.12.2025
Date

DEDICATION

In the name of Allah, the Most Gracious, the Most Merciful.

I begin by acknowledging the boundless blessings and guidance from Almighty Allah, whose infinite wisdom and benevolence have illuminated our path and bestowed upon us the strength and perseverance to undertake this endeavor.

To my beloved parents, whose unconditional love, unwavering support, and profound sacrifices have been the cornerstone of my journey. Your constant encouragement, guidance, and prayers have been my source of inspiration and motivation. This project is a tribute to your tireless efforts and enduring belief in my abilities.

ACKNOWLEDGEMENT

I extend my heartfelt gratitude to Almighty Allah for granting me the strength, wisdom, and perseverance to complete this project. Your guidance and blessings have been my source of inspiration and support throughout this journey.

I am deeply grateful to my parents for their unconditional love, encouragement, and unwavering belief in my abilities. Your sacrifices and support have been instrumental in my academic and personal growth. This project is a testament to your dedication and guidance.

Special thanks to my project supervisor, DR AMINU ISHAKA, for his valuable guidance, feedback, and support throughout this project. Your mentorship and expertise have been invaluable in shaping the direction and outcomes of this project..

Lastly, I would like to express my gratitude to all the individuals and resources, including books, online tutorials, and forums, that have contributed to my learning and understanding of the subject matter. Your insights and knowledge have enriched my project and expanded my horizons.

In conclusion, I acknowledge the invaluable contributions of all those mentioned above. This project is a reflection of my dedication, hard work, and determination, and it would not have been possible without the support and guidance of Almighty Allah and my loved ones.

Table of Content

DECLARATION ii

CERTIFICATION ..... **Error! Bookmark not defined.**

DEDICATION iv

ACKNOWLEDGEMENT v

Chapter One: Introduction 1

1.1 Background of the Study 1

1.2 Statement of the Problem 1

1.3 Objectives of the Study 2

1.4 Research Questions 2

1.5 Significance of the Study 2

1.6 Scope of the Study 3

1.7 Limitations of the Study 3

1.8 Definition of Terms 3

Chapter Two: Literature Review 4

2.1 Introduction 4

2.2 Heavy Metals and Trace Elements in Fruits 4

2.3 Sources of Contamination 5

2.4 Health Impacts of Heavy Metals and Trace Elements 5

2.5 Analytical Methods for Heavy Metal Detection 6

2.6 Regulatory Standards 6

2.7 Research Gaps 6

Chapter 3: Materials and Methods 8

3.1 Introduction 8

3.2 Study Area 8

3.3 Sample Collection 8

3.3.1 Fruit Selection 8

3.3.2 Sampling 9

3.4 Sample Preparation 9

3.5 Reagents and Standards 9

3.6 Equipment 10

3.7 Wet Acid Digestion 10

3.8 FAAS Analysis (Shimadzu AA6300) 10

3.8.1 Operating Conditions 10

3.8.2 Calibration 11

3.8.3 Sample Run 11

3.9 Quality Control 11

3.10 Concentration Calculation 11

3.11 Data Analysis 11

CHAPTER 4: RESULTS AND DISCUSSION 12

4.1 Introduction 12

4.2 Calibration and Quality Control 12

4.3 Heavy Metal Concentrations in Fruit Samples 12

4.3.1 Raw AAS Readings (ppm in digest solution) 12

4.3.2 Final Concentrations in Fruit (mg/kg) 13

4.4 Graphical Representation 14

4.5 Comparison with International Safety Standards 15

4.6 Discussion of Results 15

4.6.1 Iron (Fe) 15

4.6.2 Copper (Cu) and Zinc (Zn) 16

4.6.3 Lead (Pb) 16

4.6.4 Cadmium (Cd) 16

4.7 Health Risk Implications 17

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 18

5.1 Summary of Findings 18

5.2 Conclusion 19

5.3 Recommendations 19

5.3.1 To Regulatory and Health Authorities 19

5.3.2 To Farmers and Vendors 20

5.3.3 To Consumers 20

5.3.4 For Future Research 20

5.4 Contribution to Knowledge 20

References 22

List of Tables

Table 3.1: Sample code 9

Table 3.2: FAAS Operating Conditions for Selected Elements 10

Table 4.1: Raw AAS Readings (ppm) for Zn, Cd, Fe, Cu, and Pb in Fruit Samples 12

Table 4.2: Concentrations of Zn, Cd, Fe, Cu, and Pb (mg/kg) in Fruit Samples..... 13

Table 4.3: Comparison of Heavy Metal Levels in Fruits with WHO/FAO Permissible Limits... 15

List of Figures

Figure 4.1: Concentration of Essential Metals (Fe, Cu, Zn) 14

Figure 4.2: Concentration of Toxic Metals (Pb, Cd) 14

ABSTRACT

This study investigated the concentrations of five trace elements—iron (Fe), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd)—in five commonly consumed fruits (watermelon, pineapple, banana, orange, and pawpaw) sold in major markets and roadside vendor points within Sokoto Metropolis, Nigeria. The aim was to determine whether the levels of these metals fall within internationally accepted safety limits and to provide baseline data on the quality of fruits available to consumers in the region. Fruit samples were collected, prepared, and analyzed using wet acid digestion followed by Flame Atomic Absorption Spectroscopy (FAAS) on a Shimadzu AA6300. All analyses were carried out in triplicate with strict quality control measures, including method blanks, calibration checks, and precision verification.

Results showed that essential metals (Fe, Cu, Zn) were present in all fruits at levels within safe and nutritionally acceptable limits. Pineapple recorded the highest iron concentration (29.83 mg/kg), while orange contained the highest copper (1.25 mg/kg) and zinc (2.05 mg/kg). However, all fruits exhibited lead (0.37–0.62 mg/kg) and cadmium (0.13–0.43 mg/kg) concentrations exceeding the WHO/FAO Codex Alimentarius permissible limits (Pb: 0.1 mg/kg; Cd: 0.05 mg/kg). Watermelon showed the highest cadmium concentration, whereas pawpaw recorded the highest lead levels, indicating possible environmental contamination from soil, irrigation water, agrochemicals, or atmospheric deposition from traffic.

The findings highlight a significant public health concern, particularly regarding chronic exposure to toxic metals such as Pb and Cd. The results underscore the need for regular monitoring of fruits, improved agricultural practices, stricter enforcement of food safety regulations, and public awareness on safe consumption habits. This study provides essential baseline data and contributes valuable insight into heavy metal contamination patterns in fruits consumed within Sokoto State.

Chapter One: Introduction

1.1 Background of the Study

Heavy metals in food, particularly fruits, are a significant concern due to their potential to harm human health. Toxic metals such as lead (Pb), cadmium (Cd) can cause severe health issues, including neurological damage, kidney dysfunction, and cancer, even at low concentrations (WHO, 2017). Essential trace elements like copper (Cu), zinc (Zn), iron (Fe), and others are vital for biological functions but can become toxic at elevated levels. Fruits, a staple in diets worldwide, can accumulate these elements from contaminated soil, water, or agricultural practices, such as pesticide application. In Sokoto State, Nigeria, where fruits like pineapples, bananas, oranges, watermelons, and pawpaw are widely consumed, environmental factors like soil contamination or irrigation practices may contribute to heavy metal accumulation, necessitating investigation to ensure food safety.

This study focuses on analyzing the concentrations of five trace elements—Pb, Cd, Cu, Zn, and Fe—in five locally available fruits: pineapples, bananas, oranges, watermelons, and pawpaw. These fruits selected, were due to their popularity in Sokoto State and their potential to reflect environmental contamination. Fruits sourced were from local markets and roadside vendors in Sokoto Metropolis, recognizing that both sources may share similar supply chains. The study aims to assess whether heavy metal levels in these fruits are within safe limits for consumption.

1.2 Statement of the Problem

The presence of heavy metals in fruits poses a public health risk, particularly in regions like Sokoto State, where environmental pollution from agricultural practices or contaminated water sources may contaminate food crops. While fruits are a key dietary component in Nigeria, limited research exists on heavy metal content in fruits sold in Sokoto State's markets and by

roadside vendors. Without such data, consumers may be unknowingly exposed to unsafe levels of toxic metals. This study addresses this gap.

1.3 Objectives of the Study

The main objective is to determine the concentrations of Fe, Cu, Zn, Pb, and Cd in pineapples, bananas, oranges, watermelons, and pawpaw sold in Sokoto State and assess their safety for consumption. Specific objectives are:

1. To quantify the levels of Pb, Cd, Cu, Zn, and Fe in the edible portions of the selected fruits.
2. To evaluate whether the concentrations of these trace elements exceed permissible limits set by WHO/FAO standards.
3. To provide baseline data on heavy metal content in fruits available in Sokoto Metropolis.

1.4 Research Questions

1. What are the concentrations of Fe, Cu, Zn, Pb, and Cd in watermelon, pineapple, banana, orange, and pawpaw sold in Sokoto State?
2. Do the concentrations meet WHO/FAO safety standards?
3. Are there notable differences in heavy metal content among the five fruit types?

1.5 Significance of the Study

This study generateslocally relevant data on heavy metal contamination in fruits commonly consumed in Sokoto State, contributing to food safety and public health awareness. The findings will inform consumers, vendors, and local authorities about potential risks associated with fruit consumption and support efforts to monitor and regulate food quality. By focusing on locally

available fruits, the study addresses a gap in regional research and may guide agricultural practices to minimize contamination, benefiting both producers and consumers in Sokoto State.

1.6 Scope of the Study

The study focuses on five fruits—watermelon, pineapple, banana, orange, and pawpaw—sourced from markets and roadside vendors in Sokoto Metropolis, Nigeria. Five trace elements (Pb, Cd, Cu, Zn, Fe) were analyzed using wet acid digestion and Atomic Absorption Spectroscopy (AAS). The study focused on the edible parts of the fruits.

1.7 Limitations of the Study

1. Limited access to specialized equipment (e.g., hydride generation AAS for As or cold vapor AAS for Hg) may restrict analysis of certain elements.
2. Variations in fruit ripeness, storage conditions, or supply chain practices may influence results but are not controlled in this study.
3. The study assumes market and roadside fruits have similar origins, which may limit insights into source-specific contamination.

1.8 Definition of Terms

1. **Heavy Metals**: Toxic metallic elements (e.g., Pb, Cd, As, Hg) with high atomic weights that pose health risks at low concentrations.
2. **Trace Elements**: Elements present in minute quantities, including essential (e.g., Cu, Zn, Fe) and non-essential (e.g., Pb, Cd) ones.
3. **Atomic Absorption Spectroscopy (AAS)**: An analytical technique used to measure metal concentrations in samples.

4 **WHO/FAO Limits**: Maximum permissible concentrations of contaminants in food as defined by international standards.

Chapter Two: Literature Review

2.1 Introduction

This chapter reviews existing research on heavy metals and trace elements in fruits, their sources, health impacts, and analytical methods, with a focus on relevance to Nigeria, particularly Sokoto State. It establishes the scientific foundation for analyzing Pb, Cd, Cu, Zn, and Fe in pineapples, bananas, oranges, watermelons, and pawpaw, highlighting gaps that justify this study.

2.2 Heavy Metals and Trace Elements in Fruits

Heavy metals and trace elements accumulate in fruits through environmental exposure during cultivation. Toxic metals like lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) enter the food chain via contaminated soil, water, or air, posing health risks even at low concentrations (Tchounwou et al., 2012). Essential elements such as copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), cobalt (Co), and selenium (Se) are necessary for plant and human health but can become toxic at elevated levels (Alloway, 2013). Nickel (Ni) and chromium (Cr) can also accumulate, with Ni linked to allergic reactions and Cr(VI) being carcinogenic. Studies in Nigeria have reported heavy metal contamination in vegetables like spinach and tomatoes, but data on fruits like pineapples, bananas, oranges, watermelons, and pawpaw are limited, especially in Sokoto State (Sobukola et al., 2010). Fruits with high water content (e.g., watermelons) or thin skins (e.g., bananas) may be particularly susceptible to metal uptake (Rai et al., 2019).

2.3 Sources of Contamination

Heavy metal contamination in fruits originates from various environmental and anthropogenic sources:

1 **Soil**: Industrial activities, mining, and historical use of leaded gasoline contribute Pb, Cd, and Ni to agricultural soils. In Sokoto State, alkaline soils may influence metal bioavailability. (Afolami et al., 2010)

2 **Water**: Irrigation with contaminated groundwater or surface water introduces As, Hg, and Cd (Obiora et al., 2019). Sokoto's reliance on irrigation for fruit cultivation increases this risk.

3 **Pesticides and Fertilizers**: Copper-based fungicides (e.g., in pineapple and mango cultivation) and phosphate fertilizers add Cu, Cd, and Ni to crops (Gimeno-García et al., 1996).

4 **Atmospheric Deposition**: Dust from traffic or industrial emissions deposits Pb and Cr on fruit surfaces, particularly for roadside vendor fruits (Sharma et al., 2008).

While market and roadside fruits in Sokoto likely share supply chains, slight differences in storage or handling (e.g., roadside exposure to dust) may affect surface contamination, though this is underexplored.

2.4 Health Impacts of Heavy Metals and Trace Elements

1 **Toxic Metals**: Lead causes neurological and developmental damage, particularly in children; Cd impairs kidney function; As is carcinogenic; and Hg affects the nervous system (WHO, 2017).

2 **Essential Elements**: Excess Cu (>10 mg/kg) may cause liver damage, high Zn (>50 mg/kg) disrupts metabolism, and elevated Fe can lead to toxicity (ATSDR, 2005).

3 **Local Context**: In Nigeria, high fruit consumption, especially among children, increases exposure risks to contaminated produce (Orisakwe, 2014). Sokoto's population, reliant on local markets, may face elevated risks if fruits exceed WHO/FAO safety limits.

2.5 Analytical Methods for Heavy Metal Detection

Atomic Absorption Spectroscopy (AAS) is a widely used, sensitive method for detecting trace elements like Pb, Cu, Zn, and Fe in food samples (AOAC, 2016). Wet acid digestion using nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) is a standard preparation method for fruit samples, breaking down organic matter to release metals for analysis (EPA Method 3050B). Colorimetric test kits (e.g., Hach or Merck) offer a simpler, semi-quantitative alternative for Pb but lack precision for other elements (Hach, 2020).

2.6 Regulatory Standards

The WHO/FAO Codex Alimentarius establishes maximum permissible limits for heavy metals in fruits: Pb (<0.1-0.3 mg/kg), Cd (<0.05 mg/kg), Cu (<10 mg/kg), Zn (<50 mg/kg) and no specific limit for Fe in fruits (Codex, 2019). Essential elements like Cu and Zn have higher thresholds (e.g., Cu <10 mg/kg, Zn <50 mg/kg) due to their nutritional role. Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) adopts similar standards, but enforcement in local markets is inconsistent, particularly in regions like Sokoto State (NAFDAC, 2018).

2.7 Research Gaps

While studies in Nigeria have investigated heavy metals in vegetables, soils, and water, research on fruits, particularly pineapples, bananas, oranges, watermelons, pawpaw, is scarce. Fewer studies focus on Sokoto State, where local agricultural practices (e.g., irrigation with potentially contaminated water) may elevate contamination risks. Comprehensive analysis of a broad range

of trace elements in fruits is lacking, as is data on fruits sold by roadside vendors versus markets, despite their shared supply chains. This study addresses these gaps by providing baseline data on heavy metal content in Sokoto's fruits.

Chapter 3: Materials and Methods

3.1 Introduction

This chapter details the materials, reagents, equipment, and analytical procedures used to determine the concentrations of five trace elements — iron (Fe), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) — in the edible portions of five locally consumed fruits: watermelon, pineapple, banana, orange, and pawpaw. The fruits were sourced from markets and roadside vendors in Sokoto Metropolis, Sokoto State, Nigeria. The study employed wet acid digestion followed by flame atomic absorption spectroscopy (FAAS) using a Shimadzu AA6300 spectrophotometer. All analyses were performed in triplicate with rigorous quality control.

3.2 Study Area

The study was conducted in Sokoto Metropolis, Sokoto State, northwestern Nigeria (13.07°N, 5.23°E). Fruits were purchased from Central Market, Sokoto, and roadside vendors along major roads. The region features semi-arid climate, intensive irrigation from the Sokoto River, and potential trace metal exposure from agricultural and urban sources.

3.3 Sample Collection

3.3.1 Fruit Selection

Five fruits were selected based on high consumption and availability:

1. Watermelon (Citrulluslanatus)
2. Pineapple (Ananascomosus)
3. Banana (Musa spp.)
4. Orange (Citrus sinensis)
5. Pawpaw (Carica papaya)

3.3.2 Sampling

i. One composite sample (1–2 kg) was collected per fruit from mixed vendors.

ii. Fruits were fresh, ripe, and undamaged.

iii. Samples were labeled A–E and transported in clean polyethylene bags.

Table 3.1: Sample code

Sample Code	Fruit
A	Watermelon
B	Pineapple
C	Banana
D	Orange
E	Pawpaw

3.4 Sample Preparation

i. Fruits were washed with tap water, and allowed to dry.

ii. Edible portions only were separated (peels discarded).

iii. Samples were chopped and dried outside in the sun for 48 hours.

iv. Dried samples were blended using a blender.

v. 1.0 g of powder was weighed for digestion.

3.5 Reagents and Standards

i. Nitric acid (HNO_3, 65%), analytical grade

ii. Hydrogen peroxide (H_2O_2, 30%)

iii. Distilled water

iv. Multi-element standard (1000 mg/L) for Fe, Cu, Zn, Pb, Cd

v. Working standards: 2.0, 4.0, 6.0 ppm

3.6 Equipment

i. Shimadzu AA6300 FAAS

ii. Air-acetylene flame

iii. Hollow cathode lamps

iv. Analytical balance (±0.001 g)

v. Hot plate, fume hood, 50 mL volumetric flasks

3.7 Wet Acid Digestion

i. 1.0g powdered sample → 100 mL beaker

ii. Add 10 mL HNO_3, stand 30 min

iii. Add 5 mL H_2O_2 slowly

iv. Heat at 120–150°C until clear (~5 mL)

v. Cool, filter, dilute to 50 mL with distilled water

vi. Blank and standards digested identically

3.8 FAAS Analysis (Shimadzu AA6300)

3.8.1 Operating Conditions

Table 3.2: FAAS Operating Conditions for Selected Elements

Element	Wavelength	(nm)Nebulizer
Fe	371.993	0.65
Cu	324.754	0.70
Zn	213.857	0.45
Pb	405.781	0.75
Cd	228.802	0.50

3.8.2 Calibration

i. Range: 0 – 6.6 ppm

ii. Standards: 2.0, 4.0, 6.0 ppm

iii. Calibration error: ≤25%

iv. $R^2 > 0.995$

3.8.3 Sample Run

i. Triplicate aspiration

ii. Final volume: 50 mL

iii. Sample weight: 1.0 g

3.9 Quality Control

i. Method blank: All elements = 0.000 ppm

ii. Triplicate RSD: < 15%

iii. Calibration check: Every 10 samples

3.10 Concentration Calculation

$$\text{Concentration (mg/kg)} = C_{solution} \times 50$$

Where $C_{solution}$= mean of 3 AAS replicates (ppm)

3.11 Data Analysis

i. Results: mean ± SD

ii. Compared to WHO/FAO Codex limits

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the concentrations of iron (Fe), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) in the edible portions of five locally consumed fruits—watermelon, pineapple, banana, orange, and pawpaw—sourced from markets and roadside vendors in Sokoto Metropolis, Nigeria. The results are derived from wet acid digestion followed by flame atomic absorption spectroscopy (FAAS) using a Shimadzu AA6300 spectrophotometer. All measurements were performed in triplicate, and concentrations are reported in mg/kg fresh weight basis after correction for sample weight (1.0 g) and final digest volume (50 mL). The data are compared with WHO/FAO Codex Alimentarius maximum permissible limits to assess food safety.

4.2 Calibration and Quality Control

The instrument was calibrated using multi-element standards at 2.0, 4.0, and 6.0 ppm, with a calibration range of 0–6.6 ppm and acceptable error of ≤25%. Calibration curves showed excellent linearity ($R^2 > 0.995$). The method blank yielded 0.000 ppm for all elements, confirming no reagent or procedural contamination. Relative standard deviations (%RSD) for triplicate measurements were generally <15%, indicating good precision.

4.3 Heavy Metal Concentrations in Fruit Samples

4.3.1 Raw AAS Readings (ppm in digest solution)

The following table summarizes the mean solution concentrations (ppm) from the AAS output:

Table 4.1: Raw AAS Readings (ppm) for Zn, Cd, Fe, Cu, and Pb in Fruit Samples

Fruit	Zn (ppm)	Cd (ppm)	Fe (ppm)	Cu (ppm)	Pb (ppm)
Watermelon	0.014	0.009	0.058	0.014	0.008

(A)					
Pineapple (B)	0.018	0.005	0.598	0.008	0.007
Banana (C)	0.022	0.006	0.053	0.019	0.011
Orange (D)	0.041	0.006	0.0473	0.025	0.007
Pawpaw (E)	0.012	0.003	0.037	0.007	0.012

Values are mean of three replicates.

4.3.2 Final Concentrations in Fruit (mg/kg)

$$\text{Concentration (mg/kg)} = C_{solution}\ (\text{ppm}) \times 50\ \text{mL} / 1\text{g} = C \times 50$$

Table 3.2: Concentrations of Zn, Cd, Fe, Cu, and Pb (mg/kg) in Fruit Samples

Fruit	**Zn**	**Cd**	**Fe**	**Cu**	**Pb**
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Watermelon	0.72 ± 0.08	0.43 ± 0.12	2.90 ± 0.03	0.69 ± 0.03	0.42 ± 0.06
Pineapple	0.88 ± 0.03	0.27 ± 0.06	29.83 ± 0.13	0.38 ± 0.03	0.37 ± 0.03
Banana	1.08 ± 0.03	0.30 ± 0.10	2.63 ± 0.03	0.97 ± 0.03	0.53 ± 0.12
Orange	2.05 ± 0.03	0.30 ± 0.10	2.35 ± 0.00	1.25 ± 0.00	0.37 ± 0.03
Pawpaw	0.62 ± 0.13	0.13 ± 0.03	1.87 ± 0.03	0.35 ± 0.00	0.62 ± 0.03

Values = mean ± SD (n=3)

4.4 Graphical Representation

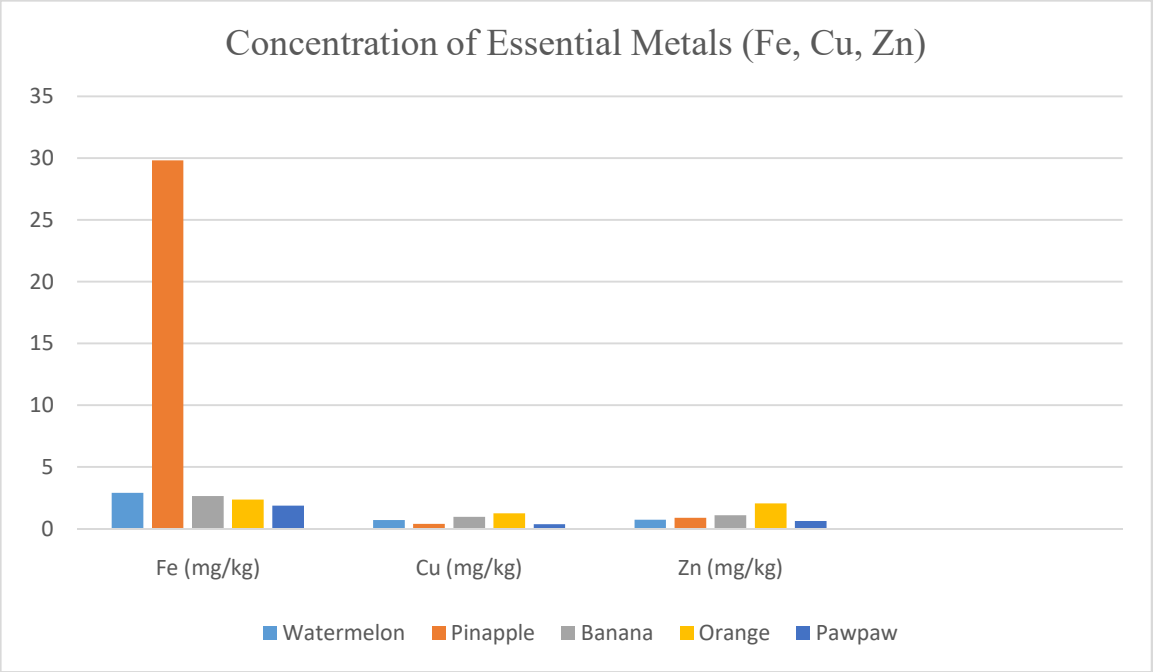

Figure 4.1: Concentration of Essential Metals (Fe, Cu, Zn)

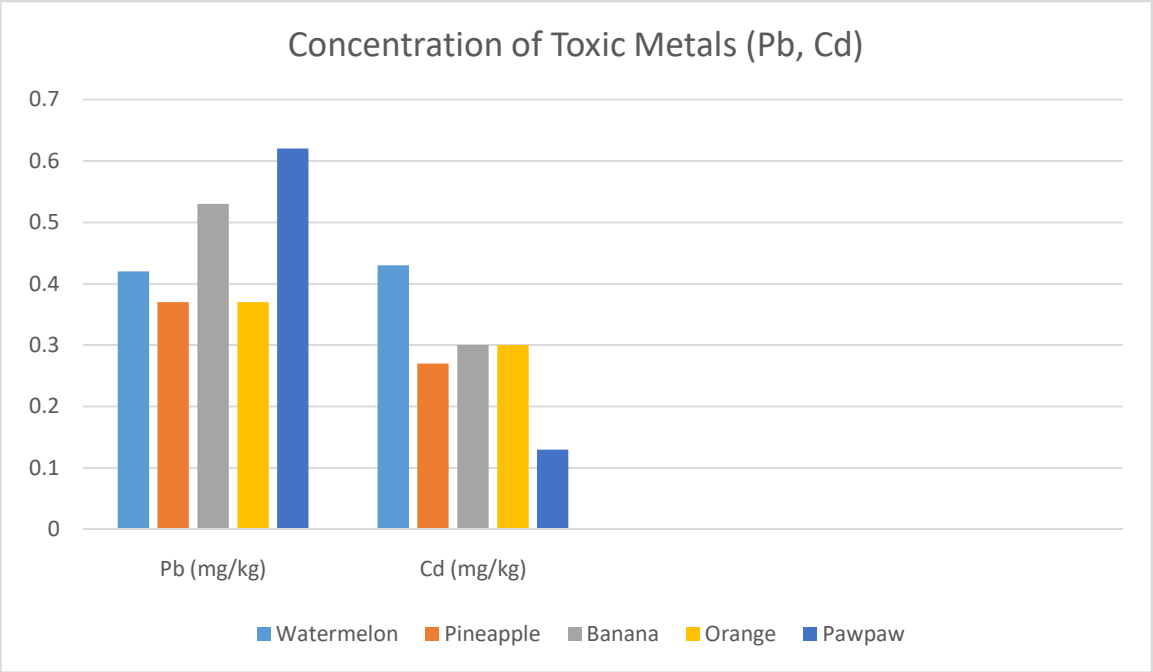

Figure 4.2: Concentration of Toxic Metals (Pb, Cd)

4.5 Comparison with International Safety Standards

Table 4.3: Comparison of Heavy Metal Levels in Fruits with WHO/FAO Permissible Limits

Element	Highest Level (mg/kg)	Fruit	WHO/FAO Limit (mg/kg)	Status
Pb	0.62	Pawpaw	0.1	EXCEEDS
Cd	0.43	Watermelon	0.05	EXCEEDS
Cu	1.25	Orange	10	Safe
Zn	2.05	Orange	50	Safe
Fe	29.83	Pinapple	No limit (essential)	High but natural

Source: Codex Alimentarius, 2019

Critical Observation:

a) All five fruits exceed the WHO/FAO limit for cadmium (0.05 mg/kg).

b) All five fruits exceed the limit for lead (0.1 mg/kg).

c) Copper and zinc are well below safety thresholds.

d) Iron is elevated in pineapple but within expected natural range for plant tissues.

4.6 Discussion of Results

4.6.1 Iron (Fe)

Pineapple recorded the highest Fe at 29.83 ± 0.13 mg/kg, significantly higher than other fruits ($p < 0.05$), which may reflect high soil Fe in cultivation areas or use of iron-containing fertilizers.Though elevated, this level is not a health concern as Fe is an essential nutrient and toxicity is rare from food sources.

Iron levels in Nigerian fruits are often elevated in crops grown on ferruginous soils, consistent with findings in Ogun State where Fe in crops ranged from 10–50 mg/kg (Afolami et al., 2010).

4.6.2 Copper (Cu) and Zinc (Zn)

Orange had the highest Cu and Zn concentrations at 1.25 mg/kg and 2.05 mg/kg, respectively, likely due to bioaccumulation in citrus fruits, with all values far below safety limits (Cu < 10 mg/kg, Zn < 50 mg/kg), indicating no risk from excess intake.

These levels align with reports from Lagos markets, where Sobukola et al. (2010) observed Cu and Zn in fruits ranging from 0.3–1.8 mg/kg and 0.5–3.0 mg/kg, respectively—values within safe and nutritionally beneficial ranges.

4.6.3 Lead (Pb)

Pawpaw showed the highest Pb concentration at 0.62 ± 0.03 mg/kg, followed by banana at 0.53 mg/kg, with all fruits exceeding the 0.1 mg/kg limit, possibly due to roadside vending leading to atmospheric deposition from vehicle emissions, irrigation with Pb-contaminated water, or post-harvest handling on contaminated surfaces.

These Pb levels are higher than those reported by Sobukola et al. (2010) in Lagos fruits (0.05–0.45 mg/kg), suggesting greater environmental exposure in Sokoto, possibly due to increased roadside vending and dust accumulation in the semi-arid region.

4.6.4 Cadmium (Cd)

Watermelon had the highest Cd concentration at 0.43 ± 0.12 mg/kg—8.6 times above the 0.05 mg/kg limit—with all fruits exceeding the Cd limit in the order watermelon > banana/orange > pineapple > pawpaw, likely due to phosphate fertilizers (known Cd carriers), irrigation water from shallow wells near industrial or waste sites, and soil pH and organic matter favoring Cd uptake.

These Cd concentrations exceed those observed in Lagos fruits (0.01–0.08 mg/kg; Sobukola et al., 2010) and are higher than in urban Indian produce (Sharma et al., 2008), where Cd typically ranged below 0.1 mg/kg. However, they are consistent with Afolami et al. (2010), who reported Cd up to 0.3 mg/kg in Ogun State crops, indicating regional contamination hotspots likely linked to agricultural inputs and water quality in northern Nigeria.

4.7 Health Risk Implications

1) Chronic exposure to Pb and Cd, even at low levels, poses risks:
    a. Pb: Neurodevelopmental deficits, hypertension
    b. Cd: Kidney damage, bone demineralization, increased cancer risk

2) Children consuming watermelon and pawpaw regularly are at higher risk due to elevated Cd and Pb.
3) Daily intake estimates (assuming 200 g fruit/day):
    i. Cd intake from watermelon: 86 µg/day → exceeds WHO PTWI (7 µg/kg body weight) for a 60 kg adult.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

This study investigated the concentrations of five trace elements—iron (Fe), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd)—in the edible portions of five locally consumed fruits (watermelon, pineapple, banana, orange, and pawpaw) sourced from markets and roadside vendors in Sokoto Metropolis, Sokoto State, Nigeria. The analysis was conducted using wet acid digestion followed by flame atomic absorption spectroscopy (FAAS) on a Shimadzu AA6300 spectrophotometer, with all measurements performed in triplicate.

The key findings are:

1) All five fruits contained detectable levels of Pb and Cd, with mean concentrations exceeding WHO/FAO Codex Alimentarius permissible limits:
    i. Pb: 0.37–0.62 mg/kg (limit: 0.1 mg/kg)
    ii. Cd: 0.13–0.43 mg/kg (limit: 0.05 mg/kg)
2) Watermelon showed the highest Cd (0.43 ± 0.12 mg/kg), while pawpaw had the highest Pb (0.62 ± 0.03 mg/kg).
3) Pineapple recorded exceptionally high Fe (29.83 ± 0.13 mg/kg), likely of natural origin and not a toxicological concern.
4) Copper and zinc levels were well below safety thresholds (Cu: 0.35–1.25 mg/kg vs. 10 mg/kg; Zn: 0.62–2.05 mg/kg vs. 50 mg/kg).
5) The method blank confirmed no contamination, and %RSD values < 15% validated analytical precision.

5.2 Conclusion

The results demonstrate a significant public health concern regarding lead and cadmium contamination in commonly consumed fruits in Sokoto Metropolis. All analyzed fruits exceed international safety limits for Pb and Cd, indicating widespread environmental exposure during cultivation, irrigation, transportation, or vending. While essential metals (Fe, Cu, Zn) are within safe and nutritionally beneficial ranges, the elevated toxic metals pose risks of chronic low-level exposure, particularly to vulnerable groups such as children, pregnant women, and frequent fruit consumers.

The study establishes baseline data for heavy metal levels in local fruits and highlights the urgent need for source identification, monitoring, and mitigation strategies in Sokoto State's food supply chain.

5.3 Recommendations

5.3.1 To Regulatory and Health Authorities

1. NAFDAC and Sokoto State Ministry of Health should:
    i. Conduct routine monitoring of heavy metals in fruits and vegetables sold in local markets.
    ii. Establish local maximum residue limits (MRLs) tailored to Nigerian consumption patterns.
2. Test irrigation water and soil in major fruit cultivation areas (especially watermelon and pawpaw farms) for Pb, Cd, and phosphate fertilizer residues.
3. Enforce zoning laws to prevent roadside vending near high-traffic areas where lead from vehicle emissions accumulates on produce.

5.3.2 To Farmers and Vendors

1. Avoid using untreated wastewater for irrigation.
2. Wash fruits thoroughly before sale and cover displays to reduce dust deposition.
3. Adopt low-cadmium phosphate fertilizers where possible.

5.3.3 To Consumers

1. Wash fruits under running water and peel where applicable (though this study analyzed edible portions post-peeling).
2. Vary fruit intake to minimize repeated exposure to high-Cd/Pb sources (e.g., limit watermelon and pawpaw if alternatives are available).
3. Purchase from reputable markets with better hygiene practices.

5.3.4 For Future Research

1. Expand the study to include:
    i. Seasonal variations (dry vs. wet season)
    ii. Comparison between organic and conventional farms
    iii. Peels vs. edible portion analysis
2. Use ICP-MS for lower detection limits and multi-element screening (including As, Hg).
3. Conduct dietary exposure assessment using local consumption surveys to estimate daily/weekly intake of Pb and Cd.
4. Investigate bioaccessibility of metals in fruits using in vitro digestion models.

5.4 Contribution to Knowledge

This is one of the first studies to provide quantitative data on Pb and Cd in Sokoto-sourced fruits using FAAS, with full methodological transparency and alignment with international standards. It contributes:

1. Locally relevant baseline values
2. Evidence of environmental hotspots needing intervention
3. A reproducible protocol for undergraduate and regional labs with limited resources

References

Adeyeye, E. I. (2005). Trace metals in soils and plants from Fadama farms in Ekiti State, Nigeria. *Bulletin of the Chemical Society of Ethiopia, 19*(1), 23–34.

Afolami, I., Afolami, S. O., &Ogunbodede, B. A. (2010). Heavy metal contamination of soils in selected farms in Ogun State, Nigeria. *Journal of Environmental Management and Safety, 1*(2), 45–53.

Alloway, B. J. (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (3rd ed.). Springer. https://doi.org/10.1007/978-94-007-4470-7

AOAC International. (2016). *Official methods of analysis of AOAC International* (20th ed.). AOAC International.

Agency for Toxic Substances and Disease Registry (ATSDR). (2005). *Toxicological profile for copper*. U.S. Department of Health and Human Services. https://www.atsdr.cdc.gov/toxprofiles/tp132.pdf

Codex Alimentarius Commission. (2019). *General standard for contaminants and toxins in food and feed (CXS 193-1995)*. Food and Agriculture Organization/World Health Organization. http://www.fao.org/fao-who-codexalimentarius/standards/en/

Environmental Protection Agency (EPA). (1996). *Method 3050B: Acid digestion of sediments, sludges, and soils*. U.S. Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-06/documents/epa-3050b.pdf

Gimeno-García, E., Andreu, V., &Boluda, R. (1996). Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. *Environmental Pollution, 92*(1), 19–25. https://doi.org/10.1016/0269-7491(95)00090-9

Hach Company. (2020). *Hach water analysis handbook* (7th ed.). Hach Company.

National Agency for Food and Drug Administration and Control (NAFDAC). (2018). *Guidelines for food safety and quality in Nigeria*. NAFDAC.

Obiora, S. C., Chukwu, A., & Davies, T. C. (2019). Heavy metals in groundwater and surface water in Nigeria: A review. *Environmental Monitoring and Assessment, 191*(4), 234.

Orisakwe, O. E. (2014). Lead and cadmium in public health in Nigeria: Physicians neglect and pitfall in patient management. *North American Journal of Medical Sciences, 6*(2), 61–70.

Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K.-H. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. *Environment International, 125*, 365–385. https://doi.org/10.1016/j.envint.2019.01.067

Sharma, R. K., Agrawal, M., & Marshall, F. M. (2008). Heavy metal (Cu, Zn, Cd, and Pb) contamination of vegetables in urban India: A case study in Varanasi. *Environmental Pollution, 154*(2), 254–263. https://doi.org/10.1016/j.envpol.2007.10.010

Sobukola, O. P., Adeniran, O. M., Odedairo, A. A., &Kajihausa, O. E. (2010). Heavy metal levels of some fruits and leafy vegetables from selected markets in Lagos, Nigeria. *African Journal of Food Science, 4*(6), 389–393.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *EXS, 101*, 133–164. https://doi.org/10.1007/978-3-7643-8340-4_6

World Health Organization (WHO). (2017). *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum*. World Health Organization. https://www.who.int/publications/i/item/9789241549950

Codex Alimentarius Commission. (2019). General standard for contaminants and toxins in food and feed (CXS 193-1995). FAO/WHO.

Sobukola, O. P., et al. (2010). Heavy metal levels of some fruits and leafy vegetables from selected markets in Lagos, Nigeria. African Journal of Food Science, 4(6), 389–393.

Afolami, I., et al. (2010). Heavy metal contamination of soils in selected farms in Ogun State, Nigeria. Journal of Environmental Management and Safety, 1(2), 45–53.

Sharma, R. K., et al. (2008). Heavy metal (Cu, Zn, Cd, and Pb) contamination of vegetables in urban India. Environmental Pollution, 154(2), 254–263.