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BIOLOGICAL SCIENCES DEPARTMENT

Prevalence and Levels of Aflatoxins in Peanuts and Peanut Butter from Informal Market Sources in Chitungwiza, Zimbabwe.

By

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A research project submitted in partial fulfillment of the requirements for the Bachelor of Science Honours Degree in Biological Sciences.

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Approval Form

The undersigned certify that they have read the dissertation titled "**Prevalence and Levels of Aflatoxins in Peanuts and Peanut Butter from Informal Market Sources in Chitungwiza, Zimbabwe**" and confirm that it is suitable for submission to the Biological Sciences Department, Faculty of Science for assessment.

Signature of student: ..... Date: 12/06/26

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Dedication

I dedicate this project to my parents**.**

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List of Tables

Table 1: Mean (± SD) Aflatoxin Concentrations (µg/kg) by Location and Sample Type 14
Table 2: Comparison of Raw Peanuts vs Peanut Butter 16
Table 3: Raw Peanuts Results in Seke ..... **Error! Bookmark not defined.**
Table 4: Peanut Butter Results in Seke ..... **Error! Bookmark not defined.**
Table 5: Raw Peanuts Results in Zengeza ..... **Error! Bookmark not defined.**
Table 6: Peanut Butter Results in Zengeza ..... **Error! Bookmark not defined.**
Table 7: Raw Peanuts Results in St Mary ..... **Error! Bookmark not defined.**
Table 8: Peanut Butter Results in St Mary's ..... **Error! Bookmark not defined.**

List of Appendices

Appendix A: P1 27
Appendix B: P2 28
Appendix C: P3 28
Appendix D: P4 28
Appendix E: P5 29
Appendix F: P6 29
Appendix G: P7 29
Appendix H: P8 29
Appendix I: P9 30
Appendix J: P10 30
Appendix K: A1 30
Appendix L: A2 31
Appendix M: A3 31
Appendix N: A4 31
Appendix O: A5 32
Appendix P: A6 32
Appendix Q: A7 32
Appendix R: A8 32
Appendix S: A9 33
Appendix T: A10 33
Appendix U: Raw Peanuts Results with Mean, Min, and Max 33
Appendix V: Peanut Butter Results with Mean, Min, and Max 34
Appendix W: Rearranged Data to Use in Two-Way ANOVA 35
Appendix X: Two-Way ANOVA Results 35

List of Abbreviations and Acronyms

AFB1 …….	Aflatoxin B1
AFB2 …….	Aflatoxin B2
AFG1 …….	Aflatoxin G1
AFG2 ……...	Aflatoxin G2
ANOVA……	Analysis of Variance
ELISA……	Enzyme-Linked Immunosorbent Assay
FDA …… …	Food and Drug Administration
GAP ……	Good Agricultural Practices
HBV ……	Hepatitis B Virus
HCC ……	Hepatocellular Carcinoma
HPLC ……	High-Performance Liquid Chromatography
IARC ……...	International Agency for Research on Cancer
LC-MS ……...	Liquid Chromatography-Mass Spectrometry
LOD ……...	Limit of Detection
LOQ ……...	Limit of Quantification
ND……...	Not Detected
RP- HPLC ……	Reversed-Phase High Performance Liquid Chromatography
SPSS …….	Statistical Package for Social Science
STDEM …….	Standard Error of Mean
WHO …….	World Health Organization
°C…….	Degrees Celsius
a …….	Alpha (Level of Significance)
BaSO4 ……	Barium Sulfate
F ……...	F- Statistic
F-crit ……...	Critical F-value
mL ……...	Millilitre
mm …….	Millimetres
nm ……...	Nanometres

p ……	Probability Value (p value)
R1, R2, R3 …….	Replicate 1, Replicate 2, Replicate 3
R^2 …….	Coefficient of Determination
rpm …….	Revolution Per Minute
SD …….	Standard Deviation
µg/kg ……	Microgram per Kilogram
µL ……	Microlitre
v/v/v …….	Volume per Volume per Volume

Abstract

Aflatoxins are toxic secondary metabolites produced by *Aspergillus* species and are among the major food threats affecting peanuts and peanut-based products worldwide. In Zimbabwe, peanuts and peanut butter sold through informal markets are widely consumed, yet they are often handled and stored under conditions that favour fungal growth and toxin production, posing health risks to consumers. This study aimed to determine the prevalence and concentrations of aflatoxins in raw peanuts and peanut butter purchased from informal market sources in Chitungwiza, Zimbabwe, and to assess whether contamination levels differed according to product type and sampling location. A total of twenty samples, consisting of ten raw peanut and ten peanut butters, were collected from Seke, Zengeza, and St. Mary's. High-Performance Liquid Chromatography (HPLC) with fluorescence detection was used to analyze the samples for aflatoxins B_1 (AFB_1), B_2 (AFB_2), G_1 (AFG_1), and G_2 (AFG_2). Data were subjected to descriptive statistics and two-way Analysis of Variance (ANOVA). The results revealed widespread aflatoxin contamination in peanuts and peanut butter from informal markets. Seventy percent of samples of raw peanuts and all peanut butter samples tested positive for aflatoxins. Peanut butter exhibited higher contaminations ranging from 10.37 to 426.97 µg/kg, and a mean concentration of 166.9 ± 59.12 µg/kg, total aflatoxin concentrations in raw peanuts ranged from not detected (ND) to 416.87 µg/kg, with a mean concentration of 87.9 ± 95.56 µg/kg. Aflatoxin B_1 was the most frequently detected and dominant aflatoxin in all sample category. The highest contamination levels were observed in Seke and Zengeza while St Mary’s exhibited comparatively lower concentrations. Statistical analysis indicated that sampling location significantly influenced aflatoxin levels ($p < 0.05$), while product type did not show a statistically significant effect. The results demonstrate that peanut butter sold in Chitungwiza informal markets pose a risk, as many samples exceeded international regulatory limits. The study recommends improving post-harvest handling and storage practices, strengthening food safety monitoring, and raising public awareness to reduce consumer exposure to aflatoxins.

Table of Contents

Approval Form i
Declaration ii
Dedication iii
Acknowledgements iv
List of Tables v
List of Appendices vi
List of Abbreviations and Acronyms vii
Abstract ix
CHAPTER 1 1
INTRODUCTION 1
1.1 Background to the study 1
1.2 Problem Statement 1
1.3 Justification for the study 2
1.4 Aim of Study 2
1.5 Research Objectives 2
1.6 Research Questions 3
1.7 Hypotheses 3
1.8 Significance of the study 3
1.9.1 Limitations 4
1.9.2 Delimitations 4
1.10 Definition of terms 4
CHAPTER 2 5
LITERATURE REVIEW 5
2.1 Biochemical Characteristics of Aflatoxins 5
2.2 Pathways of Contamination in Peanuts and Peanut Butter 5
2.3 Health Implications to humans 6
2.3.1 Acute Toxicity 6
2.3.2 Chronic Toxicity and Liver Cancer 6
2.3.3 Child Growth and Development 7
2.3.4 Immunosuppression and Nutritional Impacts 7
2.3.5 Global Findings 7
2.4 Food Safety Policies and Control Systems in Informal Markets 8
2.5 Analytical Methods for Aflatoxin Detection 8
2.6 Research Gaps and Conclusion 9
CHAPTER 3 10

MATERIALS AND METHODS 10
3.1 Study Area and Sampling 10
3.2 Sample Preparation 10
3.3 Aflatoxin Extraction 10
3.4 High-Performance Liquid Chromatography (HPLC) Analysis 11
3.5 Data Analysis 11
3.6 Quality Control and Assurance 12
CHAPTER 4 13
RESULTS 13
4.1 Overview of Aflatoxin Occurrence 13
4.2 Aflatoxin Levels in Raw Peanut Samples 15
4.2.1 Variability in Aflatoxin Levels 15
4.3 Aflatoxin Levels in Peanut Butter Samples 15
4.4 Comparison Between Raw Peanuts and Peanut Butter 16
4.5 Aflatoxin Distribution by Location 16
4.5.1 Aflatoxin Distribution in Seke 16
4.5.2 Aflatoxin Distribution in Zengeza 17
4.5.3 Aflatoxin Distribution in St Mary's 17
4.6 Statistical Analysis 17
4.6.1 Analysis of Variance (ANOVA) Results 17
CHAPTER 5 18
DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS 18
5.1 Overview of Aflatoxin Occurrence 19
5.2 Aflatoxins in Raw Peanut Samples 19
5.3 Aflatoxin Levels in Peanut Butter Samples 20
5.4 Comparison Between Raw Peanuts and Peanut Butter 20
5.5 Aflatoxin Distribution by Location 21
5.7 CONCLUSIONS 22
5.8 RECOMMENDATIONS 23
1. Agricultural Level 23
2. Post-Harvest Handling 23
3. Processing Level 23
5. Policy and Regulation 23
6. Future Research 24
REFERENCES 24
Appendix 27

CHAPTER 1
INTRODUCTION

1.1 Background to the study

For many communities around the world, peanuts constitute are a staple food and income source for many communities worldwide. However, they are highly susceptible to fungal contamination by *Aspergillus* species, particularly *Aspergillus flavus* and *Aspergillus parasiticus*, which produce aflatoxins, potent carcinogenic and hepatotoxic mycotoxins (Wild & Gong, 2010). Aflatoxins pose significant health risks including liver cancer, stunted growth in children, and immune suppression. In Zimbabwe, where peanuts and peanut butter are staple foods in many households, the consumption of aflatoxin-contaminated products in informal markets poses a serious health threat. Vulnerable populations, such as children, pregnant women, and immunocompromised individuals, are at greater risk of suffering from the toxic effects of aflatoxins (Wu, 2017). However, due to the lack of testing and regulation in informal markets, many people are unknowingly exposed to these risks, which could result in long-term health consequences. The informal food markets, often operating under limited regulatory oversight, may lack the necessary storage and quality control standards to prevent aflatoxin contamination. Informal markets are widely accessed by low-income populations but are largely unregulated, increasing the potential for food safety hazards (Mutegi et al., 2013). Peanut butter, being a processed form of groundnuts, may also harbour aflatoxins if contaminated peanuts are used during production.

1.2 Problem Statement

Peanuts and peanut butter sold in informal markets are at high risk of contamination with aflatoxins due to inadequate post-harvest handling and storage conditions. Zimbabwe has experienced periodic outbreaks of aflatoxicosis, highlighting the need for regular monitoring of staple foods like peanuts (Masaka et al.,2022). Informal market vendors often lack the resources and knowledge required to implement safe storage and handling practices, which increases the likelihood of *Aspergillus* contamination (Muzhingi et al., 2015). Furthermore, poor storage conditions, such as exposure to high humidity and temperature fluctuations, create an ideal environment for the growth of aflatoxin-producing molds (Bandyopadhyay et al., 2016). Without adequate monitoring, peanuts and peanut butter are more likely to be sold with unsafe levels of aflatoxins, presenting significant health risks to consumers.

Chitungwiza, one of Zimbabwe's largest and most densely populated towns, relies heavily on informal food supply chains. A lack of data on aflatoxin levels in such settings impedes effective policy formulation and

public health interventions. By determining aflatoxin contamination levels in these markets, this study will inform stakeholders including food safety authorities, health agencies, and consumers.

This study aimed to determine the occurrence of aflatoxin contamination in peanuts and peanut butter sold in informal markets of Chitungwiza to assess the potential public health risks linked to their consumption.

1.3 Justification for the study

This study is crucial for public health and food safety in Zimbabwe. By generating empirical data on aflatoxin contamination in peanuts and peanut butter from informal markets, the research will inform risk assessment efforts and guide the implementation of food safety regulations. Understanding the prevalence of aflatoxin in these markets is vital for public health policy, especially in a country where peanuts and peanut butter are staple foods. It will also provide a basis for health education campaigns aimed at both consumers and vendors, promoting safer storage and handling practices. Secondly, given the limited regulation and oversight of informal markets, this study will provide valuable insights into the risks associated with informal food trade and the effectiveness of current safety protocols in preventing aflatoxin contamination (Ssemanda et al., 2020).

This research will contribute to a broader understanding of how informal markets in developing countries can be better regulated and monitored to reduce food safety risks. This is particularly important in the context of rising concerns over food security, public health, and the growing informal economy. Finally, the findings could inform public health campaigns and regulatory frameworks aimed at minimizing aflatoxin exposure, thereby protecting vulnerable populations, especially children, from its harmful effects (Bhat & Vasanthi, 2003)

1.4 Aim of Study

This study aimed to establish the occurrence and levels of aflatoxin contamination in peanuts and peanut butter sold in an informal market in Chitungwiza, thereby determining the potential health risks associated with consuming aflatoxin-contaminated products, informing food safety policies and interventions.

1.5 Research Objectives

- To assess the prevalence of aflatoxin contamination in peanuts and peanut butter obtained from informal markets in Chitungwiza.
- To measure the concentrations of aflatoxins present n peanut and peanut butter samples.

- ❖ To compare aflatoxin levels with international safety standards (e.g., WHO and Codex Alimentarius).

1.6 Research Questions

- ➢ To what extent are peanuts and peanut butter from Chitungwiza's informal markets contaminated with aflatoxins?
- ➢ What are the concentrations of aflatoxins in peanuts and peanut butter samples as determined by HPLC?
- ➢ Do the contamination levels exceed international safety thresholds?
- ➢ What are the storage and handling practices of vendors that might influence aflatoxin levels?

1.7 Hypotheses

Ho: Aflatoxin contamination in peanuts and peanut butter from Chitungwiza’s informal market is not significant.

H1: Aflatoxin contamination in peanuts and peanut butter from Chitungwiza’s informal market is significant.

1.8 Significance of the study

This study is of critical importance for public health, food safety, and regulatory policymaking in Zimbabwe and other similar settings. Aflatoxins, toxic metabolites produced by certain *Aspergillus* species, pose serious health risks including hepatocellular carcinoma, immunosuppression, and stunted growth in children (Wild & Gong, 2010). By focusing on the informal markets in Chitungwiza, the research targets a supply chain that is often overlooked yet widely accessed by low-income populations who may be more vulnerable to aflatoxin exposure (Njumbe Ediage et al., 2014).

Given that peanuts are a staple food and widely used in household cooking and commercial food production, assessing aflatoxin contamination levels provides data critical for consumer protection. Previous studies have shown that informal markets typically lack proper storage and quality control systems, creating favorable conditions for fungal growth and aflatoxin production (Kachapulula et al., 2017). This makes the study area a high-risk zone and therefore a vital target for food safety interventions.

1.9.1 Limitations

The study will be using HPC for aflatoxins analysis which is readily unavailable and costly. This will result in analysing only a small sample size. Small sample sizes may not be large enough to generalize findings to the entire population of peanut and peanut butter vendors in Chitungwiza (Creswell,2014). The study relies on self-reported data from vendors, which may be subject to biases and inaccuracies. The study to be conducted only in Chitungwiza, Zimbabwe, which is a relatively small geographical area, and the findings may not be generalized to other regions or cities (Bryman, 2016).

1.9.2 Delimitations

The study is being conducted in Chitungwiza, Zimbabwe, and the findings may not be applicable to other regions or countries. The study is focusing on informal market sources in Chitungwiza, excluding formal markets and supermarkets. The study is only examining peanuts and peanuts butter and does not include other crops or food. (Shephard, 2016).

1.10 Definition of terms

Aflatoxins: According to Wild & Gong (2010), aflatoxins are toxic secondary metabolites produced by certain species of *Aspergillus* fungi, commonly found in crops, particularly peanuts. They are known to be potent carcinogens and can pose significant health risks to humans and animals.

Aspergillus: They are a genus of fungi that are capable of producing aflatoxins, particularly *Aspergillus flavus* and *Aspergillus parasiticus* (Wild & Gong, 2010). *Aspergillus* species are widely distributed in the environment and are commonly found in soil, decaying organic matter, and crops.

Carcinogens: They are substances or agents that can lead to the development of cancer in humans (IARC, 2012). Aflatoxins are classified as Group 1 carcinogens by the Agency for Research on Cancer (IARC), meaning they are confirmed to be carcinogenic to humans.

CHAPTER 2

LITERATURE REVIEW

2.1 Biochemical Characteristics of Aflatoxins

Aflatoxins are a group of toxic secondary metabolites produced by moulds belonging to the *Aspergillus* species, mainly *Aspergillus flavus* and *Aspergillus parasiticus*, which frequently contaminate agricultural commodities such as peanuts and peanut butter (Yang et al., 2023). These mycotoxins are potent carcinogens and mutagens posing a significant risk to human health. The most prevalent aflatoxins in peanuts are aflatoxin B_1 (AFB_1), B_2, G_1, and G_2, with AFB_1 being the most toxic and commonly detected in contaminated samples. Aflatoxins are highly stable compounds that are resistant to heat, acidic conditions, and many processing techniques commonly used in the food industry. This makes them difficult to eliminate once they have contaminated food products such as peanuts and peanut butter. Aflatoxin's biochemical structure includes a difuranocoumarin ring system, which is responsible for their carcinogenic properties. The levels of aflatoxins in food products such as peanuts and peanut butter can be determined using analytical methods including high-performance liquid chromatography (HPLC) and enzyme-linked immunosorbent assay (ELISA). Regulatory agencies around the world have established maximum levels for aflatoxins in food products to ensure consumer safety and prevent health risks associated with their consumption.

2.2 Pathways of Contamination in Peanuts and Peanut Butter

The contamination of peanuts and peanut butter with aflatoxins can occur at various stages, including pre-harvest, post-harvest, storage, processing, insects and rodents. (Ling et al., 2015). In Zimbabwe, approximately 75% of peanuts are cultivated by smallholder farmers, often under conditions that favour fungal growth and subsequent aflatoxin contamination such as high humidity and temperature, and results in the growth of *Aspergillus* species on the peanut plants. Post-harvest conditions, including improper drying, storage, and handling, further exacerbate contamination risks. During processing, inadequate roasting, blanching, and grinding can fail to eliminate aflatoxins, leading to their persistence in the final peanut butter product. During storage, improper temperature and humidity levels can create conditions favourable for molds growth, which can produce toxins like aflatoxin, a potent carcinogen that can contaminate peanuts and peanut butter. Additionally, insects such as stored product pests like beetles and moths, as well as rodents, can also introduce contaminants into peanuts and peanut butter during storage if proper pest control measures are not implemented (Chattopadhyay, 2017). Therefore, it is essential for producers and

manufacturers to adhere to strict quality control protocols throughout the entire production chain to ensure the safety and quality of peanuts and peanut butter for consumers.

2.3 Health Implications to humans

The high prevalence of aflatoxin contamination in peanuts and peanut butter from informal markets poses a significant public health risk, especially considering the widespread consumption of these products in Zimbabwe. The lack of formal safety inspections in informal markets exacerbates the potential for exposure (Masaka et al., 2022). Aflatoxins have been linked to a variety of health problems in humans, including liver damage, immune suppression, and an increased risk of liver cancer (Liu and Wu, 2010). Aflatoxins, particularly aflatoxin B_1 (AFB_1), are recognized as some of the most potent naturally occurring carcinogens affecting humans. These toxic secondary metabolites, mainly produced by *Aspergillus flavus* and *Aspergillus parasiticus*, are associated with a variety of acute and chronic health outcomes. Consumption of aflatoxins may result in acute toxicity, with symptoms ranging from nausea and vomiting to liver failure in severe cases. Prolonged exposure to aflatoxins, particularly, AFB_1, is associated with serious health issues such as hepatocellular carcinoma, immunosuppression, and stunted growth in children.

2.3.1 Acute Toxicity

Consumption of large amounts of aflatoxins can lead to acute aflatoxicosis, which is characterized by vomiting, abdominal pain, hepatitis, jaundice and death due to liver failure. A significant outbreak of acute aflatoxicosis was reported in Kenya in 2004, where 125 deaths was reported among 317 cases due to consumption of aflatoxin-contaminated maize (Lewis et al., 2015). The outbreak was linked to poor storage practices, which contributed to high aflatoxin levels exceeding 4000 µg/kg in some maize samples, far above the acceptable limits.

2.3.2 Chronic Toxicity and Liver Cancer

Long -term exposure to low concentrations of aflatoxins, especially AFB_1, has been strongly associated with the development of hepatocellular carcinoma (HCC). This risk is notably higher in populations with high prevalence of hepatitis B virus (HBV) infection. A well- established synergistic interaction between chronic HBV and aflatoxin exposure has been reported in regions such as The Gambia and China, where studies showed that individuals co-infected with HBV and exposed to high aflatoxin levels had a 30-fold increased risk of developing liver cancer compared to unexposed individuals (Liu & Wu, 2010).

In Tanzania, research by Shirima et al. (2013) found that schoolchildren exposed to chronic dietary aflatoxin through maize and groundnuts had detectable levels of aflatoxin-albumin adducts in their blood, indicating prolonged exposure. While immediate symptoms will be not evident, long-term consequences included impaired liver function, growth retardation, and immune suppression.

2.3.3 Child Growth and Development

Aflatoxin exposure has also been associated with stunted growth in children. In a study conducted Benin and Togo, Gong et al. (2004) reported that children with the highest quartile of aflatoxin-albumin levels in their blood had significantly reduced height-for-age Z-scores. This correlation suggested a dose-dependent effect of aflatoxin on growth impairment, likely due to intestinal inflammation, reduced nutrient absorption, and systemic toxicity.

2.3.4 Immunosuppression and Nutritional Impacts

Aflatoxins have been found to weaken the immune system, thereby making individuals more susceptible to infectious diseases. Chronic exposure compromises both cell-mediated and humoral immunity, which can be particularly dangerous in children and immunocompromised individuals. (Liu and Wu, 2010). In rural Ghana, children with higher aflatoxin exposure demonstrated lower levels of protective immunoglobulins following vaccination, raising concerns about vaccine efficacy in aflatoxin-endemic areas.

2.3.5 Global Findings

Globally, aflatoxin contamination is a significant public health concern in South-East Asia, Latin America, and sub-Saharan Africa. In China, the Qidong region has historically experienced some of the highest rates of HCC, attributed to aflatoxin-contaminated food and HBV infection (Liu & Wu, 2010). Interventions such as dietary diversification and improved storage have helped reduce liver cancer incidence in those areas, highlighting the importance of prevention.

In the United States, although regulations and food monitoring programs are in place, aflatoxin outbreaks occasionally occur, particularly in imported foods or during extreme weather events that promote fungal

growth. The U.S. Food and Drug Administration (FDA) limits total aflatoxin levels in food to 20 µg/kg, and strict monitoring helps prevent widespread exposure (Wild & Gong, 2010).

2.4 Food Safety Policies and Control Systems in Informal Markets

The regulation of aflatoxin levels in peanuts and peanut butter is critical for ensuring consumer safety and public health. While formal markets are often subject to stringent regulations and monitoring, informal markets often lack stringent enforcement of food safety policies and regulatory frameworks, leading to greater risks of aflatoxin exposure (Kitya et al., 2018).

In Zimbabwe, for instance, the maximum allowable limit for AFB_1 in peanut butter is 15µg/kg; however, studies have shown that a significant proportion of samples from informal markets exceed this limit. The lack of enforcement and resources in informal markets hampers effective control of aflatoxin contamination. Addressing these gaps in the regulatory framework is essential in mitigating aflatoxin contamination in informal market sources.

2.5 Analytical Methods for Aflatoxin Detection

Accurate quantification of aflatoxins in agricultural commodities like peanuts and peanut butter is critical for consumer safety and regulatory enforcement. Several analytical techniques are utilized, each with distinct advantages and limitations. High-performance liquid chromatography (HPLC) coupled with fluorescence or ultraviolet detection is widely considered the gold standard due to its high sensitivity, precision, and ability to separate and quantify individual aflatoxin isomers (AFB_1, AFB_2, AFG_1, and AFG_2) (Turner et al., 2015). Despite its precision, HPLC requires sophisticated laboratory infrastructure, expensive reagents, and trained personnel, making it less accessible for routine screening in resource-limited settings (Magwaza et al., 2016). Conversely, enzyme-linked immunosorbent assay (ELISA) offers a rapid, cost-effective, and user-friendly alternative for screening large volumes of samples, though it is sometimes prone to cross-reactivity and matrix interference. Understanding these analytical frameworks is essential for evaluating the true extent of contamination in informal market products where surveillance is minimal.

2.6 Research Gaps and Conclusion

Although previous studies have examined aflatoxin contamination in peanuts and peanut butter, several research gaps remain. These include the need for further studies on the specific sources of contamination in informal markets and the effectiveness of interventions to reduce aflatoxin levels in these products. Additionally, more research is required to evaluate the impact of informal market practices on aflatoxin contamination and to develop targeted interventions. By addressing these gaps, this study aims to contribute to the existing body of knowledge on aflatoxin contamination in peanut products from informal market sources in Chitungwiza. This literature review highlights the critical need for enhanced regulatory frameworks and monitoring systems to address aflatoxin contamination in informal markets, aligning with the objectives of the current study to assess and mitigate aflatoxin risks in Chitungwiza's informal peanut sector.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area and Sampling

This study was conducted in Chitungwiza, a densely populated urban area situated southeast of Harare, Zimbabwe. Samples of peanuts and peanut butter were collected from informal market sources of Chitungwiza in April 2026. Informal markets that serve as important sources of agricultural products, such as peanuts and peanut butter were selected based on high trading activity and vendor diversity. Twenty samples were collected, consisting of 10 raw peanut samples and 10 peanut butter samples, all obtained from informal vendors who operate outside the scope of formal food safety regulation.

3.2 Sample Preparation

A random sampling method was used to ensure that the collected samples fairly represent the different parts of the market area. First, markets were randomly selected from three specific locations which are Seke, Zengeza, and St Mary's. Then individual vendors within each of these areas were also picked at random.

All collected samples were then ttransported to the laboratory in sterile, zip-locked polyethylene bags and stored at 4 °C prior to analysis. In preparation for testing, the raw peanuts were ground into a fine powder using a mortar and pestle, while peanut butter samples were thoroughly manually homogenized. Each sample was weight to aapproximately 10 grams for extraction and subsequent analysis.

3.3 Aflatoxin Extraction

To determine aflatoxin levels in peanuts and peanut butter, the extraction and cleanup procedures were described based on the method used by Masaka et al. (2022). In this approach, samples were first homogenised to ensure uniform particle size. Approximately 10 g of each blended peanut or peanut butter subsample was weighed into a 50 mL centrifuge tube. Approximately 10 mL of acidified methanol was then added to each tube, and the mixture was thoroughly homogenised using a laboratory blender or homogeniser to extract the aflatoxins. The mixture was centrifuged at 3500 rpm for 12 minutes at 4 °C to isolate the extract from solid particles.

To eliminate fats and other interfering substances from the extract, 1.5 g of barium sulphate ($BaSO_4$) and 0.5 g of C18 sorbent were introduced into the supernatant followed by vortex mixing. The mixture was then centrifuged again at 3500 rpm for 12 minutes at 4 °C. The clarified supernatant was pipetted into glass tubes

and dried under a stream of nitrogen gas at 30 °C. The dried residue was re- dissolved in 500 µL of acetonitrile, vortexed, and filtered through a 0.2 µm polytetrafluoroethylene membrane filter into HPLC vials for instrumental analysis of aflatoxins.

3.4 High-Performance Liquid Chromatography (HPLC) Analysis

Quantification of aflatoxins was performed using reversed-phase high-performance liquid chromatography (RP-HPLC) coupled with fluorescence detection following derivatization, following with validated procedures described by Mupunga et al. (2014). Chromatographic separation was conducted using a C18 column (250 × 4.6 mm, 5 µm particle size). The mobile phase comprised water, methanol, and acetonitrile in the ratio of 60:20:20 (v/v/v) and was delivered at a flow rate of 1.0 mL/min. Pre-column derivatization was carried out using trifluoroacetic acid to enhance the fluorescence response of aflatoxins B1 and G1. Detection was performed with a fluorescence detector set at an excitation wavelength of 365 nm and an emission wavelength of 435 nm. Quantification was based on external calibration using certified aflatoxin standards (B1, B2, G1, and G2) obtained from Sigma-Aldrich. Calibration curves were constructed over a concentration range of 1–100 µg/kg, with linear regression coefficients (R^2) greater than 0.99. Aflatoxin concentrations in the samples were calculated by comparing the peak areas with those of the corresponding standards.

3.5 Data Analysis

Data analysisis was performed using Statistical Package for Social Science (SPSS- Version20):

First, descriptive statistics, including mean, standard error, and range of aflatoxin levels, were calculated for each type of sample (raw peanuts and peanut butter).

Next, an ANOVA test was used to compare the average aflatoxin concentrations from different vendors, across the different sample types, and under various storage conditions.

Lastly, the percentage of samples that exceeded the legal limits set by the Zimbabwe Ministry of Health, (15 µg/kg for Aflatoxin B1 and 20 µg/kg for total aflatoxins) was determined, following the standards referenced by Mupunga et al. (2014).

3.6 Quality Control and Assurance

Quality assurance measures were implemented throughout the analytical procedure to ensure the accuracy, reliability, and reproducibility of the results. Certified reference standards of aflatoxins were employed for calibration and method validation. Method blanks were included during analysis to monitor possible contamination, while recovery studies were conducted by spiking aflatoxin-free samples with known concentrations (10 µg/kg) of aflatoxins B1, B2, G1, and G2 to evaluate extraction efficiency and analytical accuracy. Duplicate analyses were performed on 10% of the total samples to assess method precision and reproducibility. The limits of detection (LOD) and limits of quantification (LOQ) were determined as at 0.5 µg/kg and 1.5 µg/kg, respectively, based on previously validated methods reported by Park et al., (2024). Recovery rates for all aflatoxins ranged from 75% to 105%, which fall within acceptable analytical limits as reported by Siwela et al., (2011). These quality control procedures are consistent with validated analytical approaches and ensure the generation of reliable results comparable to those reported by Mupunga et al., (2014).

CHAPTER 4

RESULTS

4.1 Overview of Aflatoxin Occurrence

Evaluating the occurrence and concentration of four major aflatoxins in Raw Peanuts and Peanut Butter samples obtained from informal markets in Chitungwiza (Seke, Zengeza and St Mary's). A total of 20 samples were analysed, comprising 10 raw peanut samples and 10 peanut butter samples as shown in table 4.1. Seke, Zengeza and St Mary's had each three, four and three samples respectively. Overall, aflatoxin contamination was detected in all sampling locations although concentrations varied between product type and location. Peanut butter samples showed exhibited higher frequency levels than raw peanuts.

Aflatoxins were detected in 70% of raw peanut samples (7 out of 10), while 100% of peanut butter samples (10 out of 10) were contaminated. Overall, results indicated that the results were wide spread across all sample locations although the extent of the contamination varied between sample types and location. Across all locations, AFB_1 was the most frequently detected aflatoxin followed by AFB_2 and AFG_1 while AFG_2 occurred less frequently.

Seke samples (P1–P3 and A1–A3) exhibited the highest levels and diversity of aflatoxin contamination, with several samples showing extremely elevated concentrations. Zengeza samples (P4–P7 and A4–A7) displayed moderate but variable contamination, including both low and very high values, suggesting inconsistent handling or storage practices among vendors. In contrast, St Mary's samples (P8–P10 and A8–A10) generally showed lower contamination levels, with some raw peanut samples recording not detectable (ND) aflatoxins.

Table 1: Mean (± SE) Aflatoxin Concentrations (µg/kg) in Peanut samples

Location	Sample Type	Sample	AFB_1	AFB_2	AFG_1	AFG_2	Total
Seke	Raw Peanuts	P1	27.7±0.69	ND	ND	ND	27.7±0.69
		P2	88.03±1.39	ND	328.83±4.47	ND	416.87±5.85
		P3	3.0±0.12	ND	24.2±0.44	ND	27.2±0.55
Zengeza		P4	15.83±0.35	ND	11.73±0.23	ND	27.57±0.58
		P5	2.03±0.09	60.33±	17.47±0.38	ND	79.83±1.10
		P6	ND	ND	ND	ND	ND
		P7	1.3±0.06	ND	ND	ND	1.3±0.06
St Mary's		P8	ND	ND	ND	ND	ND
		P9	ND	27.6±	ND	ND	ND
		P10	34.83±0.78	ND	ND	ND	34.83±0.78
		Mean	24.7±8.99	43.97±16.37	95.56±52.01	ND	87.9±95.56
		Minimum	ND	ND	ND	ND	ND
		Maximum	88.0	60.3	328.8	ND	416.9

Table 2: Mean (± SE) Aflatoxin Concentrations (µg/kg) in Peanut butter samples

Location	Sample Type	Sample	AFB_1	AFB_2	AFG_1	AFG_2	Total
Seke	Peanut Butter	A1	167.63±2.86	40.20±0.75	157.57±2.60	35.23±0.61	400.63±6.81
		A2	95.37±1.65	19.77±0.49	90.17±1.50	70.33±1.19	275.63±4.83
		A3	70.0±1.27	10.5±0.23	72.4±1.27	71.8±1.08	224.7±3.84
Zengeza		A4	376.4±5.93	ND	50.57±0.93	ND	426.97±6.86
		A5	144.63±2.76	ND	42.33±0.90	ND	186.97±3.65
		A6	26.53±0.72	ND	ND	ND	26.53±0.72
		A7	68.7±1.10	7.23±0.20	ND	ND	75.93±1.30
St Mary's		A8	27.37±0.72	ND	ND	ND	27.37±0.72
		A9	13.9±0.40	ND	ND	ND	13.9±0.40
		A10	10.37±0.32	ND	ND	ND	10.37±0.32
		Mean	100.09±37.72	19.43±6.89	82.61±23.19	59.12±14.61	166.9±59.12
		Minimum	10.37	ND	ND	ND	10.37
		Maximum	376.4	40.2	157.57	71.8	426.97

4.2 Aflatoxin Levels in Raw Peanut Samples

Out of the 10 raw peanut samples analysed, 7 samples (70%) tested positive for at least one type of aflatoxin, while 3 samples (30%) showed no detectable levels. The total aflatoxin concentrations ranged from not detected (ND) to 416.87 µg/kg, with a mean concentration of approximately 87.9 ± 95.56 µg/kg. The highest contamination was observed in sample P2 (416.87µg/kg), largely due to high levels of AFG_1 (328.83 µg/kg). Aflatoxin B_1 (AFB_1), the most toxic variant, was detected in several samples, with values ranging from ND to 88.03 µg/kg. This indicates that while contamination is common, it is not uniform, suggesting variability in the source of peanuts, storage conditions, and duration of storage.

4.2.1 Variability in Aflatoxin Levels

The raw peanut samples exhibited significant variability in total aflatoxin concentrations across different sampling locations (Seke, Zengeza, and St Mary's). Some samples showed low or not-detected levels of aflatoxins, while others had very high concentrations. AFB_1 was the dominant aflatoxin type in Raw Peanuts while the other aflatoxin types were detected less frequently and at lower concentrations.

4.3 Aflatoxin Levels in Peanut Butter Samples

The analysis of peanut butter samples (A1–A10) revealed a higher prevalence and concentration of aflatoxins compared to raw peanuts, indicating that processed peanut products pose an even greater food safety concern. All ten peanut butter samples (100%) contained detectable levels of aflatoxins, demonstrating universal contamination within this sample category.

Total aflatoxin concentrations in peanut butter ranged from 10.37 to 426.97 µg/kg, with a mean concentration of approximately 166.9 ± 59.12 µg/kg, which is more than double the mean observed in raw peanut samples. Several samples showed extremely high contamination, particularly A4 (426.97 µg/kg) from Zengeza and A1 (400.63 µg/kg) from Seke, indicating severe exposure risk. Aflatoxin B_1 was tested positive in all peanut butter samples, with concentrations reaching as high as 376.4 µg/kg. In addition, peanut butter samples exhibited a more diverse aflatoxin profile, with frequent co-occurrence of AFB_1, AFB_2, AFG_1, and AFG_2, especially in samples A1–A3 from Seke. Location-based analysis revealed that Seke (A1–A3) had the highest contamination levels, followed by Zengeza (A4–A7), while St Mary's (A8–A10) showed comparatively lower levels.

4.4 Comparison Between Raw Peanuts and Peanut Butter

The comparison between raw peanuts and peanut butter showed that peanut butter had a higher aflatoxin contamination level and a greater contamination frequency than raw peanuts. Peanut butter recorded a mean total aflatoxin concentration of 166.9±59.12µg/kg compared to 87.9±95.56µg/kg in raw peanuts, with contamination frequencies of 100% and 70% respectively. Peanut butter also showed a greater diversity of aflatoxins, including AFB_1, AFB_2, AFG_1 and AFG_2, whereas raw peanuts mainly contained AFB_1 and AFG_1.

Table 3: Comparison of Raw Peanuts vs Peanut Butter

Parameter	Raw Peanuts	Peanut Butter
Mean Contamination (µg/kg)	87.9± 95.56	166.9±59.12
Contamination Frequency (%)	70	100
Predominant Aflatoxins Detected	AFB_1 and AFG_1	AFB_1, AFG_1, AFG_2 and AFG_2
Overall Contamination Level	Lower	Higher

4.5 Aflatoxin Distribution by Location

Aflatoxins varied across all the three sampling locations. Seke had high concentration levels and greatest variability, while Zengeza had moderate but inconsistent contamination and St Mary's had the lowest contamination levels. Seke samples were highly contaminated with aflatoxins in both raw peanuts and peanut butter. Zengeza displayed a mixed contamination levels and St Mary's had lower concentrations.

4.5.1 Aflatoxin Distribution in Seke

Seke recorded the greatest distribution of aflatoxins among the three sampling locations. Both raw peanut and peanut butter samples from this location contained multiple aflatoxin types, including AFB_1, AFB_2, AFG_1 and AFG_2. According to the Appendix Tables, peanut butter samples A1, A2 and A3 showed high total aflatoxin concentrations of 400.63 ± 6.81 µg/kg, 275.63 ± 4.83 µg/kg and 224.7 ± 3.84 µg/kg, respectively. Raw peanut sample P2 also recorded a high total aflatoxin concentration of 416.87 ± 5.85 µg/kg. AFB_1 and AFG_1 were the most widely distributed aflatoxins within this location.

4.5.2 Aflatoxin Distribution in Zengeza

Zengeza showed moderate to high aflatoxin distribution across both raw peanut and peanut butter samples. Peanut butter sample A4 recorded the highest total aflatoxin concentration within this location at 426.97 ± 6.86 µg/kg, followed by A5 with 186.97 ± 3.65 µg/kg and A7 with 75.93 ± 1.30 µg/kg. In raw peanuts, sample P5 recorded the highest total aflatoxin concentration of 79.83 ± 1.10 µg/kg, while samples P4 and P7 showed lower contamination levels and P6 had no detectable aflatoxins. AFB_1 was the predominant aflatoxin in most samples from Zengeza.

4.5.3 Aflatoxin Distribution in St Mary's

St Mary's showed the lowest aflatoxin distribution compared to Seke and Zengeza. Most raw peanut samples had no detectable aflatoxins, except for sample P9 which contained AFB_2 at 27.6 ± 0.46 µg/kg and sample P10 which contained AFB_1 at 34.83 ± 0.78 µg/kg. Peanut butter samples from this location similarly exhibited low levels of contamination, with total aflatoxin levels ranging from 10.37 ± 0.32 µg/kg to 27.37 ± 0.72 µg/kg. Fewer aflatoxin types were detected in samples from St Mary's, indicating lower aflatoxin distribution within this location.

4.6 Statistical Analysis

4.6.1 Analysis of Variance (ANOVA) Results

The two-way analysis of variance (ANOVA) performed to evaluate the effects of product type (raw peanuts versus peanut butter), and sample locations (Seke, Zengeza, and St Mary's), and their interaction on aflatoxin concentration, indicated variation in mean aflatoxin concentrations between both product types and locations. Peanut butter samples had a higher mean aflatoxin concentration (177.0µg/kg) compared to raw peanuts (68.2µg/kg), although the variability within groups was relatively high. When analysed by location, Seke recorded the highest mean aflatoxin level (228.8 µg/kg), followed by Zengeza (124.6 µg/kg), while St Mary's had the lowest contamination levels (14.4 µg/kg).

The ANOVA results (Appendix X) showed that product type did not have a statistically significant effect on aflatoxin concentration ($F = 3.15$, $p = 0.101$, $F_{(crit)} = 4.75$). Although peanut butter exhibited a higher mean concentration than raw peanuts, this difference was not significant at the 5% level, likely due to high variability within the sample groups. In contrast, sampling location had a statistically significant effect on aflatoxin levels ($F = 4.08$, $p = 0.0446$, $F_{(crit)} = 3.89$). The results indicate that aflatoxin contamination varied significantly across the three locations. However, the interaction between product type and location was not

statistically significant ($p > 0.05$), indicating that the effect of location on aflatoxin concentration was consistent for both raw peanuts and peanut butter.

CHAPTER 5

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Overview of Aflatoxin Occurrence

The results indicated widespread aflatoxin contamination in both raw peanuts and peanut butter obtained from informal markets in Chitungwiza. Contamination was detected in all sampling locations, although the concentration and frequency varied between products and locations. Peanut butter samples showed higher contamination levels and frequency compared to raw peanuts. These findings agree with previous studies which reported that peanuts and peanut- based products are highly susceptible to aflatoxin contamination due to their high oil content and favourable conditions for fungi growth (Williams et al., 2004).

The high occurrence of aflatoxins observed in this study may be associated with poor post-harvest handling practices, high moisture content, inadequate drying, and poor storage conditions. According to the Food and Agriculture Organization (FAO, 2020), aflatoxin contamination commonly develops during storage when peanuts are exposed to warm temperatures and high humidity. Informal market systems often lack proper storage infrastructure, increasing the risk of fungal growth and toxin production.

Detection of several aflatoxin types in single samples indicates contamination with several fungal species, particularly, *Aspergillus flavus,* which produces AFB_1 and AFB_2, and *Aspergillus parasiticus* which produces AFB_1, AFB_2, AFG_1 and AFG_2. These fungi thrive in the warm and humid environments found in many parts of sub-Saharan Africa, including Zimbabwe. Drought during crop development and high moisture during storage are environmental stress factors which promote fungal colonisation and toxin production (Guchi, 2015).

Across all samples, aflatoxin B_1 (AFB_1) was the most frequently detected aflatoxin. This finding is consistent with studies by Matumba et al. (2015), which identified AFB_1 as the dominant aflatoxin in peanuts and peanut products. AFB_1 is considered the most toxic and carcinogenic aflatoxin and poses serious public health concerns due to its association with liver cancer, immune suppression and stunted growth in children (IARC, 2015).

5.2 Aflatoxins in Raw Peanut Samples

70% of raw peanut samples contained detectable aflatoxins as analysed in this study. The total aflatoxin concentrations ranged from non-detectable levels to extremely high concentration of 416.87µg/kg. These levels greatly exceed the maximum limits recommended by international food safety standards such as EU limit of 4µg/kg for total aflatoxins in peanuts meant for direct human consumption (European Commission, 2010).

The high contamination observed in sample P2 may indicate poor drying and storage conditions before marketing. Fungal species such as *Aspergillus flavus* and *Aspergillus parasiticus* are capable of producing aflatoxins under conditions of high moisture and temperature (Klich, 2007). Variability in contamination levels among samples suggests differences in storage duration, handling practices, and environmental exposure.

AFB_1 was the most prevalent aflatoxin detected in raw peanuts. Similar findings were reported by Njoroge et al. (2017) in Kenya and Monyo et al. (2012) in Southern Africa, where AFB_1 was commonly associated with

improperly stored peanuts. The detection of AFB_1 in some samples also indicates contamination by *Aspergillus parasiticus*, which produces both B and G aflatoxins.

5.3 Aflatoxin Levels in Peanut Butter Samples

Peanut butter samples showed higher contamination levels than raw peanuts, with all samples testing positive for at least one aflatoxin. The mean total aflatoxin levels in peanut butter were approximately double that observed in raw peanuts. These findings suggest that processing does not eliminate aflatoxins and may even concentrate them in the final product.

Research conducted by Kaaya and Warren (2005), reported similar trends where processed peanut products contained higher aflatoxin concentrations than raw peanuts. During peanut butter production, contaminated kernels may be mixed together, resulting in increased toxin accumulation in the processed product. In addition, aflatoxins are heat stable compounds and can survive roasting and grinding processes commonly used during peanut butter preparation (Benkerroum, (2020).

The occurrence of all four aflatoxins (AFB_1, AFB_2, AFG_1, and AFG_2) in several peanut butter samples indicates severe fungal contamination. Sample A4 from Zengeza recorded the highest total aflatoxin concentration (426.97µg/kg), suggesting extremely poor-quality raw materials or storage conditions. Such contamination levels represent a serious food safety risk to consumers, especially since peanut butter is widely consumed by children and adults.

5.4 Comparison Between Raw Peanuts and Peanut Butter

The comparison between raw peanuts and peanut butter showed that peanut butter had both a higher contamination frequency and higher mean aflatoxin concentration. Peanut butter also showed a greater diversity of aflatoxins compared to raw peanuts. These results support findings from previous studies which demonstrated that processed peanut products are often more contaminated because processors may use lower quality or damaged peanuts that are already contaminated (Matumba et al.,2015; Misihairabgwi et al., 2017).

Although peanut butter showed higher mean aflatoxin levels, the statistical analysis indicated that the difference between product types was not significant at the 5% level. This may have been due to the high variability among samples within each product category. Similar variability has been reported in studies

contacted in informal food markets where handling and storage practices differ widely between vendors (Monyo et al.,2012).

The universal contamination observed in peanut butter samples highlights the need for improved monitoring and regulation of locally processed peanut products sold in informal markets.

5.5 Aflatoxin Distribution by Location

Aflatoxin levels varied significantly across the three sampling locations. Seke recorded the highest contamination levels, followed by Zengeza, while St Mary's showed the lowest contamination. The ANOVA analysis confirmed that sampling location had a statistically significant effect on aflatoxin concentration ($p<0.05$).

The high contamination levels observed in Seke may be related to poor storage facilities, prolonged storge duration, and environmental conditions favourable for fungal growth. Similar studies in Zimbabwe and other African countries have shown that aflatoxin contamination is strongly influences by storage environment, temperature, humidity, and market handling practices (Matumba et al.,2915; Misihairabgwi et al., 2017).

Zengeza showed moderate but consistent contamination levels, indicating differences in vendor handling practices and peanut sources. Some samples exhibited very high aflatoxin concentrations while others showed little or no contamination. This variability may reflect inconsistent quality control measures within informal markets.

St Mary's recorded the lowest aflatoxin concentrations among the three locations. The lower contamination may indicate better storage conditions, shorter storage periods, or improved peanut quality. However, detectable aflatoxin levels were still present in some samples, showing that contamination remains a public health concern even in areas with lower overall levels.

5.6 Public Health Implications

The aflatoxin concentrations detected in thus study exceed recommended international safety limits and therefore pose serious health risks to consumers. Chronic exposure to aflatoxins has been associated with liver cancer, immune suppression, malnutrition, and stunted growth in Children (IARC, 2015; WHO,2018). AFB_1, the dominant toxin detected, is recognized aas a Group 1 ccarcinogen to humans by the International

Agency for Research on Cancer. The widespread contamination observed in peanut butter is particularly concerning because peanut butter is frequently consumed by children and households in Zimbabwe.

Continued cconsumption of contaminated products may elevate long-term health risks among consumers. These findings highlight the importance of strengthening food safety monitoring systems, improving storage practices, and increasing public awareness regarding aflatoxin contamination in informal markets.

5.7 CONCLUSIONS

This study evaluated the occurrence and concentration of aflatoxins in raw peanuts and peanut butter obtained from informal markets in Chitungwiza, namely Seke, Zengeza and St Mary's. The findings revealed widespread aflatoxin contamination across all sampling locations, although contamination levels varied according to product type and location. Peanut butter samples indicated higher mean aflatoxin levels than raw peanut samples. All peanut butter samples analysed (100%) contained detectable aflatoxins, while 70% of raw peanut samples were contaminated. Peanut butter exhibited a wider range of aflatoxins, including AFB_1, AFB_2, AFG_1 and AFG_2, whereas, raw peanuts were predominantly contaminated with AFB_1 and AFG_1. These findings indicate that factors such as processing, handling and storage conditions may contribute to increased aflatoxin contamination in peanut butter.

Among the aflatoxins detected, AFB_1 was the most frequently occurring and predominant toxin in both raw peanuts and peanut butter. The presence AFB_1 is a serious public health concern due to its high toxicity and carcinogenic nature. Several samples record aflatoxin concentrations far above internationally accepted safety limits, indicating a potential health risk to consumers.

Location also had a significant influence on aflatoxin contamination. Seke recorded the highest contamination levels and greater variability, followed by Zengeza, while St Mry's showed lowest contamination levels. The significant differences observed between locations suggest that environmental conditions, storage practices, and handling methods may influence aflatoxin contamination levels.

The ANOVA results showed that sampling location had a statistically significant effect on aflatoxin concentration, whereas product type did not show a statistically significant difference at the 5% level, despite peanut butter having higher mean contamination levels, The interaction between product type and sampling location not statistically significant, indicating that location influences contamination similarly in both raw peanuts and peanut butter.

Overall, the study revealed that aflatoxin contamination is common in peanuts and peanut butter sold in informal markets in Chitungwiza and may pose serious food safety and public health risks to consumers.

5.8 RECOMMENDATIONS

1. **Agricultural Level**

Farmers should be encouraged to implement good agricultural practices (GAP) to reduce aflatoxin contamination in peanuts These practices include timely harvesting, proper pest control, and maintaining field hygiene to minimize fungal infection before and during harvesting. Rapid and efficient drying of peanuts and immediately after harvest should also be promoted because high moisture levels favour the growth of *Aspergillus* species responsible for aflatoxin production. In addition, the introduction and cultivation of resistant peanut verities may help reduce susceptibility to fungal contamination and improve crop quality and safety.

2. **Post-Harvest Handling**

Improved post-harvest handling practices are necessary to minimize aflatoxin contamination during storage and transportation. Storage facilities should be enhanced to maintain suitable temperatures and moisture conditions that prevent fungal growth. The use of hermetic storage technologies is also recommended, as these systems help reduce oxygen availability and inhibit mould development. Furthermore, farmers, traders, and dealers should be educated on proper handling and storage practices to ensure that peanuts and peanut products remain safe for consumption throughout the supply chain.

3. **Processing Level**

At the processing level, strict quality control measures should be implemented during peanut butter production. Peanuts that are mouldy, damaged, discoloured, or of poor quality should be carefully sorted and removed before processing to reduce toxin contamination in the final product. Peanut butter manufacturers should establish effective quality assurance systems to monitor contamination levels during production. In addition, processors should avoid mixing peanuts from unidentified or low-quality sources, as this may increase the risk of aflatoxin contamination and compromise product safety.

4. **Public awareness and training**

Public awareness campaigns should be conducted to educate customers and vendors about the health risks associated with aflatoxin- contaminated foods. Vendors and processor should be trained on proper handling, drying, processing and storage practices to reduce fungal growth and aflatoxins. This enables adequate drying of peanuts before storage to minimise moisture and humidity which favours aflatoxin contamination.

5. **Policy and Regulation**

There is a need for stronger enforcement of aflatoxin regulations within informal markets to protect consumers from contaminated food products. Regulatory authorities should establish national aflatoxin

surveillance and monitoring programmes to regularly assess contamination levels in peanuts and peanuts products. Public awareness campaigns and educational programmes should be expanded to educate farmers, traders, processors, and consumers about the health risks associated with aflatoxin exposure and the importance of proper food safety practices.

6. Future Research

Future studies assessing the dietary exposure and health risks of aflatoxin consumption among consumers in informal markets are recommended. Studies should investigate the influence of seasonal and climatic factors on aflatoxin contamination in peanuts and peanuts products, as environmental conditions greatly affect fungal growth and toxin production. Research should also focus on developing affordable and effective detoxification methods that can reduce aflatoxin levels in contaminated products while maintaining food quality and safety. Such studies would contribute to improved food safety management and reduced healthy risks associated with aflatoxin exposure.

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Appendix

Appendix A: P1

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	27.8	ND	ND	ND	27.8

R2	26.5	ND	ND	ND	26.5
R3	28.9	ND	ND	ND	28.9
Average	27.7	ND	ND	ND	27.7
STDEM	0.69	ND	ND	ND	0.69

Appendix B: P2

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	88.6	ND	330.2	ND	418.8
R2	85.4	ND	320.5	ND	405.9
R3	90.1	ND	335.8	ND	425.9
Average	88.03	ND	328.83	ND	416.87
STDEM	1.39	ND	4.47	ND	5.85

Appendix C: P3

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	3	ND	24.1	ND	27.1
R2	2.8	ND	23.5	ND	26.3
R3	3.2	ND	25	ND	28.2
Average	3	ND	24.2	ND	27.2
STDEM	0.12	ND	0.44	ND	0.55

Appendix D: P4

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	15.9	ND	11.8	ND	27.7
R2	16.4	ND	12.1	ND	28.5
R3	15.2	ND	11.3	ND	26.5
Average	15.83	ND	11.73	ND	27.57
STDEM	0.35	ND	0.23	ND	0.58

Appendix E: P5

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total
R1	2	60.4	17.5	ND	79.9
R2	2.2	58.9	16.8	ND	77.9
R3	1.9	61.7	18.1	ND	81.7
Average	2.03	60.33	17.47	ND	79.83
STDEM	0.09	0.81	0.38	ND	1.10

Appendix F: P6

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total
R1	ND	ND	ND	ND	ND
R2	ND	ND	ND	ND	ND
R3	ND	ND	ND	ND	ND
Average	ND	ND	ND	ND	ND
STDEM	ND	ND	ND	ND	ND

Appendix G: P7

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total
R1	1.3	ND	ND	ND	1.3
R2	1.2	ND	ND	ND	1.2
R3	1.4	ND	ND	ND	1.4
Average	1.30	ND	ND	ND	1.30
STDEM	0.06	ND	ND	ND	0.06

Appendix H: P8

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total

R1	ND	ND	ND	ND	ND
R2	ND	ND	ND	ND	ND
R3	ND	ND	ND	ND	ND
Average	ND	ND	ND	ND	ND
STDEM	ND	ND	ND	ND	ND

Appendix I: P9

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	ND	27.6	ND	ND	27.6
R2	ND	26.8	ND	ND	26.8
R3	ND	28.4	ND	ND	28.4
Average	ND	27.6	ND	ND	27.6
STDEM	ND	0.46	ND	ND	0.46

Appendix J: P10

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	34.8	ND	ND	ND	34.8
R2	33.5	ND	ND	ND	33.5
R3	36.2	ND	ND	ND	36.2
Average	34.83	ND	ND	ND	34.83
STDEM	0.78	ND	ND	ND	0.78

Appendix K: A1

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	168.5	40.2	158.7	35.4	402.8
R2	162.3	38.9	152.6	34.1	387.9
R3	172.1	41.5	161.4	36.2	411.2

Average	167.63	40.20	157.57	35.23	400.63
STDEM	2.86	0.75	2.60	0.61	6.81

Appendix L: A2

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	95.6	19.8	90.3	70.5	276.2
R2	92.4	18.9	87.5	68.2	267
R3	98.1	20.6	92.7	72.3	283.7
Average	95.37	19.77	90.17	70.33	275.63
STDEM	1.65	0.49	1.50	1.19	4.83

Appendix M: A3

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	69.8	10.5	72.4	72.1	224.8
R2	67.9	10.1	70.2	69.8	218
R3	72.3	10.9	74.6	73.5	231.3
Average	70	10.5	72.4	71.8	224.7
STDEM	1.27	0.23	1.27	1.08	3.84

Appendix N: A4

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	378.6	ND	50.7	ND	429.3
R2	365.2	ND	48.9	ND	414.1
R3	385.4	ND	52.1	ND	437.5
Average	376.4	ND	50.57	ND	426.97
STDEM	5.93	ND	0.93	ND	6.86

Appendix O: A5

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total
R1	145.2	ND	42.3	ND	187.5
R2	139.6	ND	40.8	ND	180.4
R3	149.1	ND	43.9	ND	193
Average	144.63	ND	42.33	ND	186.97
STDEM	2.76	ND	0.90	ND	3.65

Appendix P: A6

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total
R1	26.5	ND	ND	ND	26.5
R2	25.3	ND	ND	ND	25.3
R3	27.8	ND	ND	ND	27.8
Average	26.53	ND	ND	ND	26.53
STDEM	0.72	ND	ND	ND	0.72

Appendix Q: A7

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total
R1	68.9	7.2	ND	ND	76.1
R2	66.7	6.9	ND	ND	73.6
R3	70.5	7.6	ND	ND	78.1
Average	68.7	7.23	ND	ND	75.93
STDEM	1.10	0.20	ND	ND	1.30

Appendix R: A8

Replicate	AFB_1	AFB_2	AFG_1	AFG_2	Total

R1	27.4	ND	ND	ND	27.4
R2	26.1	ND	ND	ND	26.1
R3	28.6	ND	ND	ND	28.6
Average	27.37	ND	ND	ND	27.37
STDEM	0.72	ND	ND	ND	0.72

Appendix S: A9

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	13.9	ND	ND	ND	13.9
R2	13.2	ND	ND	ND	13.2
R3	14.6	ND	ND	ND	14.6
Average	13.9	ND	ND	ND	13.9
STDEM	0.40	ND	ND	ND	0.40

Appendix T: A10

Replicate	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
R1	10.4	ND	ND	ND	10.4
R2	9.8	ND	ND	ND	9.8
R3	10.9	ND	ND	ND	10.9
Average	10.37	ND	ND	ND	10.37
STDEM	0.32	ND	ND	ND	0.32

Appendix U: Raw Peanuts Results with Mean, Min, and Max

Sample	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
P1	27.7	ND	ND	ND	27.7
P2	88.03	ND	328.83	ND	416.87
P3	3	ND	24.2	ND	27.2

P4	15.83	ND	11.73	ND	27.57
P5	2.03	60.33	17.47	ND	79.83
P6	ND	ND	ND	ND	ND
P7	1.3	ND	ND	ND	1.3
P8	ND	ND	ND	ND	ND
P9	ND	27.6	ND	ND	ND
P10	34.83	ND	ND	ND	34.83
Mean	24.7	43.965	95.5575	ND	87.9
Minimum	1.3	27.6	11.7	0.0	1.3
Maximum	88.0	60.3	328.8	0.0	416.9

Appendix V: Peanut Butter Results with Mean, Min, and Max

Sample	**AFB_1**	**AFB_2**	**AFG_1**	**AFG_2**	**Total**
A1	167.63	40.2	157.57	35.23	400.63
A2	95.37	19.77	90.17	70.33	275.63
A3	70	10.5	72.4	71.8	224.7
A4	376.4	ND	50.57	ND	426.97
A5	144.63	ND	42.33	ND	186.97
A6	26.53	ND	ND	ND	26.53
A7	68.7	7.23	ND	ND	75.93
A8	27.37	ND	ND	ND	27.37
A9	13.9	ND	ND	ND	13.9
A10	10.37	ND	ND	ND	10.37
Mean	100.09	19.425	82.608	59.12	166.9
Minimum	10.37	7.23	42.33	35.23	10.37
Maximum	376.4	40.2	157.57	71.8	426.97

Appendix W: Rearranged Data to Use in Two-Way ANOVA

	Seke	Zengeza	St Mary's
Raw Peanuts	27.7	27.57	0
Raw Peanuts	416.87	79.83	0
Raw Peanuts	27.2	0	34.83
Peanut Butter	400.63	426.97	27.37
Peanut Butter	275.63	186.97	13.9
Peanut Butter	224.7	26.53	10.37

Appendix X: Two-Way ANOVA Results

Raw Peanuts				
Count	3	3	3	9
Sum	471.77	107.4	34.83	614
Average	157.2567	35.8	11.612	68.22222
Variance	50549.37	1644.007	404.3763	17718.17

Peanut Butter

Count	3	3	3	9
Sum	900.96	640.47	51.64	1593.07
			17.2133	177.007
Average	300.32	213.49	3	8
	8195.03	40615.5	80.4836	27999.4
Variance	8	3	3	3

Total

Count	6	6	6
Sum	1372.73	747.87	86.47
	228.788		14.4116
Average	3	124.645	7
		26375.9	203.363
Variance	29637.9	4	2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	53254.3		53254.3	3.14838	0.10135	4.74722
Sample	4	1	4	7	3	5
	137909.		68954.5	4.07658	0.04456	3.88529
Columns	2	2	8	2	9	4
	24854.0		12427.0	0.73468		3.88529
Interaction	4	2	2	3	0.50004	4
	202977.					
Within	6	12	16914.8			
	418995.					
Total	2	17				