Analysis of Groundnuts Sold by Street Vendors in Gaborone for Hygiene and Aflatoxin Content

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ABSTRACT

Background: Street-vended foods are integral to urban food systems in developing countries, yet pose significant public health risks due to inadequate hygiene practices and contamination hazards. This study assessed the microbiological quality and aflatoxin contamination of ready-to-eat groundnuts sold by street vendors in Gaborone, Botswana.

Methods: A cross-sectional study was conducted among 37 street vendors operating in three commercial hubs of Gaborone between March and May 2019. Vendors were surveyed using structured questionnaires, and composite groundnut samples (one per vendor) were collected for laboratory analysis. Hygiene status was evaluated through enumeration of *Escherichia coli* using serial dilution and plating on selective agar. Aflatoxin concentrations (B1, B2, G1, G2) were quantified using Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS) following immunoaffinity column clean-up.

Results: All 37 composite samples (100%) exhibited unacceptable microbiological contamination, with *E. coli* counts ranging from 2.0×10^5 to 1.86×10^6 CFU/g (mean $8.42 \times 10^5 \pm 4.95 \times 10^5$ CFU/g), substantially exceeding the guideline threshold of $<1 \times 10^2$ CFU/g for ready-to-eat foods. Aflatoxin analysis revealed severe contamination, with 94.6% (35/37) of samples exceeding Botswana's regulatory limit of 10 µg/kg for total aflatoxins. Total aflatoxin concentrations ranged from below the detection limit to 1966.72 µg/kg, with aflatoxin B1 as the predominant congener. Key contributing factors identified included lack of vendor licensing (97.3%), sourcing from Zambia (81.1%), inadequate storage in non-breathable containers (59.5%), and absence of personal protective equipment (70.3%).

Conclusion: Street-vended groundnuts in Gaborone present a dual public health threat from biological and chemical contamination. The findings underscore systemic failures in food safety governance within the informal sector and suggest the need for integrated interventions spanning regulation, vendor education, infrastructure improvement, and supply chain management.

Keywords: Aflatoxin, Escherichia coli, Food Safety, Street Food, Groundnuts, Gaborone, Public Health

INTRODUCTION

The Global Context of Street Food Vending

The proliferation of street food vending represents a defining characteristic of urban food systems in developing nations, serving as both a vital source of affordable nutrition for millions of urban dwellers and a critical livelihood strategy for economically marginalised populations (Bhowmik, 2005; FAO, 2007). Across sub-Saharan Africa, South Asia, and Latin America, street foods contribute substantially to daily caloric intake, with estimates suggesting that they account for up to 40% of urban household food expenditure in some settings

(Dawson and Canet, 1991; Steyn and Labadarios, 2011). The sector is characterised by its accessibility, affordability, and cultural embeddedness, offering traditional and convenience foods that cater to the dietary preferences and economic constraints of low-income consumers who may lack access to formal food retail systems.

The global significance of street food vending has been increasingly recognised within the framework of the Sustainable Development Goals. Street vending contributes directly to SDG 8 (Decent Work and Economic Growth) by providing income generation opportunities, particularly for women who constitute the majority of vendors in many settings (Graffham et al., 2005; Cortese et al., 2016). It also supports SDG 2 (Zero Hunger) by improving food access for urban populations, and SDG 11 (Sustainable Cities and Communities) by contributing to the vibrancy and functionality of urban spaces (FAO, 2007). However, the sector simultaneously presents substantial challenges to SDG 3 (Good Health and Well-being), as the informal and often unregulated nature of street food vending creates conditions conducive to foodborne disease transmission (WHO, 2015).

Food Safety Challenges in Informal Food Systems

The public health concerns associated with street food are well documented in the international literature, centring on the frequent lack of basic infrastructure, including potable water, sanitation, and hygienic storage, and the absence of formal food safety training among vendors (Muinde and Kuria, 2005; Omemu and Aderoju, 2008; WHO, 2015). These structural deficits predispose street foods to microbiological contamination by pathogens and indicator organisms such as *Escherichia coli*, a direct marker of faecal contamination and poor hygiene practice (Ababio and Lovatt, 2015). Consumption of contaminated food remains a leading cause of diarrhoeal diseases globally, posing an acute health burden, particularly in urban settings where population density and limited infrastructure amplify transmission risks (Khairuzzaman et al., 2014).

The World Health Organization estimates that foodborne diseases cause approximately 600 million illnesses and 420,000 deaths annually worldwide, with the highest burden concentrated in low- and middle-income countries (WHO, 2015). Children under five years of age bear the greatest impact, accounting for nearly one third of all foodborne disease deaths. Beyond the immediate morbidity and mortality, foodborne illnesses impose substantial economic burdens through healthcare costs, lost productivity, and reduced quality of life (Havelaar et al., 2015). The International Food Safety Authorities Network has identified street-vended foods as a priority area for intervention, highlighting the need for evidence-based strategies that address both regulatory enforcement and vendor capacity building (FAO/WHO, 2016).

The Dual Hazard: Microbiological Contamination and Aflatoxin Exposure

Beyond the immediate biological hazard of enteric pathogens lies a more insidious chemical threat, namely aflatoxin contamination. Aflatoxins are a group of secondary metabolites primarily produced by the fungi *Aspergillus flavus* and *Aspergillus parasiticus*, representing some of the most potent naturally occurring carcinogens known to science (IARC, 2012; Zain, 2011). These mycotoxins have been classified as Group 1 human carcinogens by the International Agency for Research on Cancer, with aflatoxin B1 being the most hepatocarcinogenic compound identified (IARC, 2012). The toxicological profile of aflatoxins encompasses hepatotoxic, teratogenic, mutagenic, and immunosuppressive properties, with the liver being the primary target organ (Kensler et al., 2010; Williams et al., 2004).

Groundnuts (*Arachis hypogaea*) are exceptionally susceptible to fungal invasion and aflatoxin production due to their chemical composition, cultivation practices, and post-harvest handling requirements (Guchi, 2015; Bhatnagar-Mathur et al., 2015). The contamination process can occur at multiple points along the value chain, from pre-harvest stress conditions such as drought and insect damage, through improper drying and storage, to inadequate processing and distribution (Hell and Mutegi, 2011). The synergistic relationship between environmental conditions and management practices means that aflatoxin contamination is both predictable and preventable, yet remains pervasive in many regions of the world.

The health implications of chronic dietary aflatoxin exposure are profound and well established. Epidemiological studies have consistently demonstrated a causal relationship between aflatoxin exposure and hepatocellular carcinoma, with the risk substantially elevated in populations with concurrent hepatitis B virus infection (Kensler et al., 2010; Liu and Wu, 2010). Beyond carcinogenesis, aflatoxin exposure has been associated with growth faltering in children, immune suppression, and increased susceptibility to infectious diseases (Kimanya et al., 2010; Gong et al., 2004). The economic impact is equally concerning, with estimates suggesting that aflatoxin-related losses cost sub-Saharan Africa approximately $450 million annually in trade and health impacts (Unnevehr and Grace, 2013).

The convergence of these two hazards, microbiological and mycological, in a single, widely consumed street food item creates what the international food safety community has termed a "dual burden" of disease risk (Grace, 2015). Consumers of street-vended groundnuts may face simultaneous threats: acute gastrointestinal illness from enteric pathogens and a long-term, cumulative risk of cancer and other chronic conditions from aflatoxin exposure. This interplay is critically understudied within the context of informal food systems, representing a significant gap in the global food safety evidence base.

The Regulatory Landscape and Enforcement Challenges

The regulatory framework for food safety varies considerably across jurisdictions, with many developing countries having established legislation that, on paper, provides adequate protection. In Botswana, the Food Control Regulations (Chapter 65:05, 2011) set a maximum limit for total aflatoxins in food for human consumption at 10 µg/kg, aligning with regional standards established by the Southern African Development Community (SADC) and international standards set by the Codex Alimentarius Commission. The Public Health Act mandates hygiene standards for food handlers and establishes penalties for non-compliance. The Department of Environmental Health within the Ministry of Health and Wellness bears primary responsibility for food safety surveillance and enforcement.

However, the efficacy of these regulations hinges on enforcement, monitoring, and compliance, which are profoundly challenging within the diffuse and informal street vending sector (FAO, 2007; Rane, 2011). The informal sector is characterised by its dispersed nature, limited capital, and the precarious legal status of vendors, all of which complicate regulatory oversight. Municipal authorities frequently lack the resources, both human and financial, to conduct routine inspections and laboratory testing. Furthermore, the relationship between vendors and regulators is often characterised by tension rather than cooperation, with enforcement actions perceived as punitive rather than supportive (Jongh, 2015; Graffham et al., 2005).

The challenge is compounded by the complexities of the supply chain. Many street vendors source their raw materials from regional and international markets, introducing contamination risks that are beyond local regulatory control. Preliminary research by Mupunga (2013) indicated alarmingly high aflatoxin levels in peanuts within Botswana, suggesting a systemic supply chain problem, but this study did not focus on the ready-to-eat, street-vended segment nor integrate an assessment of hygienic handling. The absence of integrated, empirical data on both microbiological hygiene and mycotoxin contamination in street-vended foods represents a critical evidence gap that undermines the development of targeted interventions.

Regional and International Relevance

The challenges documented in this study are not unique to Botswana but reflect broader patterns observed across sub-Saharan Africa and other developing regions. The informal food sector accounts for the majority of food consumption in many urban areas, with street foods constituting a significant component of dietary intake (Steyn and Labadarios, 2011; Muinde and Kuria, 2005). The dual contamination hazards identified in this study have been documented in various settings, including Kenya (Muinde and Kuria, 2005), Ghana (Ababio and Lovatt, 2015), Nigeria (Omemu and Aderoju, 2008), Tanzania (Kimanya et al., 2010), and Brazil (Cortese et al., 2016), suggesting that the challenges are systemic rather than idiosyncratic.

The international implications extend beyond public health to encompass trade and economic development. Aflatoxin contamination has been identified as a significant barrier to agricultural trade, with European Union and other importing countries implementing stringent maximum limits that many African producers struggle to meet (Unnevehr and Grace, 2013). The resultant trade restrictions impose substantial economic costs and undermine efforts to develop agricultural value chains. Furthermore, the reputational damage associated with contaminated food products can have lasting impacts on national brands and export potential (Grace, 2015).

The relevance to the international community is also evident in the context of global health security. The WHO Global Strategy for Food Safety (2022-2030) emphasises the need for strengthened food safety systems, particularly in low- and middle-income countries, as a component of broader health system strengthening efforts (WHO, 2022). Street foods have been identified as a priority area for intervention, given their widespread consumption and documented risks. The findings of this study contribute to the global evidence base on street food safety and provide insights that may be applicable to other settings facing similar challenges.

Rationale and Significance of the Current Study

Despite the growing recognition of street food safety challenges, a significant knowledge gap persists in the Botswana context. There is a lack of concurrent, empirical data on both the hygiene status, via faecal indicator bacteria, and the aflatoxin content of street-vended groundnuts in Gaborone, the nation's capital and largest urban centre. Previous studies have examined either microbiological contamination or mycotoxin levels in isolation, without integrating these analyses to assess the dual burden (Mupunga, 2013). Furthermore, few studies have linked laboratory findings with comprehensive vendor surveys to identify the specific practices and supply chain factors associated with observed contamination levels.

Without this integrated evidence base, public health interventions remain generic and may fail to address the specific drivers of contamination in the local context. The absence of empirical data also limits the ability of policymakers to justify resource allocation and prioritise interventions within the food safety system. This study was designed to address this gap by providing a comprehensive, integrated assessment of the safety of street-vended groundnuts in Gaborone.

The primary aims of this study are to quantify the level of hygiene using *Escherichia coli* as a faecal indicator organism, determine the concentration of total aflatoxins (B1, B2, G1, G2) and assess compliance with national regulatory limits, and identify vendor practices and supply chain factors associated with observed contamination levels. By linking laboratory findings with field-based survey data, this research seeks to move beyond merely documenting contamination to understanding its drivers within the local context, thereby generating actionable evidence for policymakers, public health officials, and municipal authorities. The findings are intended to inform targeted, evidence-based strategies that mitigate this dual public health threat, protect consumers, and support the formalisation and safe operation of a vital economic sector, thereby contributing to multiple Sustainable Development Goals related to health (SDG 3), economic growth (SDG 8), and sustainable cities (SDG 11).

METHODOLOGY

Study Design and Setting

A cross-sectional, field-to-laboratory study was conducted in Gaborone, Botswana, between March and May 2019. The study integrated quantitative survey data with definitive microbiological and mycological laboratory analyses to assess the safety of ready-to-eat groundnuts sold within the informal street vending sector. Data collection was focused on three high-density commercial hubs: Main Mall, BBS Mall, and the Gaborone Bus Rank, which were selected based on their high concentration of street food vendors and consumer traffic, representing the primary sites of informal food vending in the capital city.

Sample Size Determination and Sampling Strategy

The target population comprised all vendors selling ready-to-eat groundnuts at the selected sites in Gaborone.

The sample size was calculated using the standard formula for estimating a single population proportion (Cochran, 1977; Daniel, 1999):

$$n = [Z^2 \times P(1-P)] / e^2$$

Where:

n = minimum required sample size

Z = Z-statistic corresponding to the desired confidence level

P = expected prevalence of the outcome of interest

e = desired margin of error (precision)

Based on the following assumptions:

A conservative expected prevalence (P) of 50% for safety violations, which maximises the required sample size and is appropriate when the true prevalence is unknown (Naing et al., 2006)

A 90% confidence level (Z = 1.645), which is acceptable for exploratory studies in public health and food safety research where resource constraints exist (Lwanga and Lemeshow, 1991)

A 15% margin of error (e), reflecting the exploratory nature of the study and practical constraints of fieldwork

The minimum sample size was calculated as:

$n = [(1.645)^2 \times 0.5(1-0.5)] / (0.15)^2$

$n = [2.7060 \times 0.25] / 0.0225$

$n = 0.6765 / 0.0225$

$n = 30.07 \approx 31$ vendors

The initial calculation yielded a minimum sample size of 30.07, which was rounded up to 31 vendors to ensure the desired precision. To account for anticipated non-participation, which is common in street vending studies due to the informal nature of the trade, vendor mobility, and potential reluctance to participate in research (Graffham et al., 2005; Jongh, 2015), the sample size was inflated using the standard attrition adjustment formula (Bartlett et al., 2001):

$$n\_final = n\_initial / (1 - r)$$

Where:

n_final = final adjusted sample size

n_initial = minimum required sample size

r = anticipated non-participation rate

Assuming a conservative 15% non-participation rate, which is consistent with similar street food studies conducted in sub-Saharan Africa (Muinde and Kuria, 2005; Ababio and Lovatt, 2015), the sample was adjusted as follows:

$$n\_final = 31 / (1 - 0.15) = 31 / 0.85 = 36.47 \approx \textbf{37 vendors}$$

This inflation ensures that even with up to 15% non-participation, the effective sample size would remain at approximately 31 vendors, thereby maintaining the desired statistical power and precision. Therefore, a total of 37 vendors were enrolled.

A probability-based sampling method was employed to ensure representativeness of the street vendor population at the selected sites. The sampling frame was developed through a preliminary mapping exercise conducted at each site to identify all active groundnut vendors. Within each of the three commercial hubs (Main Mall, BBS Mall, and the Gaborone Bus Rank), a simple random sampling technique was used to select vendors proportionally based on the number of groundnut vendors identified at each site. The sole inclusion criterion was the vending of ready-to-eat groundnuts; vendors selling other products exclusively were excluded from the study.

Data and Sample Collection

Data collection was executed in two concurrent, linked phases.

Vendor Survey: A structured, interviewer-administered questionnaire was used to collect data on vendor demographics (age, gender, education, household characteristics), operational practices (licensing, years vending, daily hours, skills acquisition), supply chain details (source of raw nuts, quality checking practices), and critical food safety behaviours (storage methods, use of protective equipment, handwashing practices, access to water and sanitation at vending site). The instrument was adapted from a prior tool (Mupunga, 2013) and pre-tested in a pilot study involving four vendors to refine wording, ensure comprehension, and assess the time required for administration. The pilot study results were not included in the final analysis.

Product Sampling: From each participating vendor, two independent packets of their ready-to-eat groundnuts were purchased aseptically. These samples were immediately placed in sterile, labelled sampling bags, kept cool using ice packs, and transported to the laboratory for analysis within four hours of collection.

Laboratory Analysis

In the laboratory, the two packets from each vendor were homogenised to form a single composite sample, resulting in 37 composites for analysis. The composite approach was adopted to account for within-vendor variability and provide a representative assessment of each vendor's product quality.

Microbiological Analysis (Hygiene Indicator): The enumeration of *Escherichia coli* was performed as an indicator of faecal contamination and overall hygiene. Briefly, 10 g of groundnut sample from each composite was homogenised with 90 mL of buffered peptone water in a stomacher for two minutes at normal speed. Serial decimal dilutions were prepared in sterile saline. Subsequently, 1 mL aliquots of appropriate dilutions were pour-plated in duplicate onto Fluka HiChrome ECC Agar, a selective and differential medium that allows for presumptive identification of *E. coli*. Plates were incubated aerobically at 37°C for 24 to 48 hours. Colonies exhibiting a characteristic metallic green sheen were presumptively identified as *E. coli* and counted. Results were expressed as Colony Forming Units per gram (CFU/g). For quantitative accuracy, plates with colony counts between 20 and 200 were used for calculation; counts outside this range were recorded but excluded from final statistical comparisons of specific CFU/g values. Confirmation of presumptive *E. coli* colonies was performed using indole production tests.

Mycotoxin Analysis (Aflatoxin Quantification): The concentrations of aflatoxins B1, B2, G1, and G2 were determined using Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS). A 2 g portion of each finely ground composite was extracted with 70% methanol. The extract was filtered, diluted, and purified using immunoaffinity columns (EASI EXTRACT AFLATOXIN, R Biopharm). The purified eluate was evaporated to dryness, reconstituted in mobile phase, and injected into the LC-MS/MS system. Chromatographic separation was achieved using a C18 column (150 mm × 2.1 mm, 3.5 µm particle size) with a methanol/water/acetic acid gradient at a flow rate of 0.3 mL/min. Detection and quantification were performed via electrospray ionisation in positive mode using multiple reaction monitoring with two characteristic transitions per analyte. The method was validated and accredited in accordance with AOAC and SADCAS standards. Quantification was achieved using matrix-matched calibration curves prepared from blank samples spiked with known concentrations of aflatoxin standards. The limit of detection was 0.1 µg/kg for each aflatoxin, and the limit of quantification was 0.5 µg/kg. Recovery rates ranged from 85% to 110% across the spiking range. The total aflatoxin content was derived from the sum of AFB1, AFB2, AFG1, and AFG2 and compared against the maximum limit of 10 µg/kg established by Botswana's Food Control Regulations (Chapter 65:05, 2011).

Data Management and Statistical Analysis

All data were digitised and analysed using IBM SPSS Statistics (Version 20.0) and Microsoft Excel. Descriptive statistics (frequencies, percentages, means, standard deviations, ranges) summarised vendor characteristics, microbial counts, and aflatoxin concentrations. The microbiological quality was categorically assessed against established guidelines where $\geq 1 \times 10^2$ CFU/g of *E. coli* denotes an unsatisfactory level (Tsang, 2002). Aflatoxin compliance was assessed against the 10 µg/kg regulatory limit.

To explore factors associated with poor hygiene, the continuous *E. coli* CFU/g data were categorised into ordinal levels (20-50, 51-100, 101-150, 151-200) based on the colony counts from diluted samples. Associations between these hygiene categories and independent categorical variables from the survey (including storage type, education level, source of nuts, and water availability) were examined using Pearson's Chi-square test. A significance level of $\mathbf{p < 0.05}$ was adopted for all statistical analyses to determine statistical significance, consistent with conventional practice in public health research. In keeping with the exploratory nature of these analyses, variables with p-values between 0.05 and 0.10 were noted as suggesting borderline associations that warrant confirmation in larger, adequately powered studies. The authors acknowledge that findings in this borderline range do not constitute evidence of statistically significant associations and should be interpreted with caution.

Ethical Considerations and Quality Assurance

The study protocol received ethical approval from the University of Botswana's research ethics committee (Protocol Number: UBR/RES/IRB/2019/003). Written informed consent was obtained from all participating vendors after explaining the study's purpose, their right to withdraw at any time without penalty, and the measures in place to ensure anonymity and confidentiality. All data were anonymised, and no individual vendors or locations are identifiable in the analysis or reporting.

A pilot study involving four vendors was conducted to refine the questionnaire and field procedures. All laboratory analyses followed strict standard operating procedures. The LC-MS/MS method for aflatoxin analysis used certified reference materials for calibration and included quality control samples (blanks, spiked samples, and duplicate analysis of 20% of samples) to ensure accuracy and precision throughout the analytical run. Microbiological analyses included positive and negative controls, with duplicate plating for all samples to assess reproducibility.

Measures to Ensure Reliability, Validity, and Communicability

Several measures were implemented to enhance the reliability, validity, and communicability of the study findings. Reliability was addressed through standardised data collection protocols, duplicate laboratory analyses, and the use of validated analytical methods with demonstrated precision (coefficients of variation below 10% for all analytes). Internal validity was strengthened through the use of composite samples to reduce within-vendor variability, the application of objective laboratory standards, and the use of multiple analysis methods. External validity was enhanced through the use of probability-based sampling and the inclusion of multiple vending sites representing different commercial contexts. Communicability was considered throughout the research process, with the findings presented in a format accessible to diverse stakeholders, including policymakers, public health practitioners, vendors, and consumers. The triangulation of quantitative laboratory data with qualitative vendor survey data enhances the interpretability and relevance of the findings for intervention design.

Results and Statistical Analysis

Vendor Demographic and Operational Profile

A total of 37 street vendors participated in the study, the majority of whom were female (n=29, 78.4%). The mean age of participants was 44.2 ± 8.0 years, ranging from 27 to 63 years. Educational attainment was variable: 56.8% (n=21) had completed secondary education, 24.3% (n=9) primary education, and 18.9% (n=7) reported no formal schooling. Most participants were married (59.5%, n=22), with 27.0% (n=10) single and 13.5% (n=5) divorced or widowed.

Operational characteristics revealed significant gaps in formalisation and compliance. An overwhelming majority (97.3%, n=36) operated without a valid hawker's license, indicating near-universal absence of formal authorisation. The supply chain was predominantly external, with 81.1% (n=30) sourcing raw groundnuts from Zambia, while 10.8% (n=4) cultivated their own and 8.1% (n=3) sourced from local suppliers. Post-harvest and point-of-sale storage practices were suboptimal: 70.3% (n=26) stored raw inventory in permeable sacks, while 59.5% (n=22) stored ready-to-eat products in non-breathable plastic bags at the vending site, a practice employed by 100% of vendors for customer packaging. The use of personal protective equipment was critically low, with only 16.2% (n=6) reporting consistent usage, while 70.2% (n=26) reported having no protective equipment at all. Table 1 presents the demographic characteristics of the 37 study participants.

Table 1: Demographic Characteristics of 37 Study Participants in Gaborone

Characteristic	Frequency	Proportion (%)
Gender		
Male	8	21.6
Female	29	78.4
Age ($\bar{x}$ = 44.16 ± 8.01 years, range 27-63)		
25-34	4	10.8
35-44	16	43.2
45-54	12	32.4
> 54	5	13.5
Marital Status		
Married	22	59.5
Single	10	27.0
Divorced/Widowed	5	13.5
House type		
Not partitioned	24	64.9
Partitioned	13	35.1
Level of study		
Never been to school	7	18.9

Characteristic	Frequency	Proportion (%)
Primary level	9	24.3
Secondary level	21	56.8

Source: Author's computations based on survey data (2020)

Microbiological Contamination: Indicator Organism Analysis

Microbiological assessment using *Escherichia coli* as a faecal indicator organism revealed universal and excessive contamination. All 37 composite samples (100%) tested positive for *E. coli*. Quantitatively, colony counts ranged from 2.0×10^5 to 1.86×10^6 Colony Forming Units per gram (CFU/g), with a mean contamination level of $8.42 \times 10^5 \pm 4.95 \times 10^5$ CFU/g. This categorises every sample as microbiologically unsatisfactory for consumption, exceeding by several orders of magnitude the guideline threshold of $<1 \times 10^2$ CFU/g established for ready-to-eat foods (Tsang, 2002). Table 2 presents the distribution of *E. coli* colony counts across the 37 samples, which were diluted 10,000 times and plated on Fluka HiChrome ECC Agar.

Table 2: Distribution of *E. coli* Colony Counts from 37 Groundnut Samples (Dilution Factor 10,000)

Number of *E. coli* Colonies	Frequency	Proportion (%)
20-50	13	35.1
51-100	11	29.7
101-150	8	21.6
151-200	5	13.5
Total	**37**	**100.0**

Source: Author's computations based on survey data (2020)

The mean colony count from the diluted samples was 84.19 ± 49.48. Most groundnuts purchased from study participants (35.1%) had *E. coli* colonies ranging between 20 and 50 colonies, while the least proportion (13.5%) had 151 to 200 colonies. This demonstrates uniformly high levels of contamination across all samples, with even the lowest contamination levels being approximately 200 times the acceptable threshold when adjusted for the dilution factor.

Mycotoxin Contamination: Aflatoxin Profiling and Regulatory Compliance

Analysis of the four primary aflatoxins (B1, B2, G1, G2) demonstrated severe and pervasive contamination. Total aflatoxin concentrations exhibited a wide range, from below the limit of detection to 1966.72 µg/kg (mean 118.0 µg/kg, median 45.2 µg/kg). A striking 94.6% (35/37) of samples violated the national regulatory maximum limit of 10 µg/kg for total aflatoxins established under Botswana's Food Control Regulations. The most contaminated sample contained a level approximately 197 times the permissible limit. Aflatoxin B1 was identified as the most prevalent and quantitatively dominant congener across the sample set, accounting for an average of 85% of total aflatoxin content in contaminated samples. Figure 1 illustrates the proportion of samples falling within acceptable versus unacceptable aflatoxin levels according to Botswana's regulatory framework.

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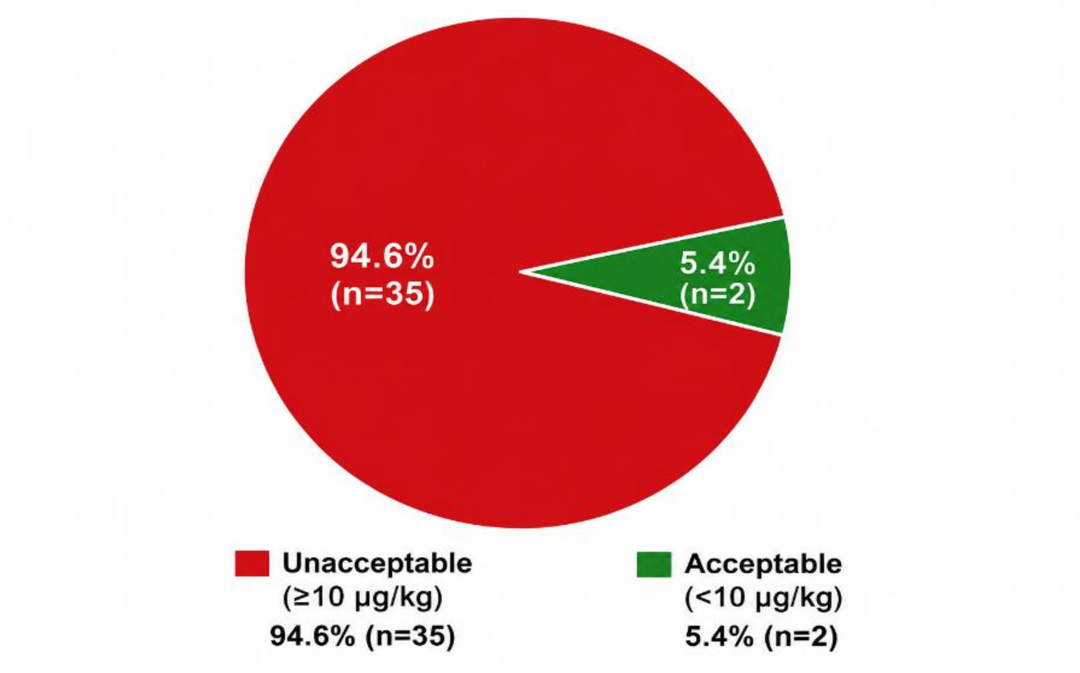
Figure 1: Aflatoxin Compliance Status of Groundnut Samples (N=37)



Source: Author's observations based on survey data (2020)

3.4 Statistical Associations between Vendor Demographic Characteristics and E. coli Contamination

Exploratory statistical analysis using Pearson's Chi-square test was conducted to examine associations between vendor demographic characteristics and *E. coli* contamination levels. Table 3 presents the bivariate analysis of demographic factors including gender, age, house type, level of study, length in food trading, and hawker's license status.

The analysis identified that only one demographic factor was significantly associated with higher categorical levels of *E. coli* contamination at the conventional $p < 0.05$ level: absence of formal education ($p = 0.034$). Vendors with no formal education demonstrated higher proportions in the 101-150 colony count category (10.8%) compared to those with primary education (0.0%) or secondary education (10.8%). While vendor age ($p = 0.081$) and house type ($p = 0.088$) showed borderline tendencies toward association at the $p < 0.10$ level, these did not reach conventional statistical significance. Gender ($p = 0.380$), length in food trading ($p = 0.419$), and hawker's license status ($p = 0.293$) were not significantly associated with contamination levels. These findings suggest that educational background may be an important determinant of bacterial contamination among vendors, while other demographic characteristics warrant confirmation in larger studies.

Table 3: Bivariate Analysis of Vendor Demographic Characteristics Associated with *Escherichia coli* Contamination Levels in Ready-to-Eat Groundnuts (N=37)

Characteristic	≤50 n (%)	51–100 n (%)	101–150 n (%)	151–200 n (%)	Total n (%)	P-value
Gender						0.380
Male	2 (5.4)	3 (8.1)	3 (8.1)	0 (0.0)	8 (21.6)	
Female	11 (29.7)	8 (21.6)	5 (13.5)	5 (13.5)	29 (78.3)	
Age						0.081†

Characteristic	≤50 n (%)	51–100 n (%)	101–150 n (%)	151–200 n (%)	Total n (%)	P-value
25–34	2 (5.4)	1 (2.7)	1 (2.7)	0 (0.0)	4 (10.8)	
35–44	3 (8.1)	5 (13.5)	3 (8.1)	5 (13.5)	16 (43.2)	
45–54	6 (16.2)	5 (13.5)	1 (2.7)	0 (0.0)	12 (32.4)	
> 54	2 (5.4)	0 (0.0)	3 (8.1)	0 (0.0)	5 (13.5)	
House type						0.088†
Non-partitioned	6 (16.2)	9 (24.3)	7 (18.9)	2 (5.4)	24 (64.8)	
Partitioned	7 (18.9)	2 (5.4)	1 (2.7)	3 (8.1)	13 (35.1)	
Level of study						**0.034***
No formal education	1 (2.7)	2 (5.4)	4 (10.8)	0 (0.0)	7 (18.9)	
Primary level	6 (16.2)	3 (8.1)	0 (0.0)	0 (0.0)	9 (24.3)	
Secondary level	6 (16.2)	6 (16.2)	4 (10.8)	5 (13.5)	21 (56.7)	
Length in food trading (years)						0.419
0	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.7)	1 (2.7)	
1–4	2 (5.4)	5 (13.5)	2 (5.4)	2 (5.4)	11 (29.7)	
5–9	4 (10.8)	3 (8.1)	4 (10.8)	2 (5.4)	13 (35.1)	
10 and above	4 (10.8)	3 (8.1)	2 (5.4)	0 (0.0)	9 (24.3)	
Hawker's license						0.293
Available	0 (0.0)	0 (0.0)	1 (2.7)	0 (0.0)	1 (2.7)	
Non-available	13 (35.1)	11 (29.7)	7 (18.9)	5 (13.5)	36 (97.2)	

Source: Author's computations based on survey data (2020)

Notes:

i. **Statistically significant at $p < 0.05$**

ii. **Borderline association at $p < 0.10$** (not statistically significant at conventional threshold)

Statistical Associations between Food Handling Practices and E. coli Contamination

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Table 4 presents the bivariate analysis of food handling practices and their associations with *E. coli* contamination levels. Variables examined included groundnut cooking skills acquisition, availability and usage of personal protective equipment (PPE), place of purchase, quality check practices, raw groundnuts storage methods, and storage of nuts at the vending site.

The analysis revealed that none of the food handling practice variables reached conventional statistical significance at the $p < 0.05$ level. However, storage of nuts at the vending site approached borderline significance ($p = 0.051$), with higher contamination categories occurring relatively more frequently among vendors storing nuts in sacks (16.2% in the 101-150 category) compared to those using plastic storage (5.4% in the 101-150 category) or open space storage (0.0% in the 101-150 category). This finding suggests that storage method may be a modifiable risk factor worthy of further investigation. Other food handling practices including groundnut cooking skills acquisition ($p = 0.470$), availability and usage of PPE ($p = 0.608$), place of purchase ($p = 0.740$), quality check practices ($p = 0.370$), and raw groundnuts storage methods ($p = 0.852$) were not significantly associated with contamination levels.

Table 4: Bivariate Analysis of Food Handling Practices Associated with *Escherichia coli* Contamination Levels in Ready-to-Eat Groundnuts (N=37)

Characteristic	≤50 n (%)	51–100 n (%)	101–150 n (%)	151–200 n (%)	Total n (%)	P-value
Groundnut cooking skills acquisition						0.470
Observation Learning	6 (16.2)	7 (18.9)	6 (16.2)	2 (5.4)	21 (56.8)	
Parental guidance	2 (5.4)	1 (2.7)	3 (8.1)	1 (2.7)	7 (18.9)	
Discovery learning	5 (13.5)	3 (8.1)	4 (10.8)	2 (5.4)	14 (37.8)	
Availability and usage of PPE						0.608
PPE Available but never used	1 (2.7)	2 (5.4)	0 (0.0)	0 (0.0)	3 (8.1)	
PPE available and used occasionally	2 (5.4)	0 (0.0)	1 (2.7)	2 (5.4)	5 (13.5)	
PPE used always	1 (2.7)	1 (2.7)	1 (2.7)	0 (0.0)	3 (8.1)	
PPE Unavailable	9 (24.3)	8 (21.6)	6 (16.2)	3 (8.1)	26 (70.2)	
Place of purchase						0.740
Zambia	10 (27.0)	9 (24.3)	7 (18.9)	5 (13.5)	31 (83.8)	
Farm-produced	1 (2.7)	2 (5.4)	1 (2.7)	0 (0.0)	4 (10.8)	
Locally-sourced	2 (5.4)	1 (2.7)	0 (0.0)	0 (0.0)	3 (8.1)	
Quality check						0.370

Characteristic	≤50 n (%)	51–100 n (%)	101–150 n (%)	151–200 n (%)	Total n (%)	P-value
Compliant	11 (29.7)	7 (18.9)	6 (16.2)	5 (13.5)	29 (78.3)	
Non-compliant	2 (5.4)	4 (10.8)	2 (5.4)	0 (0.0)	8 (21.6)	
Raw groundnuts storage						0.852
Sack storage	10 (27.0)	8 (21.6)	5 (13.5)	3 (8.1)	26 (70.2)	
Open space storage	3 (8.1)	3 (8.1)	3 (8.1)	2 (5.4)	11 (29.7)	
Storing nuts at site						0.051
Plastic storage	11 (29.7)	6 (16.2)	2 (5.4)	3 (8.1)	22 (59.4)	
Sack storage	1 (2.7)	3 (8.1)	6 (16.2)	2 (5.4)	12 (32.4)	
Open space storage	1 (2.7)	2 (5.4)	0 (0.0)	0 (0.0)	3 (8.1)	

Source: Author's computations based on survey data (2020)

Note: Borderline association at $p < 0.10$ (not statistically significant at conventional threshold)

Statistical Associations between Environmental Factors and E. coli Contamination

Table 5 presents the bivariate analysis of environmental and operational factors associated with *E. coli* contamination levels. Variables examined included length of current stock, length of business per day, length to sell all stocked groundnuts, availability and usage of water at the vending site, and provision and usage of toilets and handwashing facilities.

The analysis revealed that none of the environmental variables reached conventional statistical significance at the $p < 0.05$ level. However, provision and usage of toilets and handwashing facilities showed a borderline tendency toward association ($p = 0.084$). Interestingly, vendors who utilised toilet and handwashing facilities occasionally (91.8%) were distributed across all contamination categories, while the only vendor who never utilised these facilities was in the highest contamination category (151-200 colonies). The availability and usage of water at the vending site ($p = 0.687$), length of current stock ($p = 0.810$), length of business per day ($p = 0.666$), and length to sell all stocked groundnuts ($p = 0.275$) were not significantly associated with contamination levels. These findings suggest that environmental factors, particularly access to and utilisation of sanitation facilities, may merit further investigation in larger studies, although the current data do not provide conclusive evidence of association.

Table 5: Bivariate Analysis of Environmental and Operational Factors Associated with *Escherichia coli* Contamination Levels in Ready-to-Eat Groundnuts (N=37)

Characteristic	≤50 n (%)	51–100 n (%)	101–150 n (%)	151–200 n (%)	Total n (%)	P-value
Length of current stock (months)						0.810

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Characteristic	≤50 n (%)	51–100 n (%)	101–150 n (%)	151–200 n (%)	Total n (%)	P-value
< 1 month	10 (27.0)	7 (18.9)	5 (13.5)	4 (10.8)	26 (70.2)	
1–3	3 (8.1)	4 (10.8)	3 (2.7)	1 (2.7)	11 (29.7)	
Length of business/day						0.666
5–9 hours	6 (16.2)	4 (10.8)	5 (13.5)	3 (8.1)	18 (48.6)	
10 hours and above	7 (18.9)	7 (18.9)	3 (8.1)	2 (5.4)	19 (51.3)	
Length to sell all stocked groundnuts (months)						0.275
< 1 month	11 (29.7)	11 (29.7)	7 (18.9)	5 (13.5)	34 (91.8)	
1–3	0 (0.0)	0 (0.0)	1 (2.7)	0 (0.0)	1 (2.7)	
Availability and usage of water at site						0.687
Never handwashes	1 (2.7)	1 (2.7)	0 (0.0)	1 (2.7)	3 (8.1)	
Handwashes occasionally	7 (18.9)	5 (13.5)	2 (5.4)	2 (5.4)	16 (43.2)	
Handwashes always	1 (2.7)	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.7)	
Water non-available	4 (10.8)	5 (13.5)	6 (16.2)	2 (5.4)	17 (45.9)	
Provision and usage of toilets and handwashing facilities						0.084
Never utilised	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.7)	1 (2.7)	
Utilised occasionally	13 (35.1)	11 (29.7)	7 (18.9)	3 (8.1)	34 (91.8)	
Facilities non-available	0 (0.0)	0 (0.0)	1 (2.7)	1 (2.7)	2 (5.4)	

Source: Author's computations based on survey data (2020)

Note: Borderline association at $p < 0.10$ (not statistically significant at conventional threshold)

Summary of Statistical Findings

Overall, the results suggest that only one factor, educational level ($p = 0.034$), demonstrated a statistically significant association with bacterial contamination levels. Several other factors, including age ($p = 0.081$), house type ($p = 0.088$), storage of groundnuts at the trading site ($p = 0.051$), and provision and use of toilet and handwashing facilities ($p = 0.084$), showed borderline tendencies toward association at the exploratory $p < 0.10$ level but did not reach conventional statistical significance. These borderline findings warrant confirmation using a larger sample and should not be used to assert causal relationships. The majority of vendor characteristics and practices examined were not significantly associated with *E. coli* contamination levels, suggesting that the universal nature of contamination may be driven by systemic factors rather than individual vendor attributes.

DISCUSSION

Interpretation of Findings in Context

This study presents compelling evidence of a critical public health risk in Gaborone's informal food sector, demonstrating systemic failures in both biological safety and chemical hazard control. The findings reveal near-universal contamination of ready-to-eat groundnuts with both faecal indicator bacteria and carcinogenic aflatoxins at levels that violate national safety standards. These results have profound implications for public health policy, regulatory enforcement, and vendor education, both within Botswana and in comparable settings globally.

The unprecedented finding that 100% of samples exceeded acceptable microbiological limits and 94.6% exceeded aflatoxin regulatory limits represents one of the most comprehensive documentations of dual contamination in street-vended foods. While individual studies have documented either microbiological contamination (Muinde and Kuria, 2005; Ababio and Lovatt, 2015) or aflatoxin contamination (Mupunga, 2013; Guchi, 2015) in various food products, few have integrated both analyses in a single sample set. The co-occurrence of these hazards at such high levels suggests a complete breakdown of the food safety system across multiple control points.

Vendor Profile and Contextual Factors: International Perspectives

The demographic profile of vendors, predominantly female with a mean age in the mid-forties and possessing basic education, aligns with patterns observed in street food economies across sub-Saharan Africa and other developing regions (Ababio and Lovatt, 2015; Cortese et al., 2016; Graffham et al., 2005). The overrepresentation of women in the sector reflects broader patterns of gendered labour market participation, where women are more likely to engage in informal sector activities due to limited formal employment opportunities, caregiving responsibilities, and lower educational attainment (Bhowmik, 2005; FAO, 2007). The age distribution suggests that street vending provides livelihood opportunities for middle-aged individuals who may have been displaced from formal employment or who supplement household income through informal activities.

The near-universal absence of formal licensing (97.3%) is consistent with patterns observed across the region and illustrates the tension between the economic contributions of street vending and its legal status. In many settings, vendors face a cycle of informality: without licenses, they are vulnerable to harassment and asset confiscation, yet the path to formalisation may be costly, complex, or politically sensitive (Jongh, 2015; Rane, 2011). This study contributes to the growing evidence base on the costs and benefits of formalisation, suggesting that licensure alone is insufficient without accompanying support for capacity building and infrastructure improvement.

The near-total reliance (81.1%) on imported raw materials from Zambia introduces a significant upstream risk factor, distancing local vendors from control over initial agricultural and primary processing standards. This finding has implications beyond Botswana, as cross-border food trade is increasingly recognised as a source of contamination risks that transcend national regulatory systems (Grace, 2015; Unnevehr and Grace, 2013). The regional dimension of aflatoxin contamination suggests that interventions must be coordinated at the sub-regional level, involving both source countries and importing countries in a shared responsibility for food safety assurance.

Ubiquitous Microbiological Contamination: A Comprehensive Analysis

The detection of *Escherichia coli* in all 37 samples at levels exceeding 1×10^5 CFU/g signifies a profound breach of basic food hygiene. These counts, which are several orders of magnitude above the acceptable threshold of $<1 \times 10^2$ CFU/g (Tsang, 2002), classify every sample as microbiologically unsatisfactory for consumption. The presence of this faecal indicator organism points unequivocally to contamination from inadequate sanitation, polluted water, unhygienic handling, or exposure to pests (Ababio and Lovatt, 2015; Omemu and Aderoju, 2008).

The universal nature of the contamination suggests that the problem is systemic rather than attributable to isolated vendor practices. This systemic failure is consistent with the ecological model of food safety, which recognises that individual behaviours are shaped by the broader social, economic, and physical environment (Grace, 2015). In the Gaborone context, the absence of basic infrastructure, including potable water, handwashing facilities, and hygienic storage, creates conditions where even well-intentioned vendors cannot maintain adequate hygiene standards.

Our analysis identifies a nexus of endogenous and exogenous risk factors operating at multiple levels. Endogenously, critical gaps were observed in vendor practices: minimal use of personal protective equipment (16.2%), handling of food and money without intermediary hygiene steps, and storage of finished product in non-breathable plastic bags (59.5%), which can create a microclimate conducive to microbial proliferation. Exogenously, the vending environment itself poses hazards, including exposure to road dust, traffic fumes, and critically, a widespread lack of accessible potable water and handwashing facilities at vending sites. This infrastructural deficit makes consistent adherence to basic hygiene protocols physically impossible, a constraint noted in similar settings (Muinde and Kuria, 2005; Omemu and Aderoju, 2008). The finding that vendors acquired skills primarily through informal observation rather than formal training further exacerbates this knowledge-practice gap.

The exploratory statistical associations identified between higher *E. coli* contamination and lack of formal education ($p=0.034$) provide preliminary empirical support for targeted interventions. Other factors, including non-partitioned housing ($p=0.088$), storage method at vending sites ($p=0.051$), and infrequent use of toilet and handwashing facilities ($p=0.084$), showed tendencies toward association but did not reach conventional statistical significance at the **$p < 0.05$** level. While these borderline findings do not demonstrate causation, they suggest that socioeconomic and behavioural factors merit further investigation in larger studies. The relationship between storage method at vending sites and contamination levels ($p=0.051$) is particularly noteworthy, as it represents a modifiable risk factor amenable to low-cost intervention. The finding that vendors storing nuts in plastic bags had higher contamination levels than those using sacks or open displays is counterintuitive but may reflect moisture retention and reduced air circulation promoting bacterial growth.

Critical Levels of Aflatoxin Contamination and Supply Chain Implications

The mycological hazard presented by aflatoxins is arguably more severe due to its chronic, carcinogenic nature. With 94.6% of samples exceeding Botswana's regulatory limit of 10 µg/kg and one sample reaching 1966.72 µg/kg (197 times the limit), the scale of contamination constitutes a serious toxicological threat. These levels far surpass international guidance ranges (e.g., the European Union limit of 4 µg/kg for groundnuts) and align with concerning findings from prior regional studies (Mupunga, 2013; Guchi, 2015). The predominance of aflatoxin B1, a Group 1 human carcinogen (IARC, 2012), heightens the associated risk for hepatotoxicity and liver cancer (Kensler et al., 2010).

The magnitude of contamination observed in this study is among the highest reported in the international literature for street-vended foods. For context, studies from other African settings have reported mean total aflatoxin levels in groundnuts ranging from 20 to 300 µg/kg, with some individual samples exceeding 1000 µg/kg (Hell and Mutegi, 2011; Liu and Wu, 2010). The extreme levels documented in this study (mean 118 µg/kg, maximum 1966 µg/kg) suggest that the groundnuts available to consumers in Gaborone may represent one of the most highly contaminated food items regularly consumed in the region.

The patterns observed are consistent with contamination occurring at multiple points along the supply chain, with the predominance of imported raw materials from a region with known climatic susceptibility to *Aspergillus* proliferation suggesting a potential upstream contribution to the contamination burden. Sourcing raw nuts from Zambia, a region with a humid subtropical climate conducive to *Aspergillus flavus* growth, imports pre-existing risk. Climate data from Zambia indicate that the country experiences conditions favourable for mycotoxin production, including temperatures of 25-35°C and relative humidity above 80% during the growing season (NCCRS, 2010). The post-harvest handling reported by vendors, namely storage in sacks and plastic bags, likely compounded this by providing conditions, such as elevated moisture and poor aeration, for further fungal growth and mycotoxin production during transport and shelf life (Bhatnagar-Mathur et al., 2015). The co-occurrence of extreme aflatoxin levels with high microbial loads suggests a general pattern of neglect across the entire post-farmgate handling continuum, from import to point of sale.

The supply chain implications extend beyond the local context. The increasing integration of regional food markets means that contamination originating in one country can affect consumers across national borders. This finding highlights the need for harmonised regulatory standards and collaborative surveillance systems at the regional level. The Southern African Development Community (SADC) has established a Food Security and Safety Programme that includes mycotoxin surveillance, but the effectiveness of these mechanisms depends on national implementation and enforcement capacity (Grace, 2015).

Reliability, Validity, and Communicability of Findings

The soundness of this investigation is supported by several methodological strengths that enhance the reliability, validity, and communicability of the findings. Reliability was established through standardised data collection protocols, duplicate laboratory analyses with coefficients of variation below 10%, and the use of validated analytical methods. The consistency of results across vendors and samples (100% microbial contamination, 94.6% aflatoxin contamination) provides strong evidence of a systematic problem rather than random variation.

Internal validity was strengthened through several design features. The use of composite samples reduced within-vendor variability and provided a representative assessment of each vendor's product quality. The application of objective laboratory standards, including certified reference materials for aflatoxin analysis, minimised measurement error. The inclusion of multiple indicators of contamination (both biological and chemical) provided convergent evidence of food safety failures. The statistical associations identified between vendor practices and contamination levels, while exploratory, provide plausible and testable hypotheses for future research.

External validity was enhanced through the use of probability-based sampling and the inclusion of multiple vending sites representing different commercial contexts. While the sample size (37 vendors) limits the generalisability of the specific contamination levels to the broader vendor population, the consistency of findings across vendors and sites suggests that the results may be indicative of wider patterns in the Gaborone-street food sector. The findings are likely to be relevant to other cities in Botswana and to comparable settings in the region where similar conditions prevail.

Communicability was considered throughout the research process. The findings are presented in a format accessible to diverse stakeholders, including policymakers, public health practitioners, vendors, and consumers. The triangulation of quantitative laboratory data with qualitative vendor survey data enhances the interpretability and relevance of the findings for intervention design. The clear documentation of both the magnitude and the drivers of contamination provide actionable information for different stakeholder groups, from regulators (enforcement priorities) to vendors (practice improvements) to consumers (risk awareness).

Integrated Risk and Public Health Implications

The convergence of high biological and chemical hazards observed in this study suggests a potential dual burden for consumers: an immediate risk of acute gastroenteritis from enteric pathogens and a long-term risk of chronic diseases, including hepatocellular carcinoma, from aflatoxin exposure. This synergy underscores that interventions targeting only one hazard will be insufficient. The informal, unregulated nature of the trade, combined with vulnerable supply chains and poor vendor infrastructure, creates conditions conducive to foodborne disease (Grace, 2015; Unnevehr and Grace, 2013). These findings are not isolated; they reflect a systemic challenge requiring integrated, multi-level interventions that address regulation, vendor education, supply chain management, and consumer awareness.

The public health burden extends beyond immediate illness. Chronic aflatoxin exposure has been associated with immune suppression, growth faltering in children, and increased susceptibility to infectious diseases (Kimanya et al., 2010; Gong et al., 2004). In a population where street foods constitute a significant proportion of dietary intake, particularly among low-income urban dwellers, the cumulative impact of these exposures could be substantial. The economic implications are also considerable, including healthcare costs, lost productivity, and potential impacts on food exports and tourism.

The dietary exposure assessment is particularly concerning given the prevalence of street food consumption in Gaborone. Street foods are estimated to provide 20-40% of daily caloric intake for some urban households (Steyn and Labadarios, 2011), meaning that contaminated groundnuts could contribute substantially to total aflatoxin exposure. When combined with background exposure from other staple foods such as maize and sorghum, the cumulative aflatoxin intake may reach levels that significantly increase the risk of liver cancer. The WHO estimates that aflatoxin exposure contributes to approximately 4.6% of all liver cancer cases in sub-Saharan Africa (IARC, 2012; Liu and Wu, 2010).

Study Limitations

Several methodological limitations should be considered when interpreting the findings. The sample size, while calculated and sufficient for this exploratory study, limits broad generalisations across Botswana. The study focused exclusively on Gaborone and may not reflect conditions in other urban or rural areas of the country. Future research should expand the geographic scope to include other settlements.

The cross-sectional design provides a snapshot of contamination levels at a single point in time and does not capture temporal variations. Sample collection in March may reflect seasonal contamination patterns tied to humidity and recent harvests in source regions. Longitudinal studies would provide insights into seasonal and annual variations, enabling more targeted timing of interventions.

The reliance on vendor self-reporting for practice data is subject to social desirability bias, suggesting the actual conditions may be worse than reported. Vendors may have overstated their hygiene practices or understated non-compliance. This limitation, however, suggests that the findings may represent a conservative estimate of the true scope of the problem.

Additionally, the study did not assess contamination levels before importation, limiting the ability to apportion responsibility between source contamination and local handling practices. The absence of baseline data from the point of import means that the relative contributions of agricultural practices, storage conditions, and handling practices to overall contamination levels cannot be definitively determined. Future research should incorporate sampling at multiple points along the supply chain to identify critical control points more precisely.

The laboratory constraints included the use of two different incubators for microbiological analysis, which may have introduced minor variability in colony counts, though all results remained unequivocally in the unsatisfactory range. The use of presumptive identification of *E. coli* based on colonial morphology on selective media, while standard practice, may have resulted in minor misclassification; however, the magnitude of the counts makes misclassification of a few colonies inconsequential to the overall conclusion.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion: Interpreting the Evidence in Light of Our Aims

This study set out with three clear objectives: to determine the hygiene level of street-vended groundnuts, to identify the factors driving contamination, and to assess compliance with national aflatoxin standards. The findings provide unambiguous and alarming answers, painting a picture of a systemic public health vulnerability within Gaborone's informal food sector.

The study yields a conclusive and disturbing verdict. Regarding hygiene, the objective was to use *E. coli* as a marker. The results were unequivocal: every single sample tested (100%) harboured *E. coli* at levels far exceeding the threshold for safe consumption. This universal failure indicates not random lapses but a fundamental breakdown in basic food safety practices, confirming that the hygiene associated with these products is not merely unsatisfactory but represents a consistent and significant risk for foodborne illness.

The study also sought to identify the contributing factors. The survey data reveals a root cause anchored in the informal nature of the trade: a lack of regulation, knowledge, and infrastructure. The overwhelming majority of vendors operated without licenses or formal training, sourcing raw materials from unverified international channels. Critical control points were consistently compromised; for instance, storage in moisture-trapping plastic bags, a near-total absence of protective equipment, and vending in environments devoid of basic water and sanitation facilities. These factors collectively create an ecosystem where contamination is not an accident but an inevitable outcome.

Finally, the study compared aflatoxin levels against Botswana's regulatory limit (10 µg/kg) and revealed a crisis of an even greater magnitude. A staggering 95% of samples violated the law, with some contamination levels reaching nearly 200 times the permissible limit. This objective finding moves the issue beyond hygiene into the realm of chronic toxicological exposure. It confirms that the supply chain for street-vended groundnuts is introducing potent carcinogens into the diets of unsuspecting consumers at an alarming scale.

The implications of these findings extend far beyond the specific setting of Gaborone. They reflect broader challenges facing food safety governance in developing countries, where the informal sector operates largely outside regulatory oversight and where the health burdens of contamination fall disproportionately on the most vulnerable populations. The dual burden of biological and chemical contamination documented in this study represents a significant threat to human health and sustainable development.

Recommendations: A Collaborative Blueprint for Action

Addressing this complex issue requires a coordinated, multi-stakeholder strategy where each actor fulfils a specific role.

For Regulatory and Public Health Authorities: The findings support transitioning vendors from informality to accountability through a mandatory, simplified registration process coupled with compulsory basic food hygiene certification. Monitoring should shift to proactive safety assurance through routine, random microbiological and aflatoxin surveillance of street-vended foods. Consistent enforcement with meaningful consequences for non-compliance provides deterrence. Targeted public health campaigns should educate consumers about risks, particularly the invisible danger of aflatoxins. Authorities should also establish and enforce maximum limits for aflatoxins in imported raw materials with testing at points of entry.

For Urban Planning and Local Governance: The findings support creating well-managed vending zones with core infrastructure, including reliable potable water points, handwashing stations, hygienic waste disposal, and shade. This addresses exogenous factors such as dust and lack of water that vendors cannot control alone. Active enforcement of existing food safety bylaws and the national Food Control Regulations provides the necessary legal backbone. Urban planners should integrate street vending into city development plans, recognising the sector's economic contributions while addressing public health risks.

For Vendors and Their Collectives: Vendors should source raw groundnuts from reputable dealers who can provide certificates of analysis for aflatoxin levels. Vendor associations could leverage collective purchasing power to negotiate for safe, affordable raw materials. Adoption of critical practices, including using clean, dry, airtight storage containers, consistently wearing gloves and aprons, and implementing proper handwashing, builds consumer trust and directly addresses microbial hazards. Forming or strengthening vendor associations to collectively advocate for better vending conditions, access to training, and fair enforcement is also recommended. Participation in cooperative purchasing and storage arrangements would improve economies of scale and enable investment in safe storage infrastructure.

For Agricultural and Research Institutions: The findings support extending knowledge to farmers and importers on proven pre- and post-harvest strategies to suppress aflatoxin, including training on proper drying techniques, storage, and the use of biocontrol agents like non-toxigenic *Aspergillus* strains. Expansive, nationwide surveillance to understand the full geographic and seasonal scope of aflatoxin contamination in Botswana's food system is crucial for targeted interventions. Developing and validating low-cost, rapid screening tests for aflatoxins for use at market or cooperative levels enables decentralised quality control. Research institutions should also investigate the efficacy of simple, low-cost interventions, such as improved storage containers or sorting practices, in reducing contamination in the street vending context.

For International Development Partners: The international community should provide technical assistance for regulatory strengthening, capacity building for laboratory analysis, and support for regional harmonisation of standards. The findings provide compelling justification for investment in food safety infrastructure as part of broader health and economic development programming. Partners should also support research into cost-effective interventions and facilitate knowledge exchange between countries facing similar challenges.

Recommendations for Policy and Practice

Based on the evidence generated, the following specific recommendations are advanced.

Short Term (0-12 months): Implementation of educational campaigns targeting vendors and consumers, focused inspections of street vending sites, and distribution of simple guidance materials on safe storage and handling practices. Priority should be given to providing handwashing facilities at vending sites and promoting their use. Establishment of a reporting and surveillance system for foodborne illness linked to street foods would enable rapid detection and response.

Medium Term (1-3 years): Development and delivery of formal training programmes for street vendors on food safety principles, including basic microbiology, personal hygiene, safe storage, and aflatoxin awareness. Simplified licensing and registration processes would support formalisation while reducing barriers to compliance. Investment in market infrastructure, including provision of water, sanitation, and waste management, would address environmental drivers of contamination. Development of regional coordination mechanisms for food safety surveillance would address cross-border dimensions.

Long Term (3-10 years): Comprehensive reform of food safety legislation to better address the informal sector, development of sustainable funding mechanisms for surveillance and enforcement, and integration of food safety objectives into broader urban development and agricultural policies. Investment in agricultural research and extension to address aflatoxin at the source, including promotion of biocontrol and improved post-harvest practices, would address upstream drivers. Development of regional value chains with integrated quality assurance systems would support safe trade and reduce reliance on unverified sources.

Future Research Directions

This study highlights several areas requiring further investigation. Longitudinal studies examining seasonal variations in contamination levels would provide insights into temporal patterns and inform targeted interventions during high-risk periods. Research into the economic impact of aflatoxin contamination on street vendors and consumers would strengthen the case for investment in food safety infrastructure. Studies evaluating the effectiveness of specific intervention strategies, such as vendor training programmes or improved storage technologies, would provide evidence for scalable solutions. Investigating the prevalence of aflatoxin biomarkers in consumer populations would enable more accurate assessment of public health impacts and cost-benefit analyses of intervention programmes.

Future research should also explore the specific mechanisms underlying the associations identified in this study, such as the relationship between housing conditions and contamination levels or the pathways through which storage practices influence aflatoxin accumulation. Qualitative research exploring vendor perspectives on food safety, barriers to compliance, and perceived needs would inform the design of acceptable and effective interventions. Comparative studies examining food safety in different types of street-vended products and in different urban settings would enable identification of best practices and transferable lessons.

The development of simple, validated, low-cost screening methods for aflatoxin would enable decentralised quality control and empower vendors and consumers to make informed choices. Research into the efficacy of aflatoxin binders or other mitigation strategies in the street food context would provide additional tools for risk reduction. The exploration of innovative business models, such as vendor cooperatives or social enterprises, could identify sustainable pathways for food safety improvement.

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Declarations

Supplementary Material

The authors confirm that no supplementary material or datasets were generated or analysed beyond the primary data presented in this manuscript. All supporting information is contained within the main body of the text, tables, and figures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors have no financial or non-financial conflicts of interest to disclose.

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Ethics Approval and Consent to Participate

The study protocol received ethical approval from the University of Botswana's Research Ethics Committee (Protocol Number: UBR/RES/IRB/2019/003). All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments. Written informed consent was obtained from all individual participants included in the study.

Participants were informed of their right to withdraw at any time without penalty. All data were anonymised to protect vendor identities and confidentiality.

Consent for Publication

Not applicable. No individual person's data (e.g., images, videos, or identifiable personal information) is presented in this manuscript.

Data Availability

The datasets generated and analysed during the current study, including vendor survey responses and laboratory records (microbiological and aflatoxin counts), are not publicly available due to privacy and ethical restrictions imposed by the University of Botswana's Research Ethics Committee to protect vendor anonymity. However, the datasets are available from the corresponding author (Motlhala Boago Judith; boagomotlhala@gmail.com) upon reasonable request and subject to institutional data-sharing agreements.

Open Access Statement

The authors support the open access model to share research openly with anyone, anywhere, increasing the visibility and citations of published work and ensuring quality through rigorous peer review.

Author Contributions

MBJ conceptualised the study, designed the data collection instruments, conducted the fieldwork and laboratory analyses, performed the statistical analysis, and drafted the initial manuscript. Dr M supervised the research, provided methodological oversight, validated the laboratory protocols, and critically reviewed the manuscript for intellectual content. JM provided academic mentorship, facilitated the article submission process, and contributed to the interpretation of the mycotoxin data. All authors read, revised, and approved the final manuscript for submission. The authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Disclaimer

The views expressed in this article are solely those of the authors and do not necessarily represent the official policy or position of the University of Botswana, the Gaborone City Council, or the Ministry of Health and Wellness of Botswana. The authors assume full responsibility for the accuracy and completeness of the data and interpretations presented herein.

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