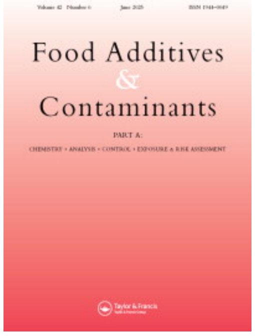

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Risk assessment of dietary exposure to aflatoxins and their levels in selected staple crops from The Gambia

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ABSTRACT

Aflatoxin contamination poses a significant public health risk in The Gambia due to its prevalence in staple crops and its association with hepatocellular carcinoma (HCC). This study assessed aflatoxin levels in maize, groundnuts, rice, and millet, and evaluated dietary exposure and liver cancer risks in the Gambian population. Aflatoxin quantification using HPLC-FLD revealed high contamination levels, particularly in groundnuts (57.5 ± 6.8 µg/kg) and maize (29.7 ± 4.2 µg/kg). Dietary exposure assessment showed that children aged 1–6 years had the highest exposure, with groundnuts contributing 350.0 ng/kg/day and maize 146.4 ng/kg/day. Margin of Exposure (MOE) values were critically low, indicating severe health risks. The estimated liver cancer risk for HBV-positive individuals was highest in children (29 cases per 100,000 from groundnuts and 12 cases per 100,000 from maize), with significant risks also observed in adults. These findings highlight the urgent need for aflatoxin mitigation strategies. Recommendations include improved pre- and post-harvest handling, investment in better storage facilities, and enforcement of regulatory limits, public health awareness campaigns, and continuous monitoring. Implementing these strategies will help reduce aflatoxin exposure and associated health risks in the Gambia.

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Aflatoxin contamination; dietary exposure; liver cancer risk; public health; mitigation strategies

Introduction

Food safety remains a critical global concern, particularly in developing countries such as sub-Saharan Africa (SSA) and South East Asia (SEA) where staple crops are susceptible to contamination by mycotoxins. These mycotoxins include aflatoxins, which are harmful metabolites produced by *Aspergillus flavus* and *Aspergillus parasiticus*. They can seriously harm both human and animal health. Aflatoxins are known carcinogens, with chronic exposure linked to hepatocellular carcinoma (HCC), immune suppression, and growth retardation in children. Their presence in staple foods such as maize, groundnuts, rice, and millet exacerbates food security challenges, particularly in sub-Saharan Africa, where climatic conditions favour fungal proliferation.

The Gambia, a small West African country having a population of about 2.5 million, relies heavily on agriculture for economic stability and food security. However, the country's warm and humid climate provides ideal conditions for aflatoxin contamination in crops. Studies indicate that aflatoxin levels in The Gambia often exceed international safety standards particularly the EU maximum limit of 4.0… g/kg and Codex Alimentarius standard of 10… g/kg, posing severe health risks, particularly for vulnerable populations such as children and individuals with hepatitis B virus (HBV) infection. Despite these concerns, limited data exist on the levels of aflatoxin contamination in staple crops and the dietary exposure of the Gambian population.

Given the significant implications of aflatoxin contamination for public health, economic stability, and food trade, there is an urgent need for comprehensive risk assessment studies. This research aims to bridge the existing knowledge

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gap by evaluating the levels of aflatoxin contamination in selected staple crops in The Gambia and assessing the dietary exposure of the population. The study provides critical data to inform policymakers, enhance regulatory frameworks, and promote effective mitigation strategies.

This research employs a multi-faceted approach, integrating fungal isolation and identification, aflatoxin quantification, dietary exposure assessment, and health risk characterisation. By analysing samples from key markets and conducting detailed consumption surveys, which will provide evidence, based insights into the extent of aflatoxin exposure in The Gambia. The findings will support efforts to develop targeted interventions, including improved agricultural practices, enhanced storage conditions, and strengthened regulatory measures to reduce aflatoxin contamination and its associated health risks.

Ultimately, this study aims to contribute to national and regional food safety policies by offering a scientific basis for aflatoxin control strategies. Addressing aflatoxin contamination in The Gambia is crucial for safeguarding public health, ensuring food security, and fostering sustainable agricultural development. Through a comprehensive risk assessment, this research seeks to highlight the urgency of aflatoxin mitigation efforts and propose actionable recommendations for reducing exposure and improving food safety standards in The Gambia.

Materials and methods

Study area

The Gambia is located in West Africa, situated between latitudes 13.280° N and 13.467° N and longitudes 16.340° W and 16.567° W. The smallest land-locked country in Africa, it has an area of 11,295 km^2, comprising 10,000 km^2 of land and 1,295 km^2 of water (Séne et al. 2024). The nation is located to the west of the Atlantic Ocean. Senegal completely encircles the nation to the north, south, and east. The Gambia River creates a long, narrow strip of land that runs through the middle of the country. The topography highlights a Miocene Pliocene stone plateau, formed from compressed quartz grains and dating back to approximately 23.7 to 1.6 million years ago. This region features predominantly flat hills accompanied by broad interfluves. To the west, small sand hills and sand depressions are present, culminating in a flat plain (Ibol 2022).

The climate of The Gambia is characterised as tropical, featuring distinct wet and dry seasons. The wet season occurs from June to November, while the dry season spans from November to May. Annual rainfall averages approximately 1,300 mm, while temperatures fluctuate between the mid-70s °F (mid-20s °C) and the low 80s °F (upper 20s °C), exhibiting minimal variation across summer and winter seasons. In the dry season, spanning December to April, the harmattan, a dry north eastern wind, reduces relative humidity (Ibol 2022).

The Gambia as shown in Figure 1 comprises five administrative regions, which include Lower River Region, Central River Region, Upper River Region, North Bank Region, and West Coast Region, along with two municipalities namely Banjul and Kanifing. The research involved a sample from Kanifing Municipality and the West Coast Region. The selection of these two regions is based on their high population density, approximately 70% greater than other areas, and their significance in trade, particularly within the agricultural sector. These regions symbolise significant agricultural and commercial centres in the country, making them suitable for an appropriate assessment of aflatoxin infestation in local food crops.

Study design

This was a cross-sectional risk assessment of aflatoxin contamination in selected staple crops of maize, groundnuts, rice, and millet in The Gambia. It involved laboratory analysis and dietary data collection to quantify the levels of contamination with aflatoxins and estimate dietary exposure among the population.

Sample collection and preparation

Ninety crop samples were collected from the four selected markets. The collection of 90 crop samples, including 20 samples each of maize, groundnuts, rice, and millet, as well as 10 samples of

Figure 1. Map of The Gambia.

imported rice, was driven by the necessity for a comprehensive and representative dataset that effectively captures the diversity of crop sources and associated contamination risks within the study area. The chosen sample size effectively balanced practical resource limitations with the necessity for statistically significant outcomes.

The stratified random sampling method was selected to improve representativeness. Stratifying the chosen markets into display and storage areas guaranteed the inclusion of both visible and stored crops, which may present varying risks of aflatoxin contamination. Random sampling within each stratum mitigates selection bias and ensures an accurate representation of the crops available for sale. This method is essential for identifying potential variations in contamination levels resulting from differences in crop handling, storage conditions, and geographical sources.

The incorporation of imported rice samples recognises the significance of international trade in food supply and the possibility of aflatoxin contamination in imported products. The study seeks to provide comprehensive data to inform food safety interventions in The Gambia by incorporating a diverse range of crop types and sources.

All samples were identified and certified by experts at the Department of Crop Production, Federal University of Technology, Minna, to ensure their authenticity and quality. Proper labelling, packaging, and transportation to the ACEMFS laboratory ensured the integrity of the samples for reliable analysis. This systematic method guarantees the reliability and relevance of the results to national food safety policies.

Upon arrival in the laboratory, samples were processed by grinding into fine flour using a milling machine and then sieving to reach a particle size of 0.5–1 mm. Milled samples were stored at -20 °C until analysis to maintain their integrity for aflatoxin contamination.

Fungal isolation and identification

Fungal isolation from the collected samples was performed using the serial dilution plate technique, following the method described by Bich et al. (2021) with minor modifications. Each milled sample was subjected to a six-level serial dilution. Specifically, 1 g of the sample was suspended in 9 mL of sterile distilled water, vortexed for 3 min, and further diluted in a stepwise manner up to 10^6 fold. From the 10^4 to 10^6 dilutions, 100 µL aliquots were plated onto three different fungal isolation media such as Potato Dextrose Agar (PDA) for general fungal growth, Malt Extract Agar (MEA) for preferential growth *of Aspergillus* and *Penicillium* species, and Yeast Extract Agar (YEA), which is selective for toxigenic fungi. All media were supplemented with 1% chloramphenicol to inhibit bacterial growth. The inoculated plates were incubated at 28 ± 2 °C for 3–7 days under normal light conditions to facilitate fungal growth.

Following the incubation period, the total fungal colonies were counted using a digital colony counter, and the fungal load was expressed as colony forming units per gram (CFU/g) of the sample. The CFU calculation was performed using the Eq. (1). Data obtained in scientific notation were transformed into the logarithmic form and presented as $\log_{10} CFU/g$ samples (Kortei et al. 2022).

$$\mathrm{CFU/g} = \frac{\text{number of collonies x } \mathit{Dilution\ factor}}{\mathit{Plating\ volumes}(\mathit{mL})} \quad (1)$$

To obtain pure fungal isolates, distinct colonies with unique morphological characteristics were sub-cultured onto fresh PDA, MEA, and YEA plates using a sterile inoculating loop. These sub-cultured plates were incubated under the same conditions until pure isolates were obtained. The purified fungal isolates were then subjected to macroscopic and microscopic identification to determine their taxonomic classification (Bich et al. 2021).

Macroscopic identification was carried out by observing key colony characteristics, including colour, texture, particle size, growth rate, and margins, on PDA, MEA, and YEA. For microscopic identification, a small portion of the fungal mycelium was placed on a glass slide, stained with lactophenol cotton blue, and observed under a compound microscope with a digital camera. Morphological structures such as hyphae, conidiophores, and conidia were examined and compared to standard taxonomic keys. Identification of *Aspergillus* species was performed using the classification keys of Klich and Pitt (1988) and (Nyongesa et al. 2015), while *Penicillium* and other fungal genera were identified using the reference guide by Pitt and Hocking (1997). Percentage occurrence of fungal species was calculated using the Eq. (2) adopted by Kortei et al. (2022)

$$\text{Percentage}(\%)\,\text{occurrence of fungal species} = \frac{\mathit{Number\ of\ species}}{\mathit{Total\ number\ of\ fungi\ isolated}} \times 100 \quad (2)$$

Aflatoxin determination

Extraction and purification

The extraction and purification of aflatoxins from various crop samples were conducted using the European Committee for Standardisation (CEN) official technique EN14123, as described by Kortei et al. (2022) with slight modification. The procedure involved sample homogenisation, filtration, dilution, and toxin elution for further quantification. For each sample, 50 g of the ground material was accurately weighed and mixed with 5 g of sodium chloride in a 1 L solvent resistant blender jar. To facilitate the extraction of aflatoxins, 100 mL of methanol (70%) was added to the mixture. The contents were then blended at high speed for 2 min using a vortex mixer to ensure thorough homogenisation. After blending, the extract was filtered through Whatman No. 113 filter paper, and the resulting filtrate was collected in a conical flask.

A 2 mL aliquot of the filtrate was diluted with 14 mL of phosphate buffered saline (PBS) to adjust the sample matrix and improve compatibility with the immunoaffinity column as recommended in LC Tech AflaCLEAN™ columns manual. From this diluted mixture, 10 mL was passed through the immunoaffinity column at a controlled flow rate of 2 mL per min to allow selective binding of aflatoxins to the column resin. Following the sample loading, the column was washed with 20 mL of ultrapure water at a flow rate of approximately 5 mL per min to remove unbound matrix components.

The bound aflatoxins were eluted from the column using 2 mL of HPLC-grade methanol, applied at a flow rate of 1 drop per second. The eluate was collected in amber glass vials to prevent light induced degradation. The purified aflatoxin extracts were then stored at 4 °C until further quantification using ultra high-performance liquid chromatography coupled with fluorescence detector (UHPLC-FLD).

Ultra high-performance liquid chromatography (UHPLC) analysis of aflatoxins

The quantification of aflatoxins (AFB1, AFB2, AFG1, and AFG2) in maize, rice, millet, and groundnut samples was conducted using UHPLC with a fluorescence detector, following a validated protocol (Kortei et al. 2022) with slight modification. The UHPLC system was optimised to achieve high sensitivity and accuracy in aflatoxin detection.

UHPLC operating conditions: The UHPLC system utilised a Spherisorb ODS1-Excel column (4.6 mm × 25 cm, 5 µm particle size, 250 Å pore size) for aflatoxin separation. The mobile phase consisted of water and methanol in the proportions of 50: 50 (v/v), delivered at a flow rate of 1 mL/min. The column temperature was maintained at 40 °C, and an injection volume of 10 µL was used for both the sample and the standard. The fluorescence detector was set at an excitation wavelength of 360 nm and an emission wavelength of 440 nm for optimal aflatoxin detection.

Limit of Detection (LOD) and Limit of Quantification (LOQ): The LOD and LOQ for aflatoxin detection were determined based on the calibration curve derived from aflatoxin standards (4 µg/kg). These parameters were calculated using the following Eqs. (3) and (4) (Kortei et al. 2022).

$$\mathrm{LOD} = \frac{3 \times standard\,deviation}{slope\,of\,calibration\,curve} \tag{3}$$

$$\mathrm{LOQ} = 3\,\mathrm{X}\,\mathrm{LOD} \tag{4}$$

Measurement accuracy

To assess the accuracy of the method, a spiking experiment was conducted using pure aflatoxin standards. Three concentration levels, low (5 ppb), medium (15 ppb), and high (30 ppb) were used for spiking blank aflatoxin free samples. The volume of pure standard added was calculated using the Eq. (5) (Kortei et al. 2022).

$$\text{Volume of Pure Standard} = \frac{sample\,weight\,(g)\,X\,Spike\,concentration\,(ppb)}{Concentration\,of\,standard\left(\frac{\mu g}{mL}\right)} \tag{5}$$

The percentage recovery was determined by analysing the spiked samples and comparing them to the blank samples using Eq. 6 (Kortei et al. 2022).

$$\%\text{Recovery} = \frac{Concentration\ measured\ in\ spiked\ sample - \text{Concentration measured in blank}}{Spiked\ amount} \mathrm{x}100\% \tag{6}$$

Measurement precision: To ensure the precision of the method, an internal reference material (IRM) was analysed under repeatability and intermediate precision conditions. Ten parallel extractions of the IRM were analysed on the HPLC system by the same technician to assess repeatability. Additionally, ten extractions of the IRM were performed by a different technician on separate days to evaluate intermediate precision. The relative standard deviation (RSD) was calculated using the Eq. (7)

$$\mathrm{RSD} = \frac{Standard\,deviation}{mean} \mathrm{X}100\% \tag{7}$$

Dietary consumption data collection

The dietary exposure to staple foods such as maize, groundnuts, rice, and millet were assessed in the Kanifing Municipality and the West Coast Region. The questionnaires assessed the frequency of consumption of these foods. This was supplemented with a two day 24-hour recall questionnaire and a weighing technique to quantify the amount consumed as adopted by Udovicki et al. (2021). The appropriate sample size was determined for the cross sectional study using the Eq. (8) as adopted by Kholmatova et al. (2016).

$$\mathrm{n} = \frac{z^2 . p . \left(1 - p\right)}{d^2} \tag{8}$$

$Z = 1.96$ (for 95% confidence level), $p = 0.5$ (estimated prevalence for maximum variability), and $d = 0.05$ (margin of error)

Substituting these values:

$$n = \frac{(1.96)^2 . 0.5 . \left(1 - 0.5\right)}{0.05^2} = 384$$

To account for the finite population of the study area, the finite population correction formula was applied in Eq. (9) (Kholmatova et al. 2016).

$$n_{adjusted} = \frac{\mathrm{n}}{1 + \frac{n-1}{N}} \tag{9}$$

N is the estimated population size of the study area. The final sample size was fixed at 272 individuals, distributed among 50 households (25 per region), after making adjustments and considering practical limits. This sample size provides enough statistical power to estimate dietary exposure to aflatoxins. The participants were distributed among 50 households, selecting 25 households from each region. The study comprised 150 males and 122 females, aged from 1 to 75 years, with an average age of 35 years. These were further classified into age groups such as 1–6 years (10%), 7–17 years (25.5%), 18–59 years (60.4%), and 60+ years (4.1%). The robust sample size was to accurately gauge the population's dietary exposure to aflatoxins.

Health risk assessment

Dietary exposure calculation

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) validated the approach of Udovicki et al. (2021) in evaluating human exposure to mycotoxins by calculating the estimated daily intake (EDI) and the percentage of tolerated daily intake (%TDI). Eq. (10) provided the method for calculating the EDI for the mean concentration of the total aflatoxins.

$$\mathrm{EDI} = \sum_{i=1}^{n} \frac{Di\, x Mi}{W} \tag{10}$$

EDI represents the quantification of daily AFB_1 intake from food, articulated in nanograms per kilogram of body weight per day. D_i presents the daily food consumption per capita for each age group, quantified in grams per person per day. M_i represents the mean concentration of AFB_1 across each dietary category, measured in Nano grams per kilogram (ng/kg). The variable 'W' represents each participant's body weight in kilograms. The average weight of the participants was calculated for each age category; 1–6 years to be 15 kg, and the average weight of those aged 7 to 17 years was found to be 35 kg. We project the average weight for the two remaining age groups 18–59 years and 60 years and above to be 60 and 55 kg, respectively. The MS Excel software was used to calculate the average daily exposure to AFB_1.

Liver cancer risk estimation using margin of exposure (MOE)

The MOE is one of the key parameters used to measure the degree of severity in relation to carcinogens like aflatoxins. The formula calculates the MOE by dividing the estimated daily intake of aflatoxins (EDI) by the Benchmark Dose Lower Confidence Limit ($BMDL_{10}$) as shown in Eq. (11), which represents the dose that causes a small but measurable effect, such as 10% in animal tests (Schrenk et al. 2020).

$$\mathrm{MOE} = \frac{\text{Benchmark Dose Lower confedence Limit}\left(\mathrm{BMDL}\right)_{10}}{\text{Estimated Daily Intake}\left(\mathrm{EDI}\right)} \tag{11}$$

Animal experiments or epidemiological findings typically lead to the development of Benchmark Dose Lower Limits (BMDLs) for aflatoxins. For instance, JECFA has suggested a

BMDL of 870 ng/kg body weight/day for aflatoxins related to the risk of liver cancer for humans (Schrenk et al. 2020).

The Gambian population's average consumption pattern and the amount of aflatoxin present in food crops form the basis of the EDI calculation. It gives the measure of intake of aflatoxin per individual per day. When it comes to genotoxic and carcinogenic substances like aflatoxins, an MOE below 10,000 is considered a health concern, potentially putting the population at risk of liver cancer. The lower the MOE, the higher the risk (Udovicki et al. 2021).

Estimated hepatocellular carcinoma (HCC) risk due to consumption of groundnut, maize, rice, and millet

The risk of HCC from aflatoxin exposure through the consumption of groundnut, rice, millet, and maize has been estimated for the Gambian population using cancer potency factors from JECFA (Shephard 2008). Aflatoxins are potent carcinogens with an estimated cancer potency of 0.3 cases per 100,000 persons per year per ng/kg bw/day for individuals infected with Hepatitis B (HBsAg+) and 30 (i.e. 0.01) times lower in the absence of the infection (HBsAg−). Using The Gambia prevalence of 25% and a total population of 2.5 million people (Ndow et al. 2022), the Eq. (12) was used to calculate the cancer potency factor (P_{cancer}) as agree by JECFA and Eq. (13) to calculate the total number of people at risk of HCC annually per 100,000 people of the population

$$\text{Cancer potency factor} = \left(\text{HBsAg} - \text{x}\,25\%\right) + \left(\text{HBsAg} + \text{x}\,75\%\right) \quad (12)$$

$$\text{HCC Population Risk} = \text{EDI x Cancer potency} \quad (13)$$

Data analysis

Data pre-processing, transformation, and analytical procedures was performed using SPSS and MS Excel software. Descriptive statistical measures, including means and standard deviations, were calculated for the aflatoxin concentration, as well as the analysis of correlations between levels of aflatoxins and health risk outcomes. One way ANOVA was used to assess the variations in aflatoxin concentration among different crops and markets, using a p-value of 5% as the level of significance.

Results and discussion

Fungal isolates in maize

Figure 2 presents some of the fungal species identified in the analysis of maize samples from different markets in The Gambia. The study isolated potentially hazardous *Aspergillus* species, which included *Aspergillus flavus* (15.8%) and *Aspergillus niger* (13.2%). Other common fungi identified were *Rhizopus* and *Aspergillus fumigatus*, both of which account for 10.5% of stored grains.

Fungal isolates in groundnut

Figure 3 presents the fungal analysis of groundnut samples from various markets in The Gambia, identifying several fungi. *Aspergillus niger* was the most frequently isolated species, 17.6%. However, the incidence of *Aspergillus flavus*, at 11.8%, was of significant concern in this study due to its potential to produce aflatoxin, which poses a significant health risk. Further, other samples reported the presence of *Rhizopus* 11.8% and Mucor 11.8%, which are known to be common spoilers of groundnut. *A. fumigatus* (8.8%) and *Penicillium verrucosum* (8.8%) in groundnuts depict a variety of fungi that might imply consequences for food safety and quality.

The percentage of fungi isolated, differed between markets, with Brikama Market (BM) being the most contaminated at 17.6% of the total isolates; Serekunda (SM) and Latrikunda Markets (LM) followed each other in terms of the rate of contamination, each contributing 14.7% of the total isolates.

Fungal isolates in millet

The analysis of millet samples from various markets in The Gambia, as shown in Figure 4, indicated a notable prevalence of *Aspergillus* species.

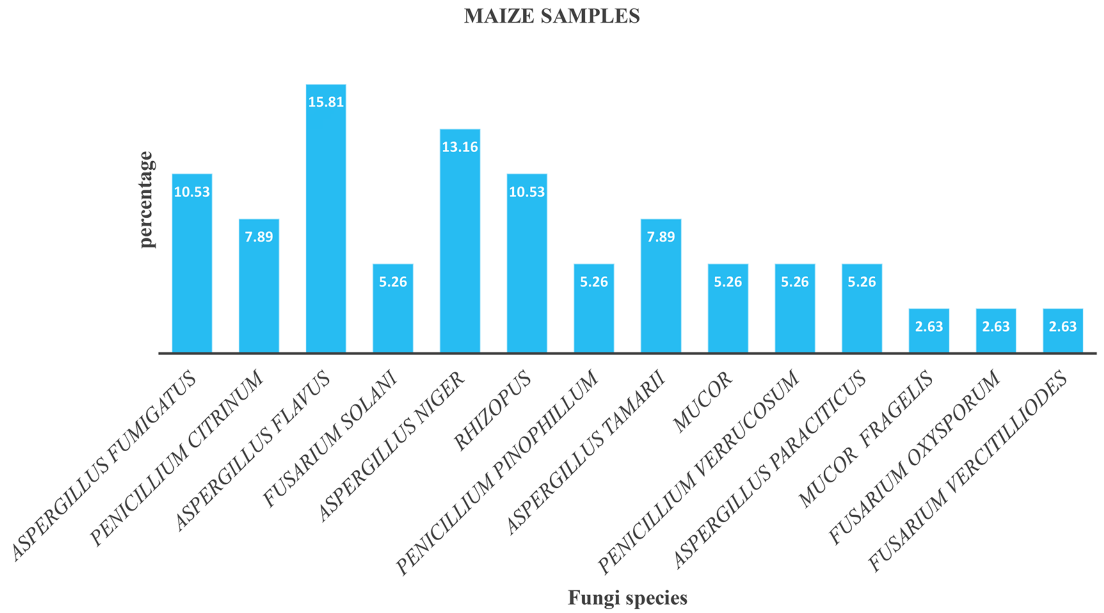

Figure 2. Fungi isolates in maize from different markets in The Gambia.

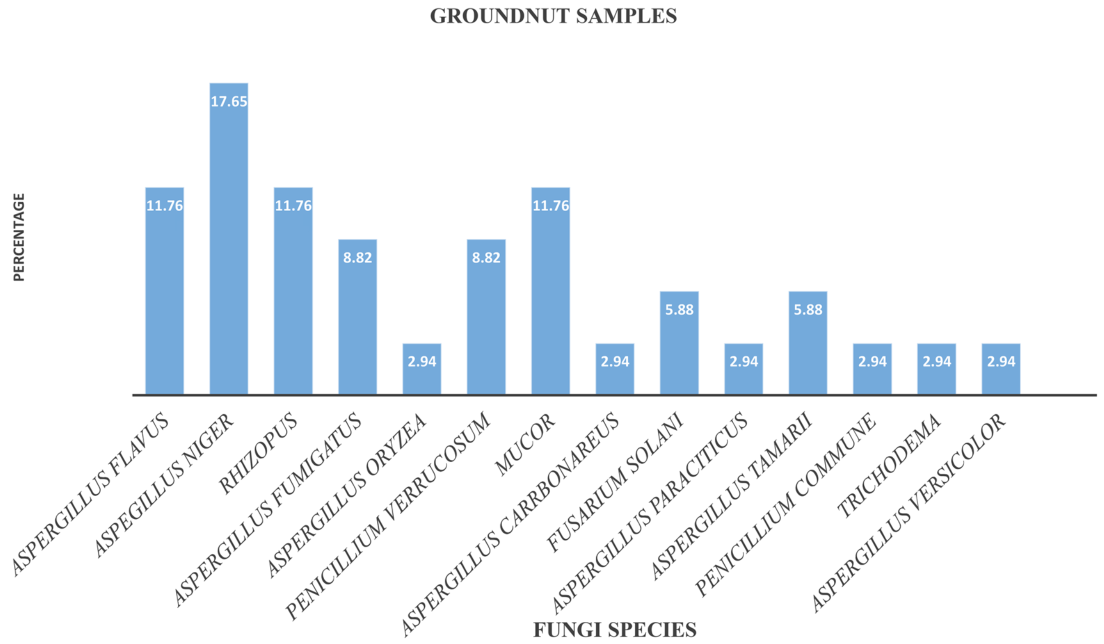

Figure 3. Fungi isolates in groundnut from different markets in The Gambia.

The recorded highest isolation frequency was 21.0% for *Aspergillus fumigatus*, followed by 15.8% for *Aspergillus flavus*, and 10.5% for *Aspergillus niger*. Additional isolated species include *Rhizopus* and *Cladosporium oxysporum*, two common storage fungi that can negatively affect grain quality and safety.

The fungal load for millet varied across the examined markets with the Latrikunda Market (LM) displaying a particularly diverse pattern. *Penicillium verrucosum*, *Penicillium citrinum*, and *Fusarium* species are less common fungi that are linked to mycotoxin risks. Brikama Market (BM) exhibited the highest total of fungal isolates, comprising 18.42%, with dominant species including *Aspergilus flavus.*

Fungal isolates in local rice

The fungal analysis of local rice varieties from various markets in The Gambia, as presented in Figure 5, revealed a predominant occurrence of

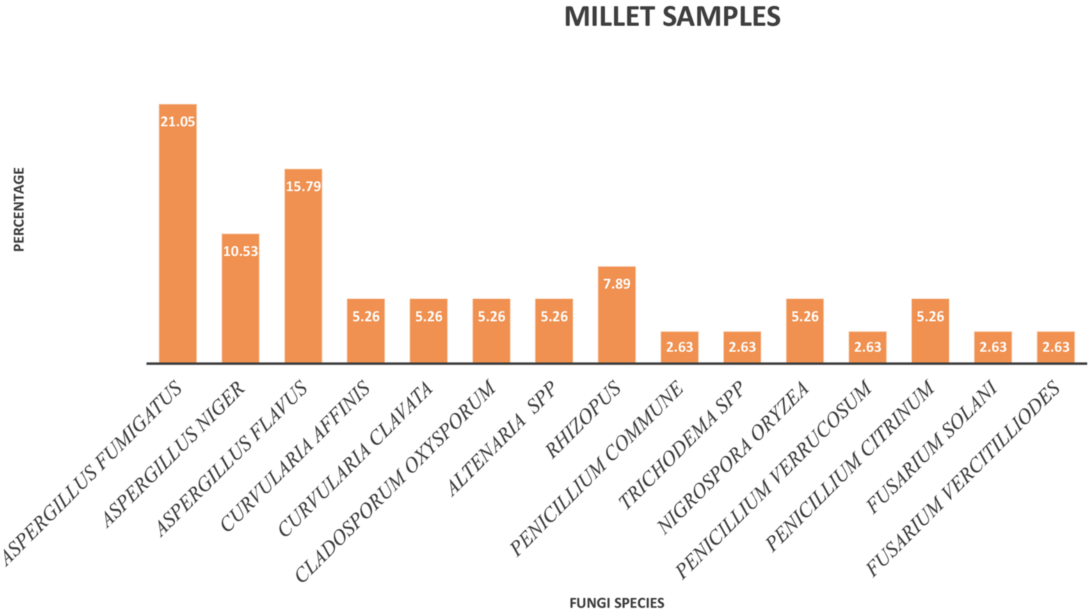

Figure 4. Fungi isolates in millet from different markets in The Gambia.

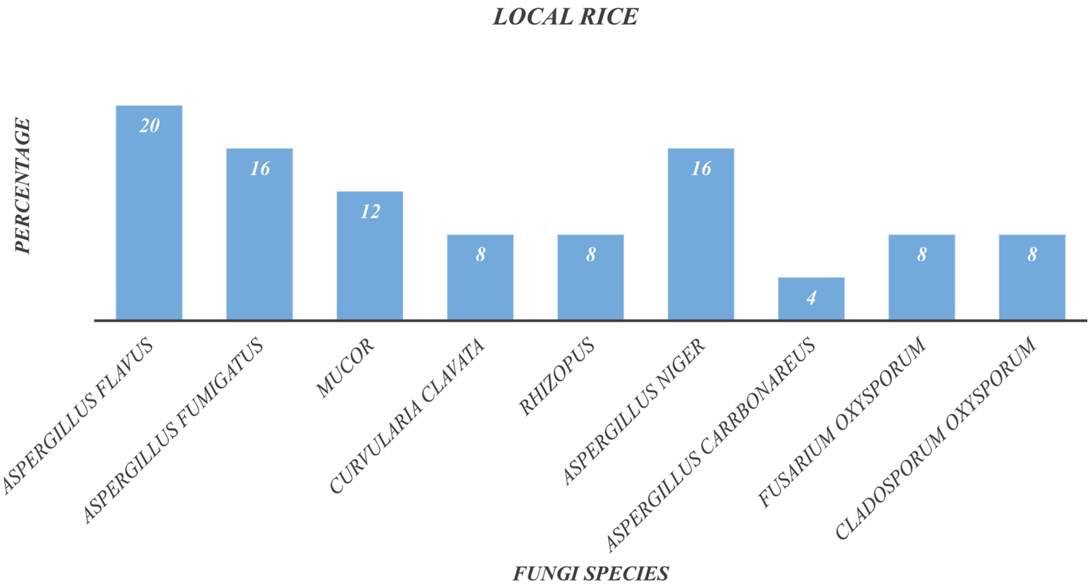

Figure 5. Fungi isolates in local rice from different markets in The Gambia.

Aspergillus flavus at 20%, followed by *Aspergillus fumigatus* and *Aspergillus niger*, each at 16%. Other rare representatives of the isolated species include *Mucor* and *Rhizopus*, which have occurrence rates of 12% and 8%, respectively.

Fungal load for local rice also exhibited variation across the different markets. Serekunda Market (SM) exhibited significant contamination, accounting for 24% of the total isolates, and harboured various fungal species, including A. niger, *Cladosporium oxysporum*, and *Rhizopus*. Additionally, both the Old Yundum (OM) Market and Brikama Market (BM) exhibited an identical fungal load of 16%, signifying the presence of multiple *Aspergillus* species within the same sample.

Fungal isolates in imported rice

The fungal analysis of imported rice samples from two markets in The Gambia, as presented in Figure 6, indicates a moderate diversity of

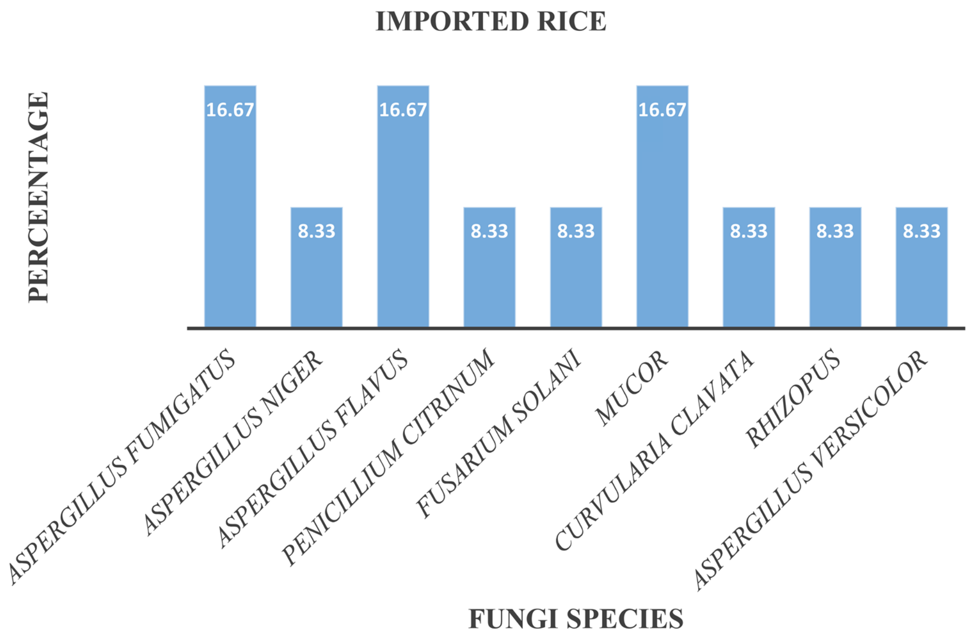

Figure 6. Fungi isolates in imported rice in The Gambia.

Table 1. The colonisation of fungi in maize, groundnut, millet, and rice.

	Number of colony X 10^3 CFU/g (Mean ± Standard Deviation)				
Market/crops	Maize	Millet	Groundnut	Local rice	Imported rice
Old Yundum	60.67±81.95^{a}	37.66±52.14^{a}	34.67±17.55^{c}	2.66±1.21^{c}	–
Brikama	28.33± 25.00^{b}	18.50±16.78^{c}	36.83±16.31^{c}	24.3±44.29^{b}	13.67±9.07^{c}
Serekunda	12.50± 14.79^{c}	36.17±40.93^{a}	54.56±30.33^{b}	16.00±23.69^{c}	–
Latrikunda	50.00± 57.46^{a}	36.67±30.53^{b}	29.20±10.53^{c}	15.50±12.53^{c}	–
Total	37.80±52.22^{a}	32.25±35.85^{b}	38.82±18.68^{c}	14.43±26.80^{c}	13.67±9.07^{c}

Mean value and standard deviation (CFU/g) with different alphabets along the column are significantly different from each other at $p < 0.05$.

fungal species. The analysis identifies three predominant species: *Aspergillus fumigatus*, *Aspergillus flavus*, and Mucor, each accounting for 16.7% of the total fungal isolates. Additional fungi identified in this study are *Aspergillus niger, Penicillium citrinum*, and *Fusarium solani*, each comprising 8.3% of the total findings.

Fungal contamination in maize, groundnut, millet, and rice

The results obtained demonstrated different levels of fungal contamination in crops and markets, measured in CFU/g, as shown in Table 1. The Old Yundum Market recorded the highest average fungal contamination for maize, ranging from 60.7 to 81.9 CFU/g. It recorded levels that are significantly higher than those of other markets. In relation to millet, the highest mean contamination was observed at Serekunda Market, with a value of 36.2 ± 40.9 CFU/g. For groundnuts, significant contamination levels were noted at Serekunda with 54.6 ± 30.3 CFU/g and at Brikama with 36.8 ± 16.3 CFU/g. Local rice samples from Brikama exhibited a notable contamination level of 24.3 ± 44.3 CFU/g. Imported rice exhibited the lowest level of contamination, with a total mean of 13.7 ± 9.1 CFU/g. The data indicate that groundnut, maize, and millet exhibit a higher susceptibility to fungal contamination in the studied markets, particularly in Old Yundum and Serekunda, thereby highlighting a potential safety concern in those areas.

Dietary consumption of maize, groundnuts, rice, and millet

Consumption frequency

The Figure 7 shows the frequency of consumption for five major crops: maize, millet, local rice,

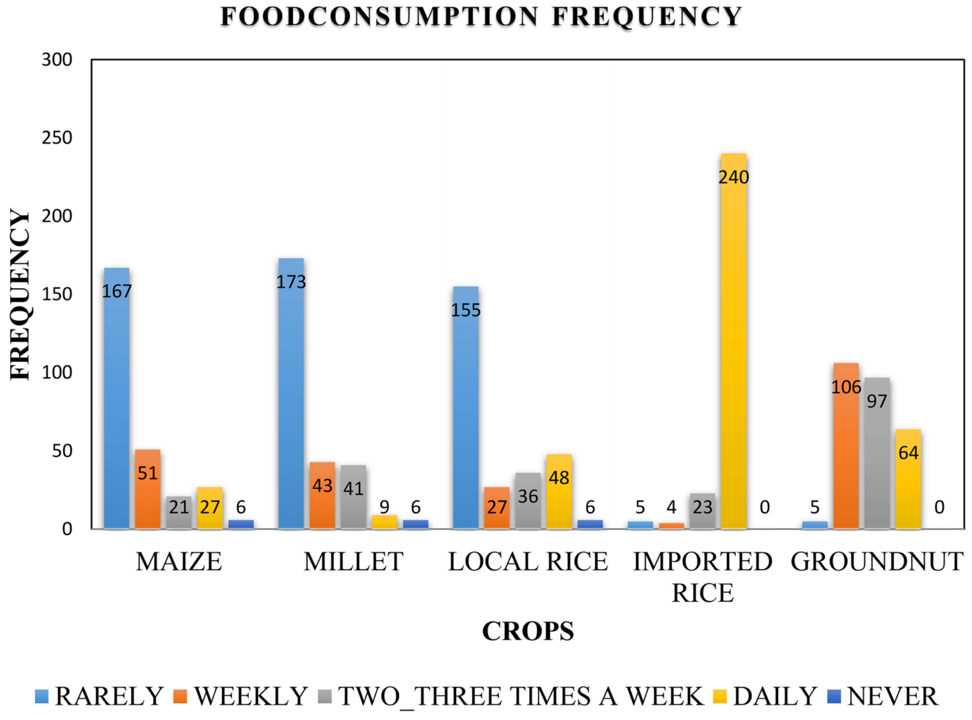

Figure 7. Food consumption frequency of staple crops in The Gambia.

imported rice, and groundnuts in The Gambia. This set categorises consumption into five levels: rarely, weekly, two - three times a week, daily, and never.

The majority of the population, represented by 187 respondents, consumes maize infrequently. A smaller proportion consumes maize once a week, which includes 51 respondents; two to three times a week includes 27 respondents; and every day also includes 27 respondents. This suggests that maize is not a staple food for most Gambians but rather a supplemental one for some people.

Most of the population rarely consumes millet, with 193 individuals reporting infrequent consumption. 45 individuals have a low rate of consumption per week; 42 individuals consume it two to three times in a week, and only 12 people consume it daily. Six individuals do not consume millet. Therefore, it appears that diets are gradually shifting away from millet to more readily available staple foods.

The consumption of local rice is equally low: 160 consume it rarely, and only 57 consume it weekly. Only 36 people consume it two to three times a week, 18 people consume it daily, and 27 people consume it never. These figures indicate a dwindling taste for locally grown rice, probably due to the increasing supply of imported rice.

Imported rice emerges as the most frequently consumed crop, with 233 individuals reporting daily consumption. It has relatively low representation in other categories: rarely (12 individuals), weekly (15 individuals), and two to three times a week (39 individuals). None of the respondents reported never consuming imported rice, emphasising its dominance in Gambian diets as the primary staple food.

The distribution of groundnut consumption across frequency levels is more even. Whereas 106 consume it once a week and 100 people consume it two to three times a week, only one-third consume it rarely (30 persons), and as many as 63 persons consume it daily. Nobody reported never consuming groundnuts.

Average daily consumption

Figure 8 below shows the daily consumption of selected food crops by age group in The Gambia. Children aged 1–6 years old consume 105 g/day of groundnut, adolescents aged 7–17 years old consume 118 g/day, adults aged 18–59 years old consume 153 g/day, and the elderly (over 60 years) consume 182 g/day. All age groups, and especially

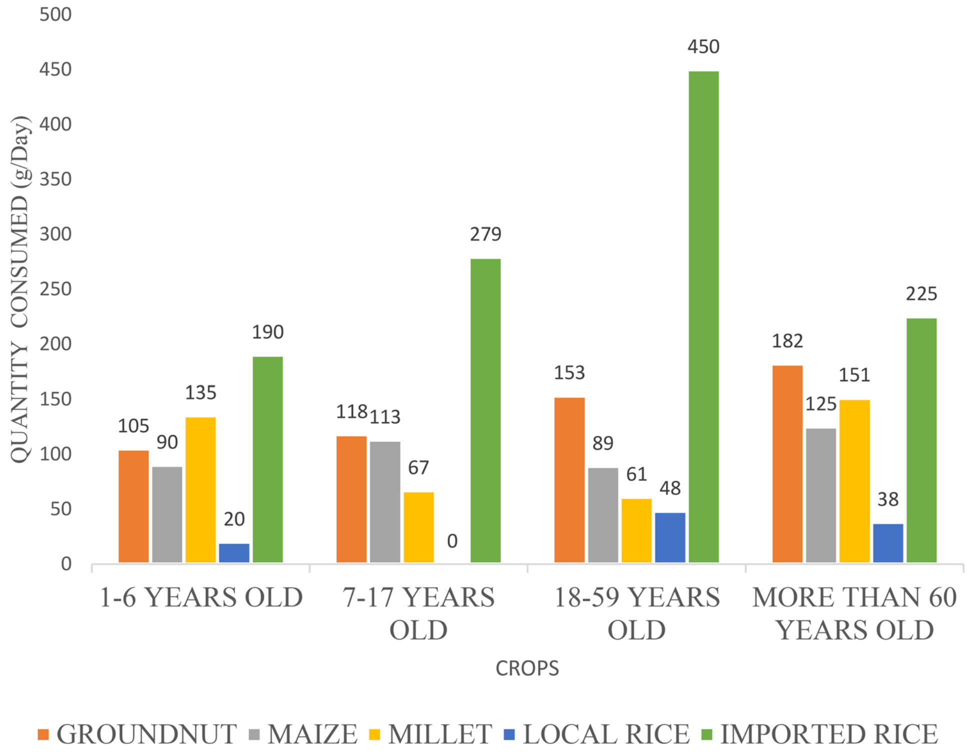

Figure 8. Average consumption in gram per day of staple crops according to age groups.

Table 2. UHPLC-FLD parameters for validating repeatability, precision, recovery, limit of Detection (LOD), and limit of quantification (LOQ) for aflatoxins detection.

Aflatoxin	**LOD* (µg/kg)**	**LOQ** (µg/kg)**	Repeatability (%RSD)	Intermediate precision (%RSD)	Recovery (%)	Linearity (R^2)
AFB_1	0.22	0.64	6.1%	12.9	105.2	0.991
AFB_2	0.18	0.49	7.0%	14.1	89.6	0.990
AFG_1	0.28	0.81	7.9%	13.4	110.2	0.988
AFG_2	0.34	1.10	11.7%	13.0	109.3	0.984

*LOD-Limit of detection: LOD for all aflatoxins should be less than 1 µg/kg.
**LOQ-Limit of quantification: LOQ for all aflatoxins should be less than 3 µg/ kg.

those in advanced stages of age, consume groundnuts, according to the trend.

The consumption of maize varies among the different age groups. It is relatively high among adolescents aged 7–17 years, at 113 g/day, and even higher for the elderly (over 60 years), at 125 g/day. Conversely, adults aged 18–59 years consume the least, at 89 g/day. This suggests that maize is a staple food for younger and older populations, but middle-aged adults consume less of it. The quantities of millet consumed are highest for children aged between 1 and 6 years at 135 g/day, and for the elderly, 151 g/day. Adolescents consume a smaller quantity of 67 g/day; while adults aged 18–59 consume even less at 61 g/day. Therefore, it seems that younger children and older individuals are more likely to include millet in their diets.

Local rice has low consumption levels across all age groups. Adults aged 18–59 years consume the highest amount at 48 g/day, while adolescents aged 7–17 years report no consumption (0 g/day). Compared to other staples, local rice consumption seems limited.

Among cereals, imported rice is the most consumed. The intake is highest among adults 18–59 years at 450 g/day, followed by adolescents at 279 g/day, the elderly at 225 g/day, and children aged 1–6 years at 190 g/day. This indicates that imported rice has become the main dietary staple for all age categories, especially in the case of adults. These findings denote a remarkable dietary pattern, dominated by imported rice and supported greatly by other staples like groundnuts, maize, and millet, though preference among age groups varies.

Table 3. Aflatoxins levels in staple crops (maize, groundnut, rice, and millet) samples from selected market in The Gambia.

Crop	Market	AFB1 (μg/kg) Mean ± SD	AFB2 (μg/kg) Mean ± SD	AFG1 (μg/kg) Mean ± SD	AFG2 (μg/kg) Mean ± SD	Total AFs (μg/kg) Mean ± SD
Maize	BM	12.27 ± 0.35^{b}	4.27 ± 0.21^{b}	5.57 ± 0.25^{b}	2.27 ± 0.25^{b}	24.37 ± 0.35^{b}
	SM	10.80 ± 0.40^{c}	3.53 ± 0.25^{c}	4.93 ± 0.25^{c}	1.87 ± 0.25^{c}	21.13 ± 0.65^{c}
	LM	15.20 ± 0.30^{a}	5.07 ± 0.25^{a}	6.77 ± 0.35^{a}	2.60 ± 0.30^{a}	29.63 ± 0.50^{a}
	OM	9.47 ± 0.35^{d}	3.23 ± 0.25^{c}	4.43 ± 0.25^{c}	1.70 ± 0.30^{c}	18.83 ± 0.65^{d}
	Total	11.93 ± 2.25^{c}	4.03 ± 0.77^{c}	5.43 ± 0.94^{c}	2.11 ± 0.44^{c}	23.49 ± 4.26^{c}
Local Rice	BM	6.70 ± 0.40^{c}	2.13 ± 0.25^{c}	3.20 ± 0.30^{c}	1.10 ± 0.30^{c}	13.13 ± 0.65^{c}
	SM	5.30 ± 0.30^{d}	1.70 ± 0.30^{d}	2.90 ± 0.30^{d}	1.00 ± 0.30^{c}	10.90 ± 0.60^{d}
	LM	14.87 ± 1.39^{a}	5.13 ± 1.01^{a}	6.87 ± 1.17^{a}	2.60 ± 1.37^{a}	29.47 ± 4.85^{a}
	OM	9.30 ± 1.05^{b}	3.07 ± 0.95^{b}	4.43 ± 0.99^{b}	1.50 ± 0.89^{b}	18.30 ± 3.80^{b}
	Total	9.04 ± 3.90^{d}	3.01 ± 1.51^{d}	4.35 ± 1.77^{d}	1.55 ± 0.98^{c}	17.95 ± 7.95^{d}
Imported Rice	BM	4.83 ± 0.35^{a}	1.50 ± 0.20^{e}	2.13 ± 0.25^{a}	0.80 ± 0.30^{a}	9.27 ± 0.60^{a}
	SM	3.60 ± 0.30^{b}	1.10 ± 0.20^{e}	1.70 ± 0.30^{b}	0.70 ± 0.30^{a}	7.10 ± 0.50^{b}
	Total	4.22 ± 0.74^{e}	1.30 ± 0.28^{e}	1.92 ± 0.34^{e}	0.75 ± 0.27^{d}	8.18 ± 1.29^{e}
Groundnut	BM	25.40 ± 0.40^{b}	8.30 ± 0.30^{b}	12.20 ± 0.30^{b}	4.60 ± 0.30^{b}	50.50 ± 0.70^{b}
	SM	21.70 ± 0.40^{c}	7.40 ± 0.30^{c}	10.80 ± 0.30^{c}	3.90 ± 0.30^{c}	43.80 ± 0.70^{c}
	LM	28.20 ± 0.30^{a}	9.70 ± 0.30^{a}	14.40 ± 0.30^{a}	5.20 ± 0.30^{a}	57.50 ± 0.60^{a}
	OM	20.30 ± 0.40^{c}	6.80 ± 0.30^{d}	9.70 ± 0.30^{d}	3.40 ± 0.30^{c}	40.20 ± 0.70^{d}
	Total	23.9 ± 3.26^{a}	8.05 ± 1.17^{a}	11.78 ± 1.85^{a}	4.28 ± 0.76^{a}	48.00 ± 6.93^{a}
Millet	BM	8.87 ± 0.35^{c}	2.80 ± 0.30^{c}	4.30 ± 0.30^{c}	1.50 ± 0.30^{c}	17.47 ± 0.65^{c}
	SM	7.57 ± 0.35^{c}	2.40 ± 0.30^{c}	3.80 ± 0.30^{c}	1.30 ± 0.30^{c}	15.07 ± 0.65^{d}
	LM	28.20 ± 1.45^{a}	9.63 ± 1.23^{a}	14.43 ± 1.01^{a}	5.13 ± 1.15^{a}	57.40 ± 4.83^{a}
	OM	19.93 ± 1.33^{b}	6.43 ± 1.27^{b}	9.37 ± 1.32^{b}	3.23 ± 1.35^{b}	38.97 ± 5.25^{b}
	Total	16.14 ± 8.88^{b}	5.32 ± 3.17^{b}	7.98 ± 4.57^{b}	2.79 ± 1.79^{b}	32.23 ± 18.29^{b}
Total	BM	11.61 ± 7.59^{c}	3.80 ± 2.53^{c}	5.48 ± 3.68^{c}	2.05 ± 1.43^{b}	22.95 ± 15.18^{c}
	SM	9.79 ± 6.66^{d}	3.23 ± 2.33^{c}	4.83 ± 3.29^{c}	1.75 ± 1.21^{c}	19.60 ± 13.43^{d}
	LM	21.62 ± 6.93^{a}	7.38 ± 2.49^{a}	10.62 ± 4.03^{a}	3.88 ± 1.55^{a}	43.50 ± 14.86^{a}
	OM	14.75 ± 5.66^{b}	4.88 ± 1.95^{b}	6.98 ± 2.76^{b}	2.46 ± 1.15^{b}	29.08 ± 11.34^{b}
	Total	14.03 ± 7.96	4.68 ± 2.77	6.77 ± 4.04	2.47 ± 1.53	27.95 ± 16.21

Mean ± standard = deviation of triplicates. Values with different superscripts in a column are significantly different ($p \leq 0.05$).
BM = Berikama Market; SM = Serekunda Market; LM = Latrikunda Market; Old Yundum Market; AF = Aflatoxin. Maximum tolerable limit for total aflatoxins is 4.0 μg/kg base on EU standard.

Aflatoxin quantification in maize, groundnut, rice, and millet

The results of aflatoxin quantification in maize, groundnut, rice, and millet samples from different markets in The Gambia showed varying levels of contamination. The highest aflatoxin contamination in maize as shown in Table 3 was recorded at Latrikunda Market (29.6 ± 0.5 μg/kg), followed by Brikama Market (24.4 ± 0.3 μg/kg), Serekunda Market (21.1 ± 0.6 μg/kg), and Old Yundum Market (18.8 ± 0.6 μg/kg). Groundnut samples exhibited the highest contamination among all the crops, with Latrikunda Market showing the highest mean total aflatoxin concentration (57.5 ± 0.6 μg/kg), followed by Brikama Market (50.5 ± 0.7 μg/kg), Serekunda Market (43.8 ± 0.7 μg/kg), and Old Yundum Market (40.2 ± 0.7 μg/kg).

Local rice samples had lower contamination levels, with aflatoxin concentrations ranging from 10.9 ± 0.6 μg/kg at Serekunda Market to 13.1 ± 0.6 μg/kg at Brikama Market. Imported rice had the lowest aflatoxin contamination, with Brikama Market showing 9.3 ± 0.6 μg/kg and Serekunda Market 7.1 ± 0.5 μg/kg. Millet samples showed moderate contamination, with Latrikunda Market recording the highest total aflatoxin concentration of 57.4 ± 4.8 μg/kg, followed by Serekunda Market with 17.5 ± 0.6 μg/kg.

The Limit of Detections (LOD) for AFB$_1$, AFB$_2$, AFG$_1$, and AFG$_2$ as presented in Table 2 were set at 0.22, 0.18, 0.28, and 0.34 μg/kg, respectively, while the Limit of Quantifications (LOQ) were set at 0.64, 0.49, 0.81, and 1.10 μg/kg, respectively. All aflatoxin concentrations measured in this study were above the LOQ, ensuring the reliability of the findings. The recovery rates obtained in the UHPLC-FLD method ranged from 85% to 120%, indicating a high level of precision and accuracy.

Exposure assessment, margin of exposure, hazard quotient, and estimated hepatocellular carcinoma risk

Dietary exposure

The dietary exposure as illustrated in Table 4, for children aged 1–6 years with average body weight of 15 kg, the highest dietary exposure was

Table 4. Aflatoxin exposure in maize, groundnut, rice, and millet from the Gambia and estimated annual primary liver cancer risk/100,000 people for various age categories in the Gambia.

Age group	Crop	Contamination (ng/g)	Daily Food Intake (g/day)	Exposure (ng/kg/day)	Annual PLCR/100,000 (HBV+)
1–6 years	Maize	24.4	90	146.4	12.1
	Groundnut	50.5	105	353.5	29.2
	Local Rice	13.1	20	17.5	1.4
	Millet	17.5	135	157.5	13.0
7–17 years	Maize	24.4	113	78.8	6.5
	Groundnut	50.5	118	170.3	14.0
	Millet	17.5	67	33.5	2.8
18–59 years	Maize	24.4	89	36.2	3.0
	Groundnut	50.5	153	128.8	10.6
	Local Rice	13.1	48	10.5	0.9
	Millet	17.5	61	17.8	1.5
60+ years	Maize	24.4	125	55.5	4.6
	Groundnut	50.5	182	167.1	13.8
	Local Rice	13.1	38	9.1	0.8
	Millet	17.5	151	48.0	4.0

The average body weight for age group 1–6, 7–17, 18–59, and 60 above are 15, 35, 60, and 55 years, respectively.
PLCR = primary level of cancer risk.

Table 5. Health risk characterisation of exposure to various crops from the Gambia using margin of exposure.

Age group	Crop	Exposure (ng/kg/day)	MOE
1–6 years	Maize	146.4	6.0
	Groundnut	353.3	2.5
	Local rice	17.5	50.0
	Millet	157.5	5.5
7–17 years	Maize	78.8	11.0
	Groundnut	170.3	5.1
	Millet	33.5	30.0
18–59 years	Maize	36.2	24.0
	Groundnut	128.8	6.8
	Local Rice	10.5	82.5
	Millet	17.8	48.9
60+ years	Maize	55.5	15.7
	Groundnut	167.1	5.2
	Local rice	9.1	95.6
	Millet	48.0	18.1

Human BMD lower limit for 10% increased risk, taken as 870 ng·kg^{-1} body weight day-1

recorded for groundnuts (353.3 ng/kg/day), followed by millet (289.8 ng/kg/day), maize (146.4 ng/kg/day), and local rice (17.5 ng/kg/day). Adults aged 18–59 years with average body weight of 60 kg also exhibited high dietary exposure levels, particularly for groundnuts (128.8 ng/kg/day) and maize (36.2 ng/kg/day). The lowest exposure levels were observed in the elderly population (60+ years) with average body weight of 55 kg for local rice (9.1 ng/kg/day).

Margin of exposure (MOE)

The MOE values across all age groups and crops as shown in Table 5 were significantly below the threshold of 10,000, indicating a high health risk. For the age group 1–6 years, MOE values were lowest for groundnuts (2.5) and millet (3.0). Similarly, for adults aged 18–59 years, MOE values for groundnuts and maize were 6.8 and 24, respectively, highlighting a critical health concern.

Estimated hepatocellular carcinoma risk

The annual primary liver cancer risk due to aflatoxin exposure as shown in Table 4, expressed per 100,000 individuals, was highest in children aged 1–6 years. For HBV-positive individuals, groundnuts presented a cancer risk of 29.0 cases per 100,000, while maize posed a risk of 12.0 cases per 100,000, and millet presented a cancer risk of 23.9 cases per 100,000. Among adults aged 18–59 years, the cancer risks were highest for groundnuts 10.6 cases per 100,000 and maize 2.9 cases per 100,000).

The average daily intake and estimated daily intake for each the groundnut, maize, millet and rice were used to determine the total number of people at risk of liver cancer and margin of exposure to characterise the risk of exposure of each crop as illustrated in Table 6. The average body weight for the age categories is 41 years and average daily intake for groundnut is 140 g/day, maize is 104 g/day, millet is 103.5 g/day and local rice is 27 g/day. The average estimated daily intake using average body weight, daily intake, and the concentration of aflatoxins in crops, the value for groundnut is 172.4 ng/kg bodyweight per day and maize 61.9 ng/kg bodyweight per day. The average margin of exposure for groundnut is 5.0 and that of maize is 14.1. The total number of Gambians at risk of liver cancer due to aflatoxins exposure is illustrated in Table 6 for the consumption of

Table 6. The average daily intake, estimated daily intake, margin of exposure, and the total number of people at risk of HCC per 100,000 population using an average body weight of 41 kg for the consumption of various crops in The Gambia.

Crop	Contamination (ng/Kg)	Average daily intake (g/day)	EDI (ng/Kg/day	MOE	PLCR/100,000/year
Groundnut	50.5	140	172.4	5.0	14.2
Maize	24.4	104	61.9	14.0	5.1
Millet	17.5	103.5	44.2	19.7	3.6
Local rice	13.1	27	8.6	101.2	0.7

European Food Safety Authority(EFSA) $BMDL_{10}$ for human 870 ng/Kg was used to calculate the margin of exposure. EFSA maximum limit for total aflatoxins in foods is 4μ g/Kg.
PLCR = primary liver cancer risk, EDI = estimated daily intake and MOE = margin of exposure.

groundnut is 14.2 persons per 100,000 population and maize is 5.1 persons per 100.000 population.

Discussion

The results highlight significant fungal contamination in staple crops from The Gambia, with *Aspergillus flavus* and *Aspergillus niger* being the most prevalent species. These findings align with studies from other African regions, confirming that warm and humid conditions support fungal growth (Ezekiel et al. 2021; Kortei et al. 2023). Among the sampled crops, maize exhibited the highest fungal contamination, particularly in Old Yundum Market, where levels ranged from 60.67 to 81.95 CFU/g. This is consistent with studies from Ghana's rural markets (Asare Bediako et al. 2019). High fungal loads in maize samples could be attributed to post-harvest handling, prolonged storage, and inadequate drying methods, which favour fungal proliferation. Similarly, groundnuts exhibited high contamination with *Aspergillus niger* (17.65%) and *A. flavus*, mirroring findings from Ghana and Senegal (Faye et al. 2022; Kortei et al. 2022). The relatively high moisture content in improperly stored groundnuts creates favourable conditions for fungal growth. Millet samples contained *Aspergillus fumigatus* (21.05%) and *Aspergillus flavus* (15.79%), suggesting that poor storage conditions contribute to fungal infestation (Omara et al. 2021). Local rice samples, particularly those from Serekunda Market, showed high fungal contamination, akin to reports from urban areas in Sierra Leone and Guinea (Camara et al. 2022). The lower contamination levels observed in imported rice suggest better handling and processing practices, aligning with reports from Tanzania (Dossou and Silue 2018). The presence of other fungi such as *Penicillium verrucosum* and Mucor suggests additional mycotoxin risks beyond aflatoxins. These fungi are known producers of ochratoxins and fumonisins, which pose additional food safety concerns.

The dominance of *Aspergillus* species, particularly *A. flavus*, is concerning due to their production of aflatoxins, potent carcinogens linked to hepatocellular carcinoma (Schrenk et al. 2020). Aflatoxin B_1, the most toxic variant, has been associated with acute and chronic liver damage, immune suppression, and stunted growth in children (Kayanda et al. 2024). Additionally, *Aspergillus fumigatus*, identified in millet samples, is a major causative agent of pulmonary aspergillosis, which is particularly dangerous for immune-compromised individuals (Godet et al. 2022). The presence of *Penicillium verrucosum* raises concerns over ochratoxin A exposure, which has been linked to kidney damage and immunotoxicity (Karczmarczyk et al. 2017). These findings emphasise the need for targeted interventions to minimise fungal contamination and subsequent mycotoxin exposure.

Aflatoxin quantification using UHPLC-FLD revealed widespread contamination, with maize from Latrikunda Market showing the highest aflatoxin B_1 levels (29.7 ± 4.2 µg/kg) and groundnuts exhibiting the highest total aflatoxin concentration (57.5 ± 6.8 µg/kg). The Gambia adopting the European Union (EU) maximum permissible limits for aflatoxin B_1 and total aflatoxins are 4 µg/kg and 10 µg/kg, respectively. These findings indicate that both crops including maize and groundnuts exceed the safety thresholds, posing significant health risks. Similar contamination levels have been reported in sub-Saharan Africa, where inadequate storage conditions contribute to high aflatoxin accumulation (Shephard 2008; Jallow et al. 2021). The dietary exposure assessment found that groundnuts and maize are the main sources of aflatoxin, and children aged 1–6 years are the most at risk because they weigh less and eat more food for their size, as noted by Kayanda et al. (2024). The margin of exposure (MOE) values were significantly below the safety threshold of 10,000, indicating elevated risks. The estimated risk of liver cancer was greatest for people with HBV who consumed groundnuts (29 cases per 100,000) and maize (12 cases per 100,000), backing up previous studies that link aflatoxin exposure to liver cancer in Africa.

Given the high fungal contamination and aflatoxin levels, several innovative strategies can be implemented to reduce risks. Pre-harvest interventions, such as using biocontrol agents like atoxigenic Aspergillus strains (e.g. AflaSafe), have proven effective in reducing aflatoxin contamination in Africa as it was successfully introduced in the Gambia and Senegal (Senghor et al. 2021). Improved storage and handling practices, including the adoption of hermetic storage bags and proper drying techniques, can limit fungal growth and mycotoxin production as highlighted in many researches (Asare Bediako et al. 2019; Ezekiel et al. 2021; Joutsjoki and Korhonen 2021). Encouraging dietary diversification by promoting the consumption of alternative staples with lower contamination risks, such as properly processed imported rice, can help reduce exposure. Post-harvest detoxification methods, including nixtamalisation (alkaline cooking) and the use of food grade binders (e.g. clay-based binders), have been shown to reduce aflatoxin bioavailability (Guo et al. 2021). Strengthening policy and regulatory frameworks to enforce strict aflatoxin monitoring and implementing rapid detection technologies can enhance food safety compliance. These results underscore the urgent need for interventions to mitigate aflatoxin contamination and its health implications in The Gambia. The high prevalence of toxicogenic fungi in staple crops and the exceedance of permissible aflatoxin levels highlight significant food safety risks. Regulatory enforcement, alongside innovative mitigation measures, is essential to reduce aflatoxin exposure and safeguard public health.

Conclusions

This study assessed the level of aflatoxin contamination and associated dietary exposure risks of staple crops from The Gambia, particularly maize, groundnuts, rice, and millet. The results show a significant contamination of staple crops by aflatoxins, where groundnuts and maize contained exceptionally high levels of these toxins and are staple items in the Gambian diet. The dietary exposure analysis indicates that people in The Gambia are at high risks of health issues such as liver cancer, immunosuppression, and retarded growth, which are caused by chronic ingestion of aflatoxins.

Key findings are the presence of high levels of aflatoxins, with the highest contamination found in groundnuts that exceeded internationally accepted permissible limits for human consumption. Estimated dietary exposures to aflatoxins in The Gambia ranked among the highest in the world and, consequently, pose a major public health risk. Aflatoxin exposure has been strongly associated with increased risk of liver cancer, especially in populations with high hepatitis B prevalence. Additionally, insufficient mitigation strategies, substandard agricultural and storage practices, exacerbate contamination meaning that there is a critical need for more intensive interventions. This study seeks to emphasise the importance of systematic measures aimed at reduction of aflatoxin contamination and its health effects in the Gambia community.

Recommendations

Based on the findings, the following recommendations are proposed:

i. **Better Farming Practices**: Encourage pre-harvest practices that include planting resistant varieties of crops and ensuring good field sanitation to reduce fungal infections. Promote the use of biological control methods such as Aflasafe, which use atoxigenic strains of *Aspergillus flavus* to competitively exclude toxigenic strains in the field. Encourage harvesting at the right time and proper drying techniques to limit the growth of fungi
ii. **Better Storage Facilities:** Investments in airtight, moisture-proof storage solutions that will reduce post-harvest contamination. Train

farmers on the importance of proper storage conditions.

iii. **Policy and Regulation:** Developing and adopting strict regulatory limits of aflatoxin in food products to be in line with the international standards. Developing national policies for regular testing of crops and food products from aflatoxin.

iv. **Public Health Interventions:** Launch public awareness programs on the perils of aflatoxin to farmers and the community and how it can be prevented. Encourage and enable access to affordable aflatoxins reduction technologies such as chemical detoxifiers and biological control products.

v. **Research and Monitoring**: Continual research on the trends of aflatoxin contamination and its socioeconomic impact. Establish a national surveillance system to monitor aflatoxin levels in the food supply chain.

vi. **International Cooperation**: Working with international organisations in mobilising resources and expertise to combat aflatoxin contamination. Harmonising Gambian efforts with global food safety efforts.

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Disclosure statement

The authors have no interests to declare.

References

Asare Bediako K, Dzidzienyo D, Ofori K, Offei SK, Asibuo JY, Adu Amoah R, Obeng J. 2019. Prevalence of fungi and aflatoxin contamination in stored groundnut in Ghana. Food Control. 104(February):152–156. doi: 10.1016/j.foodcont.2019.04.034.

Bich GA, Castrillo ML, Kramer FL, Villalba LL, Zapata PD. 2021. Morphological and molecular identification of entomopathogenic fungi from agricultural and forestry crops. Floresta Ambient. 28(2). doi: 10.1590/2179-8087-floram-2018-0086.

Camara I, Cao K, Sangbaramou R, Wu P, Shi W, Tan S. 2022. Screening of Beauveria bassiana (Bals.) (Hypocreales: cordycipitaceae) strains against Megalurothrips usitatus (Bagnall) (Thysanoptera: thripidae) and conditions for large-scale production. Egypt J Biol Pest Control. 32(1). doi: 10.1186/s41938-022-00584-w.

Dossou B, Silue D. 2018. Rice pathogens intercepted on seeds originating from 11 African countries and from the USA. Seed Sci Tech. 46(1):31–40. doi: 10.15258/sst.2018.46.1.03.

Ezekiel CN, Ayeni KI, Akinyemi MO, Sulyok M, Oyedele OA, Babalola DA, Ogara IM, Krska R. 2021. Dietary risk assessment and consumer awareness of mycotoxins among household consumers of cereals, nuts and legumes in north-central Nigeria. Toxins (Basel). 13(9):635. doi: 10.3390/toxins13090635.

Faye A, Diop Y, Sarr D, Gueye PY, Coly A. 2022. Characterization of strains of Aspergillus flavus and A. parasiticus isolated from groundnut (Arachis hypogea), rice (Oryza sativa) and maize (Zea mays) in Senegal. Int J Bio Chem Sci. 16(1):367–377. doi: 10.4314/ijbcs.v16i1.31.

Godet M, Munaut F, Nguyen TTK, Nguyen LT, Chau TTH, Nguyen TTK, Tran BN, Taniguchi T, Hayashidani H, Ly KTL, et al. 2022. Health and food security, and management strategies in Pakistan. Toxins. 8(3). http://dx.doi:10.3114/sim.2011.69.05%0Ahttp://dx.doi:10.1080/23311932.2016.1191103%0A/pmc/articles/PMC8829407/%0A/pmc/articles/PMC8829407/?report=abstract%0Awww.ncbi.nlm.nih.gov/pmc/articles/PMC8829407/%0Adx.doi:10.1111/j.1574-.

Guo Y, Zhao L, Ma Q, Ji C. 2021. Novel strategies for degradation of aflatoxins in food and feed: a review. Food Res Int. 140(June):109878. doi: 10.1016/j.foodres.2020.109878.

Ibol PM. 2022. Assessing the change of land use and land cover in the Gambia. EJSSS. 8(1):175–187. doi: 10.46827/ejsss.v8i1.1351.

Jallow A, Xie H, Tang X, Qi Z, Li P. 2021. Worldwide aflatoxin contamination of agricultural products and foods: from occurrence to control. Compr Rev Food Sci Food Saf. 20(3):2332–2381. doi: 10.1111/1541-4337.12734.

Joutsjoki VV, Korhonen HJ. 2021. Management strategies for aflatoxin risk mitigation in maize, dairy feeds and milk value chains—case study Kenya. Food Quality Safety. 5(April). doi: 10.1093/fqsafe/fyab005.

Karczmarczyk A, Bäumner AJ, Feller K-H. 2017. Development of biosensors for mycotoxins detection in food and beverages. Fakultät Für Chemie Und Pharmazie, Ph.D. 135. epub.uni-regensburg.de/36587/1/A.Karczmarczyk_thesis.pdf.

Kayanda RA, Ngure FM, Kassim N. 2024. Dietary exposure of infants and young children to aflatoxins and fumonisins in the East African Region: a review. Curr Res Nutr Food Sci. 12(2):471–489. doi: 10.12944/CRNFSJ.12.2.1.

Kholmatova KK, Gorbatova MA, Kharkova OA, Grjibovski AM. 2016. Cross-sectional studies: planning, sample size, data analysis. Ekologiya Cheloveka (Human Ecology). 23(2):49–56. doi: 10.33396/1728-0869-2016-2-49-56.

Klich MA, Pitt JI. 1988. Differentiation of Aspergillus flavus from A. parasiticus and other closely related species. Transac British Mycol Society. 91(1):99–108. doi: 10.1016/S0007-1536(88)80010-X.

Kortei N, Amanor D, Wiafe-Kwagyan M, Annan T, Boakye A, Essuman E, Deku J, Tettey C, University of Health and Allied Sciences. 2022. Profile of fungal contaminants of maize (Zea mays) intended for consumption and their potential health implications in the Ho municipality of Ghana. AJFAND. 22(115):21890–21918. doi: 10.18697/ajfand.115.21645.

Kortei NK, Badzi S, Nanga S, Wiafe-Kwagyan M, Amon DNK, Odamtten GT. 2023. Survey of knowledge, and attitudes to storage practices preempting the occurrence of filamentous fungi and mycotoxins in some Ghanaian staple foods and processed products. Sci Rep. 13(1):8710. doi: 10.1038/s41598-023-35275-5.

Kortei NK, Tetteh RA, Wiafe-Kwagyan M, Amon DNK, Odamtten GT. 2022. Mycobiota profile, phenology, and potential toxicogenic and pathogenic species associated with stored groundnuts (Arachis hypogaea L.) from the Volta Region, Ghana. Food Sci Nutr. 10(3):888–902. doi: 10.1002/fsn3.2719.

Ndow G, Cessay A, Cohen D, Shimakawa Y, Gore ML, Tamba S, Ghosh S, Sanneh B, Baldeh I, Njie R, et al. 2022. Prevalence and clinical significance of occult hepatitis B infection in the Gambia, West Africa. J Infect Dis. 226(5):862–870. doi: 10.1093/infdis/jiab327.

Nyongesa BW, Okoth S, Ayugi V. 2015. Identification key for species isolated from maize and soil of Nandi County, Kenya. AiM. 05(04):205–229. doi: 10.4236/aim.2015.54020.

Omara T, Kiprop AK, Wangila P, Wacoo AP, Kagoya S, Nteziyaremye P, Peter Odero M, Kiwanuka Nakiguli C, Baker Obakiro S. 2021. The scourge of aflatoxins in Kenya: a 60-year review (1960 to 2020). J Food Qual. 2021:1–31. doi: 10.1155/2021/8899839.

Pitt JI, Hocking AD. 1997. Penicillium and related Genera. In: Fungi and food spoilage. Springer US; p. 203–338. doi: 10.1007/978-1-4615-6391-4_7.

Schrenk D, Bignami M, Bodin L, Chipman JK, del Mazo J, Grasl-Kraupp B, Hogstrand C, Hoogenboom L, Leblanc JC, Nebbia CS, et al. 2020. Risk assessment of aflatoxins in food. EFSA J. 18(3):e06040. doi: 10.2903/j.efsa.2020.6040.

Séne SMK, Faye C, Pande CB. 2024. Assessment of current and future trends in water resources in the Gambia River Basin in a context of climate change. Environ Sci Eur. 36(1). doi: 10.1186/s12302-024-00848-2.

Senghor AL, Ortega-Beltran A, Atehnkeng J, Jarju P, Cotty PJ, Bandyopadhyay R. 2021. Aflasafe SN01 is the first biocontrol product approved for aflatoxin mitigation in two nations, Senegal and the Gambia. Plant Dis. 105(5):1461–1473. doi: 10.1094/PDIS-09-20-1899-RE.

Shephard GS. 2008. Risk assessment of aflatoxins in food in Africa. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 25(10):1246–1256. doi: 10.1080/02652030802036222.

Udovicki B, Tomic N, Trifunovic BS, Despotovic S, Jovanovic J, Jacxsens L, Rajkovic A. 2021. Risk assessment of dietary exposure to aflatoxin B1 in Serbia. Food Chem Toxicol. 151(March):112116. doi: 10.1016/j.fct.2021.112116.