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Effects of Mycotoxins on Nutritional Qualities of some Varieties of Sorghum Consumed in Bauchi State, Nigeria

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Abstract

Sorghum, a staple food crop, is vulnerable to fungal contamination, particularly by *Aspergillus flavus*, *Aspergillus niger*, and *Rhizoctonia*, which produce mycotoxins such as aflatoxins. These mycotoxins pose significant health risks, including carcinogenic and immune-suppressing effects. Sorghum samples, both stored and unstored, were analyzed for fungal contamination, proximate composition, mineral content, and amino acid profile. This study investigates the effects of mycotoxins on the nutritional qualities of different varieties of sorghum consumed in Bauchi State, Nigeria. The results revealed that stored sorghum had the highest contamination, with *Aspergillus flavus* and *Aspergillus niger* predominantly present, particularly in red sorghum. Aflatoxin concentrations were significantly higher in stored sorghum, with the highest concentration of AFB1 (0.497 mg/ml) and AFM1 (2.892 mg/ml) found in stored red sorghum. Proximate analysis showed significant differences in protein, fat, and carbohydrate content between stored and unstored samples. Stored red sorghum had the highest crude protein content of 14.5% compared to 12.3% in unstored samples. Mineral analysis revealed stored red sorghum had the highest calcium content of 8.07 mg/100g, while unstored yellow sorghum had the lowest calcium value of 2.79 mg/100g. The amino acid profile indicated a decrease concentration of lysine, a key limiting amino acid, which was found to be lower than the FAO/WHO recommended levels. These findings underscore the adverse effects of mycotoxin contamination on sorghum's nutritional value, emphasizing the need for improved storage practices and regular monitoring to safeguard public health and nutritional standards in Bauchi State.

Keywords: *Mycotoxins, Sorghum, Aflatoxins, Nutritional Quality, Fungal Contamination*

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Introduction

Sorghum (*Sorghum bicolor* L.) is a vital cereal crop that significantly contributes to global food and nutritional security, particularly in semi-arid and arid regions where other staple cereals like maize and rice face cultivation challenges (Tadele, 2016; Dickoet *al.*, 2006). Its remarkable tolerance to drought, adaptability to varied soil types, and minimal input requirements make it indispensable for millions, especially across sub-Saharan Africa and South Asia (Mekbib, 2009; Obilana & Manyasa, 2002). Worldwide, sorghum is cultivated on approximately 46 million hectares, producing nearly 60 million tons annually (FAOSTAT, 2023). It has diverse uses, ranging from human food and livestock feed to industrial applications such as alcohol distillation and biofuel production (Ratnavathi *et al.*, 2011). From a nutritional standpoint, sorghum is rich in carbohydrates, moderate-quality protein, dietary fiber, and key micronutrients such as iron, calcium, phosphorus, and magnesium (Kayode *et al.*, 2011). However, its nutritional benefits can be limited by anti-nutritional factors, including tannins and polyphenolic compounds, which

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reduce protein digestibility and mineral bioavailability (El Khier*et al.*, 2018).

In Bauchi State Nigeria, sorghum is one of the most widely cultivated and consumed staple foods, serving as a primary dietary component for both humans and livestock. However, its safety and nutritional quality are often compromised by fungal contamination, leading to the production of harmful mycotoxins. Mycotoxins are toxic secondary metabolites synthesized by fungal species such as *Aspergillus*, *Penicillium*, and *Fusarium*, which proliferate under conditions of high humidity, poor storage, and suboptimal post-harvest handling (De Saeger, 2011). Among these toxins, aflatoxins and ochratoxins are considered the most pathogenic, posing significant health risks upon ingestion (Alshannaq & Yu, 2017). Aflatoxins, in particular, have been extensively linked to hepatotoxicity and carcinogenicity, with chronic exposure leading to aflatoxicosis, immune suppression, liver dysfunction, and hepatocellular carcinoma (Alshannaq & Yu, 2017). Acute aflatoxicosis can result in severe liver damage and, in extreme cases, death. These health hazards are particularly concerning in regions where staple foods such as sorghum are frequently contaminated, exacerbating public health crises and nutritional deficiencies.

Beyond health implications, mycotoxin contamination in sorghum significantly impacts food security by reducing the quantity of safe and edible grains available for consumption. This issue is especially pronounced in developing nations, where food shortages remain a persistent challenge. As of 2022, an estimated 735 million people globally face chronic hunger, with millions at risk of hunger-related complications and death (FAO, IFAD, UNICEF, WFP, & WHO, 2023). This crisis is further intensified by the rapid growth of the global population, which increases the demand for food resources while simultaneously exerting pressure on agricultural production systems (UN DESA, 2022). Despite efforts to enhance food security, post-harvest losses due to spoilage and fungal infestations continue to contribute to significant food wastage. Each year, vast quantities of cereals, including sorghum, are rendered unfit for consumption due to poor agricultural storage conditions, microbial spoilage, and contamination (FAO, 2020). Inadequate storage infrastructure, improper handling, and substandard processing methods create favorable conditions for fungal proliferation, ultimately leading to mycotoxin accumulation and food loss (Kana *et al.*, 2021).

Given the critical role of sorghum in the diet of people in Bauchi State, Nigeria it is imperative to assess the extent of mycotoxin contamination and its impact on the nutritional quality of commonly consumed sorghum varieties. Understanding these relationships will provide essential insights into food safety risks, inform policymakers, and guide the development of mitigation strategies to safeguard public health. This study aims to determine the effects of mycotoxin contamination on the nutritional quality of some varieties of sorghum consumed in Bauchi State, Nigeria. The findings will contribute to improving food safety standards, enhancing food security, and reducing the health risks associated with mycotoxin exposure.

Materials and Methods

Study area

This study was conducted in Bauchi State, located in the northeastern region of Nigeria(approximately between latitude 9.3°N and 12.3°N, and longitude 8.5°E and 11.3°E). Bauchi State is known for its significant sorghum production, with various local varieties being cultivated and consumed. The study area was selected due to its reliance on sorghum as a major food crop and the prevalence of mycotoxin contamination in agricultural products within the region.

Sampling Procedure

A total of 6 sorghum samples were randomly collected from local markets, farms, and storage facilities across different regions within Bauchi State, Nigeria. The samples were obtained from three distinct varieties of sorghum: red, yellow, and white. Each sample consisted of 5 kilograms of sorghum grains, making a total of 3 samples per variety. The samples were collected during the harvest season, ensuring that the samples were fresh and representative of typical sorghum used for consumption in the state.

Sample Preparation

The collected sorghum samples were cleaned to remove dirt, stones, and damaged grains. The cleaned sorghum grains were then divided into portions for different analyses. Part of each sample was used for mycotoxin detection, while another portion was used for proximate composition, mineral content, and amino acid profile analyses.

Mycotoxin Detection

Mycotoxin contamination was assessed using High-Performance Liquid Chromatography (HPLC), following the method described by **Turner et al. (2009)**. Aflatoxins (B1, B2, G1, G2) were the primary mycotoxins analyzed due to their prevalence in sorghum and their known toxic effects. The samples were first ground into fine powder and extracted with a solvent mixture. The extracted samples were then filtered, concentrated, and analyzed using HPLC. The results were compared with international safety standards to assess the contamination levels.

Fungal Isolation and Identification

To determine the fungal species associated with mycotoxin production, fungal isolation was performed using the standard plate count method. Approximately 10g of each sorghum sample was suspended in sterile distilled water and serially diluted. One milliliter of each dilution was plated onto Potato Dextrose Agar (PDA) and incubated at 28°C for 5-7 days. Fungal colonies were identified based on their morphological characteristics, and *Aspergillus* species were isolated for further identification. The identification was confirmed through microscopic examination and molecular techniques, including PCR (Polymerase Chain Reaction) for species-specific identification.

Proximate Composition Analysis

The proximate composition of the sorghum samples was analyzed to determine the moisture content, crude protein, crude fat, crude fiber, ash, and carbohydrates. The methods used for these analyses were in accordance with the AOAC (Association of Official Analytical Chemists, 2005) standards:

Moisture Content: Determined by drying the sorghum samples in an oven at 105°C until a constant weight was achieved.

Crude Protein: Measured by the Kjeldahl method, where nitrogen content was determined and converted to protein using a conversion factor of 6.25.

Crude Fat: Extracted using petroleum ether and determined by gravimetric analysis.

Crude Fiber: Analyzed by acid-alkali digestion methods.

Ash Content: Measured by incinerating the samples at 550°C.

Carbohydrates: Calculated by difference, subtracting the sum of the moisture, protein, fat, fiber, and ash contents from 100%.

Mineral Content Analysis
The mineral content of the sorghum samples, including calcium, magnesium, iron, potassium, and sodium, was determined using Atomic Absorption Spectrophotometry (AAS). The samples were first digested using a mixture of nitric acid and perchloric acid, and the mineral concentrations were quantified against standard calibration curves for each mineral.

Amino Acid Profile Analysis
The amino acid composition of the sorghum varieties was analyzed by High-Performance Liquid Chromatography (HPLC) after hydrolyzing the sorghum samples in 6N HCl. The resulting hydrolysate was analyzed for essential amino acids such as lysine, tryptophan, leucine, and phenylalanine. The amino acids were quantified by comparing their retention times with those of known standards.

Ethical Considerations
Ethical approval for the study was obtained from the Research Ethics Committee of Bauchi State University Gadau, Bauchi, Nigeria. All sorghum samples were collected in accordance with local regulations, and informed consent was obtained from farmers and market vendors involved in the study. The research was conducted with respect for the local agricultural practices and sustainability.

Data Analysis
The data collected from the mycotoxin, proximate composition, mineral content, and amino acid analyses were subjected to statistical analysis using SPSS version 22.0. Descriptive statistics (mean and standard deviation) were used to summarize the data. One-way Analysis of Variance (ANOVA) was employed to test for significant differences in nutritional composition and mycotoxin contamination levels among the different sorghum varieties. Post-hoc tests (Tukey's HSD) were performed to identify which groups differed significantly. The level of significance was set at $p<0.05$.

Results

Fungal Contamination in Newly Harvested and Stored Sorghum
The analysis of fungal contamination in different varieties of sorghum revealed the presence of *Aspergillus niger*, *Aspergillus flavus*, and *Rhizoctonia* across both newly harvested and stored samples (Table 1). *Aspergillus niger* was consistently isolated in all sorghum varieties, indicating its resilience and potential dominance in sorghum storage environments. While *Rhizoctonia* was present in both stored and unstored red and yellow sorghum, it was found only in newly harvested white sorghum, suggesting a possible decline during storage. Additionally, *Aspergillus flavus* was present in both stored and unstored white sorghum but absent in other varieties.

Table 1: Fungi Isolated from Different Varieties of Newly Harvested and Stored Sorghum

Stored Samples	Fungi Isolated	Newly Harvested Samples	Fungi Isolated
Red Sorghum	*Aspergillus niger*, *Rhizoctonia*	**Red Sorghum**	*Aspergillus niger*, *Rhizoctonia*
White Sorghum	*Aspergillus niger*, *Aspergillus flavus*	**White Sorghum**	*Aspergillus flavus*, *Rhizoctonia*
Yellow Sorghum	*Aspergillus niger*	**Yellow Sorghum**	*Aspergillus niger*, *Rhizoctonia*

Aflatoxin Contamination in Sorghum
Aflatoxin analysis showed that stored sorghum had higher concentrations of both *Aflatoxin M1 (AFM1)* and *Aflatoxin B1 (AFB1)* compared to newly harvested samples (Table 2). Among the stored varieties, red sorghum had the highest *AFM1* concentration (2.892 mg/cm³), whereas white sorghum had the lowest (2.501 mg/cm³). The *AFB1* concentration was also elevated in stored yellow sorghum (0.484 mg/cm³), while newly harvested white sorghum had the lowest levels (0.046 mg/cm³). These findings suggest that storage conditions may contribute to the accumulation of aflatoxins, potentially due to fungal growth and environmental factors.

Table 2: Aflatoxin Concentration for Different Varieties of Newly Harvested and Stored Sorghum

Parameters	Stored Samples	Newly Harvested Samples
	Red Sorghum	**White Sorghum**
AFM1 (mg/cm³)	2.892	2.501
AFB1 (mg/cm³)	0.456	0.313

AFM1 = Aflatoxin M1, AFB1 = Aflatoxin B1

Proximate Composition of Sorghum
The proximate composition analysis revealed notable differences between stored and newly harvested sorghum (Table 3). Newly harvested sorghum showed significantly higher protein content, particularly in yellow sorghum (16.85%), while stored samples had relatively lower protein

values. Fat content was also higher in newly harvested sorghum, particularly in yellow sorghum (1.64%), compared to stored samples. Moisture content was slightly higher in newly harvested white sorghum (9.01%), while carbohydrate levels were generally higher in stored sorghum. Fibre content varied across different varieties, with stored white sorghum showing the highest value (12.91%). Energy content remained relatively stable across the samples, with the highest value recorded in newly harvested white sorghum (342.85 kcal/g).

Table 3: Proximate Composition of Different Varieties of Newly Harvested and Stored Sorghum

Parameters	Stored Samples	Newly Harvested Samples
	Red Sorghum	White Sorghum
Ash (%)	2.04 ± 0.37[a]	2.29 ± 0.52[a]
Moisture (%)	7.80 ± 0.19[a]	7.59 ± 0.08[a]
Fat (%)	0.33 ± 0.06[a]	0.46 ± 0.04[a]
Fibre (%)	7.24 ± 0.12[a]	12.91 ± 0.29[a]
Protein (%)	6.24 ± 0.09[a]	7.53 ± 0.36[a]
Carbohydrate (%)	76.35 ± 0.37[a]	69.22 ± 0.43[a]

Values are presented as mean ± standard deviation. Different superscripts (a, b) indicate significant differences between stored and newly harvested samples within the same sorghum variety.

Mineral Composition of Sorghum

The mineral analysis of stored and newly harvested sorghum varieties revealed significant differences in calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), and sodium (Na) concentrations (Table 4). Stored red sorghum exhibited the highest calcium content (8.07 mg/ml), while newly harvested white sorghum had the lowest (2.79 mg/ml). Iron content was generally higher in stored samples, particularly in red sorghum (3.25 mg/ml), compared to the newly harvested samples, which showed a decline in Fe concentration across all varieties. Potassium levels were significantly higher in stored red sorghum (482.15 mg/ml) compared to its newly harvested counterpart (273.70 mg/ml). Magnesium levels showed minimal variation, with stored red sorghum containing 54.63 mg/ml and its freshly harvested counterpart slightly higher at 58.75 mg/ml. Sodium content was noticeably lower in newly harvested samples, particularly in yellow sorghum, which had the lowest Na concentration (1.07 mg/ml).

Table 4: Mineral Analysis for both Newly Harvested and Stored Varieties of Sorghum

Minerals (mg/ml)	Stored Samples	Newly Harvested Samples
	Red Sorghum	White Sorghum
Ca	8.07 ± 6.58[a]	3.18 ± 0.01[a]
Fe	3.25 ± 2.16[a]	1.88 ± 0.30[a]
K	482.15 ± 51.94[a]	256.60 ± 16.30[a]
Mg	54.63 ± 12.52[a]	31.33 ± 4.79[a]
Na	7.71 ± 0.90[a]	6.73 ± 0.07[a]

Values are mean ± standard deviation. Different superscripts (a, b) indicate significant differences between stored and newly harvested samples within the same sorghum variety.

Amino Acid Profile of Sorghum Varieties

The amino acid composition of stored and newly harvested sorghum varieties revealed significant differences in essential and non-essential amino acids (Table 5). Newly harvested red sorghum had the highest total amino acid content (1067.50 mg/g protein), while stored red sorghum had the lowest (835 mg/g protein). Among the essential amino acids, leucine was the most abundant, with newly harvested red sorghum containing 140.20 mg/g protein, while stored red sorghum had 103.60 mg/g protein. Non-essential amino acids such as glutamic acid were also highest in newly harvested yellow sorghum (210.50 mg/g protein), while the lowest was recorded in stored red sorghum (171.80 mg/g protein).

Storage appeared to reduce the overall amino acid content across all varieties, though the decline varied depending on the type of amino acid and sorghum variety. The total essential amino acids (EAA) were highest in newly harvested red sorghum (472.10 mg/g protein) and lowest in stored red sorghum (365.30 mg/g protein). Similarly, the total non-essential amino acids (NEAA) were highest in stored yellow sorghum (583.30 mg/g protein) and lowest in stored red sorghum (469.70 mg/g protein). These findings suggest that storage conditions may influence the nutritional quality of sorghum by affecting its amino acid composition.

The comparison of limiting amino acids in stored and unstored white sorghum across different varieties (Red, White, and Yellow)

The comparison of limiting amino acids in stored and unstored white sorghum across different varieties (Red, White, and Yellow) shows clear variations in the amino acid profiles.

Leucine content is relatively higher in the unstored sorghum samples. The stored red sorghum has 103.60 mg/g of leucine, while unstored red sorghum contains 140.20 mg/g. White sorghum also shows an increase in leucine content, with stored white sorghum at 120.50 mg/g and unstored white sorghum at 133.30 mg/g. Yellow sorghum follows a similar trend, with stored yellow sorghum having 138.10 mg/g, while unstored yellow sorghum contains 129.00 mg/g.

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Table 5: Amino Acid Profile of Newly Harvested and Stored Sorghum Varieties (mg/g protein)

SN	Amino Acid	Stored Red Sorghum	Stored White Sorghum	Stored Yellow Sorghum	Unstored Red Sorghum	Unstored White Sorghum	Unstored Yellow Sorghum
1	Glutamic acid	171.80	182.40	210.50	213.00	202.80	191.60
2	*Leucine	103.60	120.50	138.10	140.20	133.30	129.00
3	Alanine	70.20	73.90	89.90	93.30	86.10	82.30
4	Proline	68.00	71.10	85.30	89.40	83.20	77.20
5	Aspartic acid	63.30	70.10	74.10	75.10	71.60	70.10
6	*Valine	47.10	48.80	54.10	55.30	53.50	50.60
7	*Phenylalanine	39.90	43.50	43.50	53.20	51.40	48.80
8	*Isoleucine	35.70	38.60	43.90	44.20	42.60	40.30
9	Arginine	37.80	40.40	44.70	46.50	43.00	42.20
10	*Tyrosine	34.40	34.40	39.60	41.30	39.60	36.10
11	Serine	33.70	37.50	41.90	44.90	40.00	38.60
12	*Threonine	28.30	30.20	33.90	35.00	32.80	31.60
13	Glycine	24.90	28.00	30.90	33.20	32.50	29.00
14	*Lysine	20.70	22.30	24.10	24.70	24.40	23.10
15	*Histidine	20.10	20.80	23.30	23.30	22.70	21.70
16	*Methionine	16.00	17.40	22.20	22.40	21.60	20.00
17	*Cystine	10.30	12.10	18.20	19.40	16.90	14.50
18	*Tryptophan	9.20	10.80	12.90	13.10	12.60	12.10
	Total AA	**835.00**	**902.80**	**1031.10**	**1067.50**	**1010.60**	**958.00**
	Total EAA	**365.30**	**399.40**	**453.80**	**472.10**	**451.40**	**427.80**
	Total NEAA	**469.70**	**503.40**	**583.30**	**505.40**	**559.20**	**531.00**

Essential amino acids (EAA) are marked with an asterisk (*).

Histidine, on the other hand, shows a slight increase in unstored samples as well. In stored sorghum, red sorghum has 20.10 mg/g of histidine, while the unstored red sorghum contains 23.30 mg/g. White sorghum in stored form has 20.80 mg/g, compared to 22.70 mg/g in the unstored version. Yellow sorghum follows the same pattern, with 23.30 mg/g in stored and 21.70 mg/g in unstored samples.

Threonine content is also higher in the unstored sorghum. Stored red sorghum contains 28.30 mg/g, while unstored red sorghum has 35.00 mg/g. White sorghum shows a similar trend with 30.20 mg/g in stored and 32.80 mg/g in unstored. Yellow sorghum contains 33.90 mg/g in stored form and 31.60 mg/g in the unstored variety.

Valine content is consistently higher in the unstored varieties across all sorghum types. Stored red sorghum contains 47.10 mg/g, while unstored red sorghum has 55.30 mg/g. Stored white sorghum has 48.80 mg/g, compared to 53.50 mg/g in unstored. Yellow sorghum has 54.10 mg/g in the stored form and 50.60 mg/g in the unstored version.

Isoleucine content follows a similar pattern, with higher values in the unstored sorghum samples. Stored red sorghum has 35.70 mg/g, while unstored red sorghum contains 44.20 mg/g. White sorghum contains 38.60 mg/g in stored form and 42.60 mg/g in unstored. Yellow sorghum shows 43.90 mg/g in stored and 40.30 mg/g in unstored.

Tryptophan also exhibits higher levels in unstored sorghum, with stored red sorghum having 9.20 mg/g and unstored red sorghum containing 13.10 mg/g. Stored white sorghum has 10.80 mg/g, compared to 12.60 mg/g in the unstored version. Yellow sorghum shows 12.90 mg/g in stored form and 12.10 mg/g in unstored.

The combined aromatic amino acids, phenylalanine and tyrosine (Phe + Tyr), are higher in the unstored sorghum varieties as well. Stored red sorghum contains 74.30 mg/g, while unstored red sorghum has 94.50 mg/g. White sorghum shows 77.90 mg/g in stored form and 91.00 mg/g in the unstored version. Yellow sorghum contains 83.10 mg/g in stored form and 84.90 mg/g in unstored form.

Methionine and cysteine (SAA) show a similar increase in unstored varieties. Stored red sorghum has 26.30 mg/g, while unstored red sorghum contains 41.80 mg/g. White sorghum contains 29.50 mg/g in the stored form and 38.50 mg/g in the unstored variety. Yellow sorghum has 40.40 mg/g in stored form and 34.50 mg/g in unstored.

Finally, lysine content is slightly higher in the unstored samples. Stored red sorghum has 20.70 mg/g, while unstored red sorghum contains 24.70 mg/g. White sorghum shows 22.30 mg/g in the stored form and 24.40 mg/g in the unstored version. Yellow sorghum contains 24.10 mg/g in stored form and 23.10 mg/g in unstored.

In summary, the amino acid content of unstored sorghum generally exceeds that of stored sorghum across all varieties, with notable increases in leucine, histidine, threonine, valine, isoleucine, tryptophan, phenylalanine + tyrosine, methionine + cysteine, and lysine.

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Table 6: Comparison of the limiting amino acids in descending order of the scoring pattern

Amino Acid	Stored Sorghum Samples			Unstored Sorghum Samples		
	Red	White	Yellow	Red	White	Yellow
Leu	103.60	120.50	138.10	140.20	133.30	129.00
His	20.10	20.80	23.30	23.30	22.70	21.70
Thr	28.30	30.20	33.90	35.00	32.80	31.60
Val	47.10	48.80	54.10	55.30	53.50	50.60
Ile	35.70	38.60	43.90	44.20	42.60	40.30
Tryptophan	9.20	10.80	12.90	13.10	12.60	12.10
Phe + Tyr (AAA)	74.30	77.90	83.10	94.50	91.00	84.90
Met + Cys (SAA)	26.30	29.50	40.40	41.80	38.50	34.50
Lys	20.70	22.30	24.10	24.70	24.40	23.10

Discussion

Fungi Isolation and Mycotoxin Production

Various environmental factors influence the growth of mycotoxin-producing fungi, with storage conditions being particularly crucial. During the storage of grains, such as sorghum, beans, and other cereals, fungi find a rich nutrient source in these grains, which promotes their growth and contamination. Sorghum, being nutrient-dense, serves as a favorable medium for the proliferation of fungi. Mycotoxin production typically occurs under stress conditions, signaling the presence of these fungi in the grain matrix (Sweeney & Dobson, 1998).

In this study, fungi species were isolated from sorghum grains, revealing the presence of three primary fungal species: *Aspergillus niger*, *Rhizoctonia*, and *Aspergillus flavus*. The latter, *Aspergillus flavus*, is known for producing aflatoxins, particularly aflatoxin B1 (AFB1), which poses significant health risks when consumed (Baquiao*et al.*, 2015). *Aspergillus flavus* was isolated mainly from stored and unstored white sorghum, whereas *Aspergillus niger* was found in almost all sorghum samples except unstored white sorghum. The presence of *Rhizoctonia* was also detected in several samples, although it was absent in some varieties of both stored and unstored red sorghum.

The contamination of sorghum with these fungi is of significant concern due to the potential health risks posed by the mycotoxins they produce. Aflatoxins, particularly AFB1, are known carcinogens and have been linked to liver damage, immune system suppression, and increased risk of cancer (Bennett & Klich, 2018). Furthermore, the contamination of sorghum with mycotoxins not only compromises its nutritional value but also presents serious economic and public health challenges. The reduced quality of contaminated grains and the potential for livestock toxicity due to consumption of infected grains exacerbate food insecurity and economic instability (Amra *et al.*, 2017). These mycotoxins also hinder the export potential of contaminated grains, contributing to global agricultural losses (Williams *et al.*, 2014).

Proximate Composition of Sorghum Varieties

The proximate composition of the sorghum samples was analyzed to assess the impact of mycotoxin contamination on the nutritional quality of sorghum. Table 3 highlights the differences in proximate composition between stored and unstored sorghum varieties. For moisture content, no significant difference was observed between stored and unstored red sorghum, while significant differences ($p < 0.05$) were noted in white and yellow varieties. Moisture content plays a crucial role in fungal growth, and higher moisture levels often correlate with increased fungal contamination (Mustapha & Magdi, 2003).

For ash content, which reflects the mineral composition of the grains, significant differences were observed across all varieties, with stored sorghum exhibiting higher ash content. This indicates a potential shift in mineral availability, possibly due to fungal activity or changes in nutrient composition during storage (Akinsola, 1993).

Crude fat, crude fiber, and crude protein content were also significantly different in stored versus unstored varieties, suggesting that storage conditions, which allow fungal growth, may reduce the nutritional value of sorghum. The highest protein content was found in unstored yellow sorghum, with a mean value of 16.85 ± 2.72, while carbohydrate content was highest across stored varieties (Adeyeye & Adewole, 1992). These nutritional components are essential for human health, providing energy and supporting growth and cellular functions (Emebu & Anyika, 2011).

Mineral Composition and Implications for Health

Minerals are essential for various physiological processes, and their concentration in sorghum can significantly impact its nutritional quality. Table 4 presents the mineral composition of sorghum varieties. Calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), and sodium (Na) were the key minerals analyzed.

The calcium content in the samples was moderate, with stored red sorghum exhibiting the highest concentration (8.07 ± 6.58 mg/g), which can contribute to bone health and potentially reduce the risk of type 2 diabetes (Kim & Oh, 2018). Iron levels were highest in stored red sorghum (3.25 ± 0.16 mg/g), which is crucial for preventing anemia. Potassium levels were also relatively high, particularly in stored red sorghum (482.15 ± 51.94 mg/g), which is beneficial for maintaining cardiovascular health by managing blood pressure (Kim & Oh, 2018).

Magnesium and sodium concentrations also varied across the samples, with the highest magnesium content found in unstored red sorghum (58.75 ± 5.21 mg/g) and the highest sodium concentration in stored red sorghum (7.71 ± 0.90

mg/g). These minerals are involved in various metabolic functions, and their balance is important for maintaining health (Emebu & Anyika, 2011).

Amino Acid Composition and Effects of Aflatoxins

Amino acids are the building blocks of proteins, and their composition in sorghum affects its nutritional value. Table 6 presents the amino acid profile of sorghum varieties, revealing that sorghum protein is rich in glutamic acid, leucine, and alanine but deficient in lysine, a limitation common in most cereal grains. This deficiency in lysine may be attributed to the high content of prolamin in sorghum (Neucere & Sumrell, 1979).

The presence of aflatoxins can further affect amino acid content, as decreased amino acid digestibility has been reported in contaminated foods (Applegate *et al.*, 2009). The consumption of aflatoxin-contaminated sorghum may thus lead to compromised protein quality and reduced nutritional benefits, particularly in populations suffering from protein energy malnutrition (PEM).

Conclusion

The contamination of sorghum with mycotoxins, particularly aflatoxins, is a significant concern in Bauchi State, Nigeria and poses a serious threat to both human and livestock health. The storage conditions of sorghum play a crucial role in the proliferation of mycotoxin-producing fungi, which in turn reduces the nutritional quality of the grains. Mycotoxin contamination leads to a decline in proximate composition, mineral content, and amino acid profile, which may contribute to various health conditions, including cancer and malnutrition. Effective storage practices and regular monitoring for mycotoxins are essential to mitigate these risks and ensure the safety and nutritional value of sorghum consumed in Bauchi State, Nigeria.

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Conflict of Interest

None

Authors Contribution

AM contributed to the conceptualization, study design, data collection and manuscript drafting. MM, IMS, MZS, AUA were responsible for the data analysis, literature review, manuscript editing, methodology. All authors reviewed and approved the final manuscript.

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