

Nutritional Composition and Aflatoxin Contamination of Marketed Grains in Wukari, Nigeria

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ABSTRACT

This study evaluated the proximate composition, amino acid profile, and total aflatoxin contamination of seven staple grains and legumes sold in three major markets in Wukari. Sixty-three composite samples (maize, rice, millet, shelled groundnut, soybean, sesame, and shelled melon) were analysed. Proximate analyses followed AOAC methods; amino acids were quantified after acid/alkaline hydrolysis using an amino acid analyser; total aflatoxins were measured by competitive ELISA following 70% methanol extraction (LOD 0.05 µg/kg; recoveries 85–105%). All assays were performed in triplicate and data were evaluated by ANOVA (SPSS v23) at $P < 0.05$. Legumes exhibited markedly higher crude protein (18.1–42.2%) and ether extract (30.5–57.1%) compared with cereals, which showed higher nitrogen-free extract (68.1–75.9%), reflecting their carbohydrate dominance. Moisture, ash, and crude fibre varied by commodity; sesame and melon seeds had relatively higher ash and moisture. Amino acid profiles differed across commodities: glutamic and aspartic acids and arginine were abundant overall, while cereals were relatively deficient in lysine and tryptophan. Total aflatoxin concentrations ranged 0.10–15.43 µg/kg, peaking in millet and maize from one market, yet remaining below the 20 µg/kg regulatory limit in force at sampling. These findings suggest that the analysed grains and legumes deliver complementary macronutrient and amino acid contributions to local diets. However, observed inter-market variability and elevated aflatoxin in particular commodities underscore the need for continued monitoring, improved postharvest handling, and targeted food-safety interventions. Policy-makers, market regulators, and smallholder producers should prioritise education, routine testing, and affordable storage solutions to urgently reduce contamination and improve food quality.

Keywords: proximate composition; amino acid profile; aflatoxin; cereals; legumes

INTRODUCTION

Grains, including cereals and legumes, form the dietary backbone of many developing countries, providing essential macronutrients, micronutrients, and phytochemicals that are critical for health and economic stability (Ebbisa *et al.*, 2022). In Nigeria, cereals such as maize (*Zea mays*), rice (*Oryza sativa*), and millet (*Pennisetum glaucum*) are widely cultivated and consumed as staple foods, while legumes including groundnut (*Arachis hypogaea*), soybean (*Glycine max*), sesame (*Sesamum indicum*), and melon (*Citrullus colocynthis*) complement diets with proteins, oils, and minerals (Chinonso *et al.*, 2025). Together, cereals and legumes provide a nutritional balance that supports both energy and amino acid requirements, especially in communities where animal protein is scarce or expensive (Falade *et al.*, 2022).

Despite their nutritional importance, grains are susceptible to quality deterioration due to poor post-harvest handling, inadequate storage, and microbial contamination (Bonkougou *et al.*,

2024). Among the most concerning contaminants are aflatoxins secondary metabolites produced mainly by *Aspergillus flavus* and *Aspergillus parasiticus* (Borrelli & Ficco, 2025). These toxins are potent hepatocarcinogens, mutagens, and teratogens, with chronic exposure linked to liver cancer, immunosuppression, growth retardation, and in severe cases, acute aflatoxicosis (Ujong *et al.*, 2023; Adepeju *et al.*, 2024).

The International Agency for Research on Cancer (IARC) has classified aflatoxin B₁, the most toxic form, as a Group 1 human carcinogen (Onyeke *et al.*, 2020).

Aflatoxin contamination occurs primarily during pre-harvest, drying, storage, and transportation stages, with high humidity and temperature accelerating fungal growth (Gaudichon, 2024). In Nigeria's tropical climate, such conditions are common, especially in rural markets where grains may be stored in open containers or bags placed directly on the ground (Joshi *et al.*, 2022).

The safety limits for total aflatoxins in food are set at 20 µg/kg by both the United States Food and Drug Administration (FDA) and the National Agency for Food and Drug Administration and Control (NAFDAC) in Nigeria (Majola *et al.*, 2021). However, surveys have shown that aflatoxin contamination in Nigerian grains can occasionally exceed these limits, posing public health and trade challenges (Anih *et al.*, 2024).

From a nutritional perspective, the proximate composition of cereals and legumes varies significantly. Cereals are typically higher in carbohydrate content (reflected in nitrogen-free extract values), while legumes generally provide higher levels of crude protein and ether extract (Garutti *et al.*, 2022). Amino acid profiles also differ: cereals are often limited in lysine and tryptophan, while legumes tend to be deficient in sulphur-containing amino acids such as methionine and cysteine (Zhang *et al.*, 2024). These complementary profiles make cereal–legume combinations nutritionally valuable for improving protein quality in human diets (Han *et al.*, 2021).

Previous studies in Nigeria and other sub-Saharan African countries have focused on either nutritional profiling (Veldsman *et al.*, 2023) or mycotoxin contamination (Shuluwaa *et al.*, 2021) of grains, but few have integrated both nutritional and safety assessments for a comprehensive evaluation. In rural communities such as Wukari, Taraba State, where market-sourced grains constitute a major portion of daily food intake, there is a need to generate data that informs both public health policy and nutrition planning.

Therefore, this study aimed to evaluate the proximate composition, 20 amino acid profile, and aflatoxin contamination of selected cereals and legumes retailed in Wukari markets. The findings provide insight into both the nutritional quality and safety of commonly consumed grains, with implications for consumer health, food safety monitoring, and agricultural storage practices.

MATERIALS AND METHODS

Study Area

Wukari is an important agricultural and trade centre in southern Taraba State, Nigeria, situated between latitudes 7°50'N and 9°30'N and longitudes 9°30'E and 11°45'E. The region has a tropical wet-and-dry climate, with an annual rainfall of 1,200–1,600 mm and an average temperature range of 25–32 °C (Angye *et al.*, 2024). These climatic conditions favour grain cultivation but also create an environment conducive to fungal growth and mycotoxin production, particularly during storage.

Sample Collection

A total of 63 grain samples were obtained from three major markets in Wukari Local Government Area: Wukari New Market, Wukari Old Market, and Dorowa Market. The samples comprised maize (*Zea mays*, n=9), rice (*Oryza sativa*, n=9), millet (*Pennisetum glaucum*, n=9), shelled groundnut (*Arachis hypogaea*, n=9), soybeans (*Glycine max*, n=9), sesame (*Sesamum indicum*, n=9), and shelled melon seeds (*Citrullus colocynthis*, n=9).

Sampling employed a composite approach (Adeyemi *et al.*, 2024). For each grain type in each market, subsamples of approximately 200 g were collected from multiple vendors, pooled to form a composite sample, and placed in sterile, airtight polyethylene bags. All samples were labelled and transported in insulated coolers to the Biochemistry Laboratory, Federal University Wukari, where they were stored at 4 °C until analysis.

Sample Preparation

Prior to analysis, samples were manually cleaned to remove debris, stones, and damaged kernels. Each composite sample was milled to fine powder using a laboratory grinder (Philips HR2860, Netherlands) and passed through a 0.5 mm mesh sieve to ensure uniform particle size.

Proximate Composition Analysis

Proximate composition was determined using the methods of the Association of Official Analytical Chemists (AOAC International, 2023).

Moisture content: Oven-drying at 105 °C until constant weight.

Ash content: Incineration at 550 °C in a muffle furnace for 6 h.

Crude protein: Determined by the Kjeldahl method, with total nitrogen multiplied by 6.25.

Ether extract: Soxhlet extraction with petroleum ether for 6 h.

Crude fibre: Sequential acid and alkali digestion (Multescu *et al.*, 2024).

Nitrogen-Free Extract (NFE): Calculated by difference: $NFE (\%) = 100 - (\text{moisture} + \text{ash} + \text{crude protein} + \text{ether extract} + \text{crude fibre})$.

All measurements were carried out in triplicate, and results were expressed as mean \pm standard deviation (SD).

Amino Acid Profiling

Amino acid composition was analysed following the method of Moore and Stein (Navarro-Abril *et al.*, 2022), with modifications:

Acid hydrolysis: 200 mg of each powdered sample was hydrolysed in 10 mL of 6 M HCl under nitrogen atmosphere at 100 °C for 22 h in sealed hydrolysis tubes.

Sulphur amino acids: Determined after performic acid oxidation prior to hydrolysis.

Tryptophan: Measured separately after alkaline hydrolysis with 4.2 M NaOH at 110 °C for 20 h.

Quantification: Amino acids were separated using a high-performance amino acid analyser (Hitachi L-8900, Japan) and detected by post-column ninhydrin derivatization at 570 nm (proline at 440 nm).

Results were expressed as percentage of total dry matter.

Aflatoxin Quantification

Total aflatoxins (B₁, B₂, G₁, G₂) were determined using a competitive enzyme-linked immunosorbent assay (ELISA) kit (Puttaswamy *et al.*, 2025).

Extraction: 20 g of milled sample was extracted with 100 mL of 70% methanol containing 0.5% KCl, followed by filtration through Whatman No. 1 filter paper.

Assay: 50 μ L of filtrate and 50 μ L of aflatoxin standard were added to antibody-coated microplate wells, followed by enzyme conjugate. Plates were incubated, washed, and substrate

was added. Colour development was stopped with 1M H₂SO₄, and absorbance was read at 450 nm using a microplate reader (BioTek ELx800, USA).

Quantification: Aflatoxin concentrations were calculated from standard curves generated with known aflatoxin concentrations.

Detection limit for the method was 0.05 µg/kg, and recovery rates ranged from 85–105%.

Statistical Analysis

The aflatoxin levels, proximate and amino acid composition of the food commodities were assessed by Analysis of Variance (ANOVA) using SPSS Version 23. A significant level of P < 0.05 was employed to determine statistical significance.

RESULTS AND DISCUSSION

Proximate Composition

The proximate composition of the cereals and legumes showed marked differences between the two grain groups (Table 1). Legumes exhibited significantly higher crude protein and ether extract contents compared to cereals (p < 0.05). In contrast, cereals had higher nitrogen-free extract (NFE) values, reflecting their carbohydrate-rich nature. Moisture content ranged from 4.12% in maize to 11.10% in melon seeds, while ash content was highest in sesame seeds (9.12%).

Table 1. Proximate composition (%) of selected cereals and legumes retailed in Wukari Markets

Commodity	Ash (%)	Crude Fibre (%)	Crude Protein (%)	Ether Extract (%)	Nitrogen Free Extract (%)	Moisture (%)
Maize	3.15 ± 0.12	1.48 ± 0.08	11.23 ± 0.45	2.15 ± 0.07	75.12 ± 0.55	4.76 ± 0.10
Rice	2.56 ± 0.11	3.62 ± 0.09	9.21 ± 0.35	2.22 ± 0.05	75.91 ± 0.60	6.48 ± 0.14
Millet	4.65 ± 0.15	3.98 ± 0.10	13.14 ± 0.52	3.00 ± 0.08	71.08 ± 0.50	5.00 ± 0.12
Groundnut	3.62 ± 0.13	4.25 ± 0.12	25.78 ± 0.85	50.33 ± 1.02	9.11 ± 0.30	4.60 ± 0.10
Soybean	4.72 ± 0.14	5.13 ± 0.11	37.42 ± 1.10	33.12 ± 0.90	10.44 ± 0.32	9.00 ± 0.15
Sesame	9.12 ± 0.18	6.10 ± 0.14	18.06 ± 0.72	53.14 ± 1.15	5.13 ± 0.20	10.30 ± 0.16
Melon	5.21 ± 0.16	13.00 ± 0.35	29.00 ± 0.88	57.11 ± 1.20	5.60 ± 0.18	11.10 ± 0.15

(values are mean ± standard deviation, n = 3. This is a single column summary i.e. mean across the three markets for each of the commodities)

This table presents the proximate composition of cereals and legumes sold in Wukari markets, showing values for ash, crude fibre, crude protein, ether extract, nitrogen free extract, and moisture. All results are expressed as mean ± standard deviation, with nitrogen free extract calculated by difference. The data highlight the nutritional contrasts between cereals and legumes in terms of protein, fat, and carbohydrate content.

Figure 1 is a Bar chart showing mean proximate composition (%) ash, crude fibre (CF), crude

protein (CP), ether extract (EE), nitrogen-free extract (NFE) and moisture (MC) for selected cereals (maize, rice, millet) and legumes (groundnut, soybean, sesame and melon seed); values are means \pm SD (n = 3) corresponding to Table 1; cereals exhibit higher NFE while legumes show elevated CP and EE, highlighting the compositional differences summarized in Table 1.

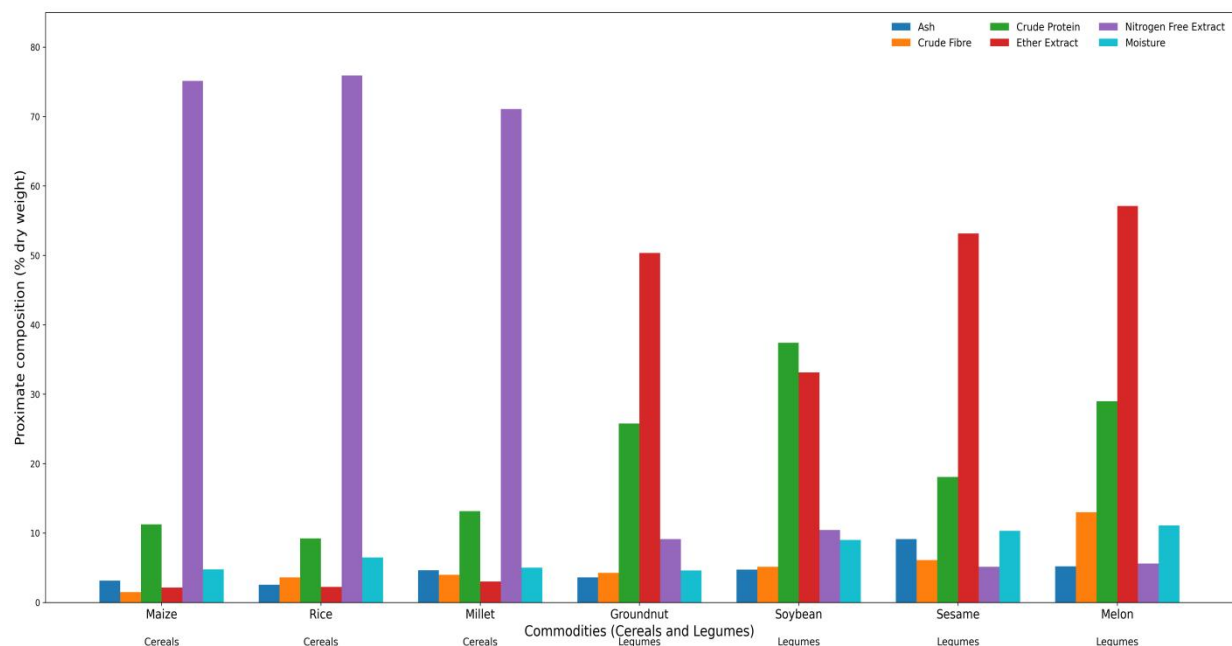


Figure 1 — Comparative proximate composition of cereals and legumes from Wukari markets (Self-generated).

Colored bars represent mean percent composition for each analyte (values = means \pm SD, n = 3). Abbreviations: CP = Crude Protein; EE = Ether Extract; CF = Crude Fibre; Ash = Inorganic residue after combustion; NFE = Nitrogen-Free Extract; MC = Moisture Content.

Amino Acid Profile

Amino acid composition varied significantly among grains (Table 2). Cereals were generally lower in lysine and tryptophan, while legumes had higher levels of most essential amino acids, particularly lysine, leucine, and valine. Glutamic acid, aspartic acid, and arginine were the most abundant amino acids across all samples.

Table 2. Essential amino acids (% dry weight) in selected cereals and legumes retailed in Wukari markets

Amino Acid	Maize	Rice	Millet	Groundnut	Soybean	Sesame	Melon
Lysine	0.12 \pm 0.01	0.15 \pm 0.02	0.27 \pm 0.03	3.42 \pm 0.10	6.20 \pm 0.15	4.18 \pm 0.12	2.08 \pm 0.09
Isoleucine	0.21 \pm 0.02	0.25 \pm 0.02	0.31 \pm 0.02	2.58 \pm 0.08	4.72 \pm 0.12	3.20 \pm 0.10	2.88 \pm 0.08
Leucine	0.49 \pm 0.03	0.53 \pm 0.04	0.93 \pm 0.05	5.62 \pm 0.15	7.60 \pm 0.18	6.15 \pm 0.14	4.50 \pm 0.11
Threonine	0.18 \pm 0.02	0.19 \pm 0.02	0.29 \pm 0.02	2.21 \pm 0.07	3.20 \pm 0.09	2.60 \pm 0.07	2.10 \pm 0.06
Tryptophan	0.01 \pm 0.00	0.00 \pm 0.00	0.01 \pm 0.00	1.05 \pm 0.04	1.51 \pm 0.05	1.22 \pm 0.03	0.85 \pm 0.03
Valine	0.29 \pm 0.00	0.34 \pm 0.00	0.41 \pm 0.00	3.50 \pm 0.09	4.79 \pm 0.11	4.05 \pm 0.10	2.82 \pm 0.08

	0.02	0.03	0.02					
Histidine	0.18 ± 0.05	0.13 ± 0.03	6.02 ± 1.82	± 2.06 ± 0.30	3.00 ± 0.19	2.10 ± 0.03	1.98 ± 0.50	
Phenylalanine	0.39 ± 0.09	0.36 ± 0.06	1.92 ± 0.62	± 3.49 ± 0.60	5.30 ± 0.55	3.82 ± 0.04	4.33 ± 0.51	
Arginine	0.41 ± 0.05	0.49 ± 0.08	0.65 ± 0.14	± 7.11 ± 1.05	6.81 ± 0.83	7.00 ± 0.14	8.10 ± 1.05	

(values are mean ± standard deviation, n = 3. This is a single column summary i.e. mean across the three markets for each of the commodities)

This table shows the essential amino acid composition of selected cereals and legumes expressed as percentage of dry weight. Amino acids listed include lysine, methionine, isoleucine, leucine, threonine, tryptophan, and valine, histidine, phenylalanine, and arginine with values given as mean ± standard deviation. The results illustrate the complementary amino acid profiles of cereals and legumes, emphasizing their dietary importance.

Figure 2 is a Bar chart comparing mean (% dry weight) concentrations of ten essential amino acids (Lys, Met, Ile, Leu, Thr, Trp, Val, His, Phe and Arginine) across maize, rice, millet, groundnut, soybean, sesame and melon (data = means ± SD, n = 3) as reported in Table 2; legumes (notably soybean and groundnut) show substantially higher levels of most essential amino acids than cereals.

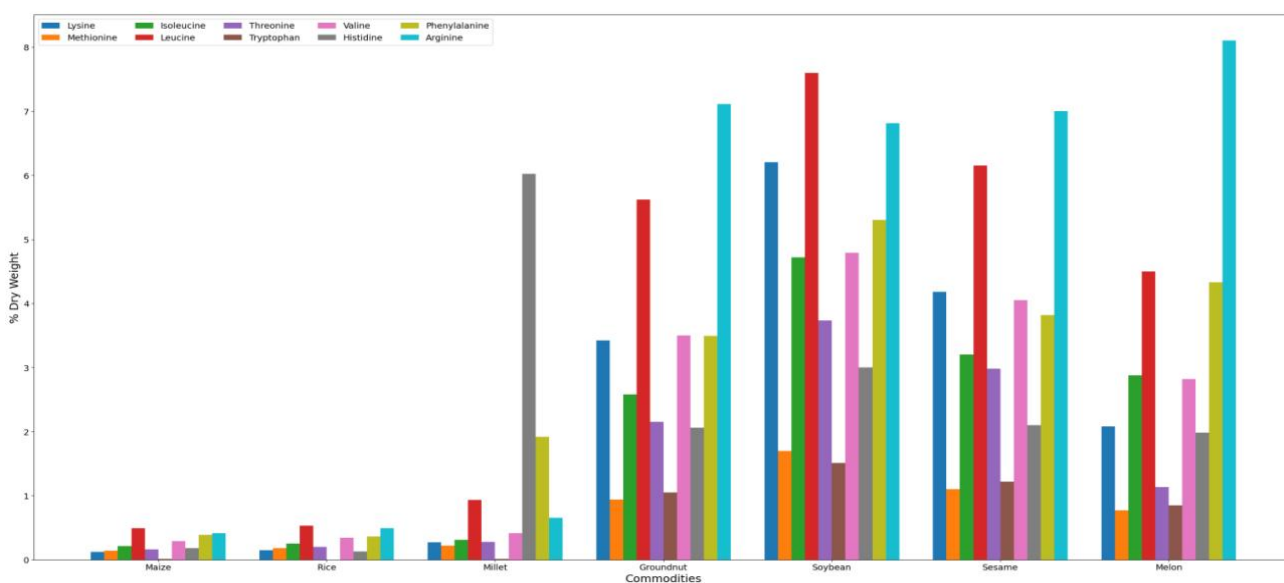


Figure 2 — Essential amino acid profiles (% dry weight) of cereals and legumes retained in Wukari markets (Self-generated).

Colored bars represent mean essential amino acid content (% dry weight) for each commodity (n = 3; mean ± SD); bars for each amino acid are grouped by commodity. Abbreviations: Lys = Lysine, Met = Methionine, Ile = Isoleucine, Leu = Leucine, Thr = Threonine, Trp = Tryptophan, Val = Valine; SD = standard deviation; n = number of replicates (3).

Aflatoxin Levels

Aflatoxin concentrations varied significantly among commodities and markets (Table 3). The highest aflatoxin levels were detected in millet (15.43 µg/kg) and maize (13.10 µg/kg) from

Dorowa Market. Despite this variation, all values were below the FDA and NAFDAC regulatory limit of 20 µg/kg.

Table 3. Total aflatoxin concentrations (micrograms per kilogram) in selected cereals and legumes retailed in Wukari markets (values are mean ± standard deviation, n = 3)

Commodity	Range (µg/kg)	Highest Detected (µg/kg)	Market with Highest Value
Maize	3.11 – 13.10	13.10	Dorowa
Rice	0.47 – 1.00	1.00	Old Market
Millet	6.13 – 15.43	15.43	Dorowa
Groundnut	0.50 – 1.17	1.17	New Market
Soybean	0.10 – 0.20	0.20	Old Market
Sesame	1.53 – 3.17	3.17	New Market
Melon	0.47 – 3.27	3.27	Old Market

This table reports the total aflatoxin concentrations in cereals and legumes retailed in Wukari markets, expressed in micrograms per kilogram. Values are presented as ranges, highest detected levels, and the specific market where the highest contamination occurred. The results provide a clear picture of contamination patterns across commodities and markets, all within regulatory safety limits.

Figure 3 is a large grouped bar chart showing the highest detected total aflatoxin levels for each commodity (Maize, Rice, Millet, Groundnut, Soybean, Sesame, Melon) as reported in Table 3 of the uploaded manuscript. Values plotted correspond to the “Highest Detected” column in Table 3 (e.g., Millet 15.43 µg/kg; Maize 13.10 µg/kg), visually emphasizing commodities with elevated contamination. The figure complements Table 3 by providing an immediate visual comparison of aflatoxin burden across commodities and highlights market-specific risk patterns described in the Results.

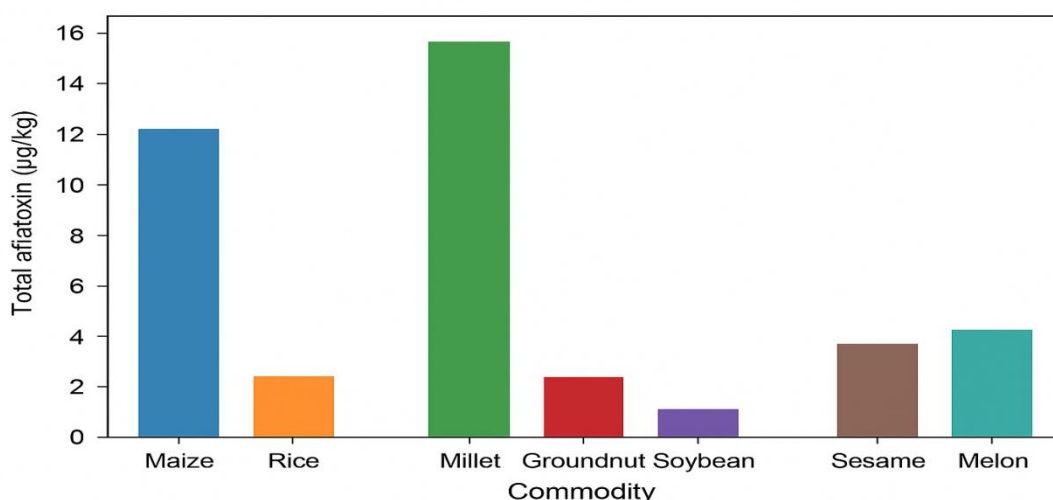


Figure 3 — Total aflatoxin concentrations (µg/kg) detected in cereals and legumes retailed in Wukari markets (Self-generated).

Bars represent the highest measured total aflatoxin concentration (µg/kg) for each commodity (data from Table 3; n = 3; means ± SD reported in the table). Commodities: Maize, Rice, Millet,

Groundnut, Soybean, Sesame, Melon — colors distinguish each commodity for clarity. Abbreviations: $\mu\text{g}/\text{kg}$ = micrograms per kilogram; SD = standard deviation; n = number of replicates (3).

Nutritional Value of Cereals and Legumes

The present study confirms that cereals and legumes retailed in Wukari markets provide complementary macronutrient profiles. Legumes demonstrated significantly higher crude protein (18.06–42.22%) and ether extract (30.51–57.11%) contents compared to cereals, which were richer in nitrogen-free extract (68.05–75.91%). These findings align with earlier Nigerian studies on market-sourced grains in Kaduna and Benue States, where legumes consistently outperformed cereals in protein and lipid content (Ola *et al.*, 2022; Anih *et al.*, 2025b). The higher lipid levels in legumes such as groundnut, sesame, and melon are nutritionally important for energy density and fat-soluble vitamin absorption, particularly in low-income households where calorie-dense foods are valued (Jacobson *et al.*, 2024).

Amino Acid Complementarity

The amino acid profiles observed here corroborate earlier reports that cereals are generally low in lysine and tryptophan, while legumes are deficient in sulphur-containing amino acids (Ghorbani Nejad *et al.*, 2023). The high lysine content in soybean (6.20%) and groundnut (3.42%) complements the leucine- and methionine-rich profile of cereals such as millet and maize (Anih *et al.*, 2025a). This supports the long-standing recommendation for cereal–legume dietary combinations to improve protein quality and net protein utilization (Moreno-León & Aguayo, 2025). Similar patterns have been reported in studies from Ghana (Opoku *et al.*, 2023) and Ethiopia (Yousuf *et al.*, 2025), indicating a regional nutritional synergy in traditional diets such as maize–bean or millet–groundnut porridges.

Aflatoxin Contamination and Market Variation

Although aflatoxin levels in all samples were below the FDA/NAFDAC safety limit of 20 $\mu\text{g}/\text{kg}$, the detection of concentrations as high as 15.43 $\mu\text{g}/\text{kg}$ in millet and 13.10 $\mu\text{g}/\text{kg}$ in maize from Dorowa Market warrants attention. Previous studies in Nigeria have documented occasional exceedances of the regulatory limit, especially in poorly stored maize (Asghar *et al.*, 2022; Tengea *et al.*, 2024). Factors contributing to contamination include high post-harvest moisture, delayed drying, and storage in jute or polypropylene bags that allow moisture migration (Kaptoge *et al.*, 2024).

The higher aflatoxin concentrations in Dorowa Market samples may be linked to longer storage times before sale and possibly higher humidity in storage environments, as reported in similar rural market studies in Cameroon (Monono *et al.*, 2024). The consistently low aflatoxin levels in soybeans (0.10–0.20 $\mu\text{g}/\text{kg}$) observed here are consistent with findings from Tanzanian markets (Nyangi *et al.*, 2024), likely due to their lower susceptibility to *Aspergillus* colonization compared to cereals.

Public Health Implications

While acute aflatoxicosis is rare in Nigeria, chronic low-dose exposure is a public health concern due to its synergistic effect with hepatitis B virus infection in increasing hepatocellular carcinoma risk (Kinyenje *et al.*, 2023). Children are particularly vulnerable, with documented links between aflatoxin exposure and stunting (Gichohi-Wainaina *et al.*, 2023). The relatively safe levels reported here suggest that, at the time of sampling, Wukari grains did not pose an immediate aflatoxin hazard. However, variations between markets and commodities highlight the need for continuous surveillance.

Policy and Food Safety Recommendations

From a food safety perspective, this study underscores the importance of implementing regular mycotoxin monitoring programs at local market level (Kayanda *et al.*, 2024). Training traders on best post-harvest practices, including rapid drying to moisture levels below 13% and use of hermetic storage systems, can reduce contamination risk (Nwokolo *et al.*, 2023). Government and extension agencies could also incentivize adoption of improved storage technologies such as Purdue Improved Crop Storage (PICS) bags (Ebrahimi *et al.*, 2022).

Integrating nutritional composition data with safety assessments as demonstrated in this study can help policymakers prioritize interventions that not only reduce contamination but also preserve nutrient quality. This is particularly important in rural Nigerian contexts where grains are both a dietary staple and an economic commodity.

CONCLUSION

This study provides a combined nutritional and food safety assessment of cereals and legumes retailed in Wukari, Nigeria. Legumes demonstrated superior protein and lipid contents, while cereals were richer in carbohydrates. Amino acid profiling confirmed the complementary nature of these food groups, reinforcing the nutritional value of cereal–legume dietary combinations. Aflatoxin contamination was detected across all commodities, with the highest levels recorded in millet (15.43 µg/kg) and maize (13.10 µg/kg) from Dorowa Market. Despite these variations, all concentrations were within FDA and NAFDAC regulatory limits for human consumption at the time of sampling. Nevertheless, observed differences between markets underscore the potential for localized contamination risks, influenced by storage practices and environmental conditions.

From a public health perspective, maintaining grain safety is vital in rural Nigerian markets, where dietary reliance on these commodities is high. This study highlights the importance of continuous surveillance, improved storage systems, and integration of nutritional data into food safety policy-making.

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CONFLICTS OF INTEREST

The authors confirm that, to the best of their knowledge, no financial or personal relationship exists that could have influenced the work presented in this manuscript

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