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Original Article

Aflatoxin Contamination of Rice along the value chain in Rice Producing Communities of Kogi State

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ABSTRACT

Aflatoxins are highly toxic and carcinogenic secondary metabolites produced predominantly by *Aspergillus flavus* and *A. parasiticus*, with aflatoxin B1 (AfB1) being the most potent. Contamination of rice with AfB1 poses a significant threat to food safety and public health, particularly in tropical regions such as Nigeria, where environmental conditions and traditional agricultural practices are conducive to fungal growth. This study aimed to profile AfB1 contamination in rice along the value chain in five major rice-producing local government areas (LGAs) of Kogi Stat; Bassa, Omala, Yagba-West, Lokoja, and Ibaji with a focus on identifying high-risk stages, contributing cultural practices, and geographic hotspots. A total of 220 rice samples, comprising freshly harvested and stored (9–15 months old) samples, were collected from farms, mills, and homes. Samples were composited into 44 groups and analysed for AfB1 using a competitive ELISA method. Results showed a significantly higher incidence and concentration of AfB1 in stored rice samples compared to freshly harvested ones ($p < 0.05$). Bassa LGA recorded the highest mean AfB1 levels in both sample types (2.894$\pm$4.178 µg/kg for freshly harvested and 9.921$\pm$3.963 µg/kg for stored rice), while Ibaji had the lowest levels (0$\pm$0.00 µg/kg in fresh rice and 2.489$\pm$1.790 µg/kg in stored rice). All stored samples had AfB1 levels exceeding or approaching the 2 µg/kg regulatory threshold, indicating storage as the critical contamination stage. The findings highlight the impact of poor storage practices, and cultural factors like ground-level drying, on aflatoxin contamination. The study identifies Bassa as an aflatoxin hotspot requiring urgent intervention and suggests Ibaji may offer insights into resistant varieties or best practices. The study recommends improved postharvest handling, adoption of hermetic storage, awareness campaigns, and enforcement of safety standards to mitigate AfB1 contamination and enhance the quality and competitiveness of locally produced rice in Kogi State and beyond.

Keywords: Aflatoxin B1, Food safety, Contamination, Rice, Kogi state

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INTRODUCTION

Rice (*Oryza sativa*) is a staple food crop of global and regional importance, particularly in sub-Saharan Africa where it serves as a major source of caloric intake for millions. Nigeria is one of the top rice-producing countries in Africa, with rising local production aimed at reducing import dependence and ensuring food security. In Nigeria, rice is one of the most produced and consumed agricultural commodities [1]. However, the safety of rice consumed locally remains a concern due to frequent contamination by mycotoxins, particularly aflatoxins [2].

Aflatoxins are secondary metabolites primarily produced by *Aspergillus flavus* and *A. parasiticus*, especially under warm and humid tropical climates that are characteristic of many Nigerian agroecological zones. Among these, AfB1 stands out as the most potent natural hepatocarcinogen and has been classified by the International Agency for Research on Cancer (IARC) as a Group 1 human carcinogen (IARC, 1993) [3]. Chronic exposure to AfB1 has been implicated in liver cancer, immunosuppression, and growth retardation in children [4,5]. Exposure to high levels of aflatoxin led to an estimated 9, 28, and 126 liver cancer cases/100,000 persons/year in Mali, Burkina Faso, and Niger, respectively [6]. Nigeria recorded a 617-billion-naira (390 million USD) loss due to higher levels of mycotoxins compared to the safe limit in agricultural products [7].

The postharvest phase of rice production, including drying, storage, and vending practices, significantly affects the levels of fungal contamination and aflatoxin accumulation. In Nigeria, rice is often stored under non-hermetic and ambient conditions that promote mold growth and aflatoxin biosynthesis, particularly in open markets and traditional storage systems [5]. Moisture content above 14%, along with high ambient temperatures (25–37°C), creates optimal conditions for the proliferation of *Aspergillus* spp. [4].

Despite the known risks, data on aflatoxin contamination in rice particularly AfB1 remain sparse in Nigeria. Most available studies either focus on maize or provide limited geographic coverage. Notably, data from major rice-producing states such as Kogi remain scant. In order to prevent and control the incidence and harmful effects of this food borne toxin in rice in Kogi state, and arising from the need to technically and scientifically enhance the competitiveness of the Kogi rice through quality improvement, there is need to map aflatoxin occurrence, spatial distribution and severity of contamination along the rice value chain in Kogi State, where rice production takes place. Based on this reason, the study was conducted to establish a comprehensive aflatoxin profile of rice in Kogi state along the value chain and the stage along the rice value chain, where aflatoxin levels are frequently higher than the set standards. The study also aimed to identify the cultural practices that predispose the crop to fungal infection and subsequent aflatoxin contamination, and to identify zones that are aflatoxin Hot spots for immediate intervention, as well as those with less aflatoxin problems. The research will contribute to evidence-based interventions and policy decisions on rice safety, postharvest management, and public health.

MATERIALS AND METHODS

Study Area

The study area was Kogi state. Kogi is in the central region of Nigeria. It is popularly called the Confluence State because of the confluence of River Niger and River Benue at its capital, Lokoja, which is the first administrative capital of modern-day Nigeria. The state which was founded in 1991 covers a land mass of an area of 29,833 km^2. The state shares border with ten other states which are Federal Capital Territory (Nigeria) to the north, Nasarawa State to the north east, Benue State to the east, Enugu State to the south east, Anambra State to the south, Edo State to the south west, Ondo State to the west, Ekiti State to the west, Kwara State to the west, and Niger State to the north (Figure 1).

Sampling of rice was conducted in five selected LGAs across the state. Selection was based on the Kogi State Agricultural Development Project (KGDP) structure and in rice producing regions namely, Yagba-West, Bassa, Omala, Lokoja, and Ibaji.

Figure 1. Map of Kogi State, Nigeria showing the sampling locations in Kogi State. **Source:** Ukwuru and Murtala, 2023 [13]

Sampling Methods and Sample Size

Rice samples were purchased from rice mills (freshly harvested samples) and homes of farmers/traders (stored sample from previous season being 9-15 months old). Two hundred and twenty (220) samples were collected. At each sampling spot, 500g of milled rice was collected into Ziploc bags. Samples were then composited based on their sites of production/location from which they were brought to the market/mill into 44 samples. The samples were blended using Excella mixer grinder (KHANCHAN INTERNATIONAL LIMITED) and taken for aflatoxin analyses.

Oral interviews were conducted at the site of sample collection to gather information about the storage practices and rice processing methods from the farmer/traders.

Extraction and Quantification of Aflatoxin B1

The method described in Onyedum *et al.* (2020) was used for quantification of Aflatoxin B1 [8].

Aflatoxin B1 Extraction

For extraction, 5 g of the ground sample was weighed into a clean container, followed by the addition of 25 mL of 70% ELISA grade methanol (prepared by mixing 70 mL of absolute methanol with 30 mL of distilled water). The mixture was shaken vigorously for 3 minutes using a mechanical shaker. The extract was centrifuged at 3500 × *g* for 10 minutes at room temperature (20–25 °C) to obtain a clear supernatant. An aliquot of 1 mL of the filtrate was diluted with 1 mL of deionized water, resulting in a 1:1 dilution for use in the ELISA.

Quantification of Aflatoxin B1

Quantitative analysis of AFB1 was performed using the RIDASCREEN® Aflatoxin B1 30/15 competitive enzyme immunoassay kit (R-Biopharm AG, Darmstadt, Germany), according to the manufacturer's instructions.

Briefly, 50 µL of each standard solution (0, 1, 5, 10, 20, and 50 µg/kg) and 50 µL of each prepared sample were pipetted into the wells of a microtiter plate pre-coated with capture antibodies. Subsequently, 50 µL of enzyme conjugate and 50 µL of anti-AFB1 antibody solution were added to each well. The plate was gently mixed and incubated at room temperature (20–25 °C) for 30 minutes in the dark.

Following incubation, the wells were emptied, tapped dry, and washed three times with 250 µL of PBS-Tween wash buffer. After washing, 100 µL of substrate/chromogen solution was added to each well, and the plate was incubated again for 15 minutes at room temperature in the dark.

Finally, the reaction was stopped by adding 100 µL of stop solution per well, and the absorbance was measured at 450 nm using a microplate reader (STAT FAX Elisa Reader MODEL: 303 PLUS). All samples and standards were analysed in duplicate. Detection Limit for Cereals: 1 µg/kg (ppb), recovery rate was approximately 93% and the specificity for aflatoxin B1 was 100 %.

The percentage absorbance for each sample was calculated using the formula:

$$\% \text{ Absorbance} = \frac{\text{Absorbance of sample or standard}}{\text{Absorbance of zero standard}} \times 100$$

The AFB1 concentration in the rice samples was determined by plotting a standard curve and extrapolating sample concentrations directly, as the kit standards were already adjusted for the dilution factor during sample preparation.

Data Analyses

Data obtained were analysed using MS Excel 2013, to determine mean and standard deviation data. The data were subjected to IBM SPSS version 20 to determine test for significance using Duncan method.

RESULTS

The AFB1 concentration in the rice samples was determined by plotting a standard curve and extrapolating sample concentrations directly, as the kit standards were already adjusted for the dilution factor during sample preparation.

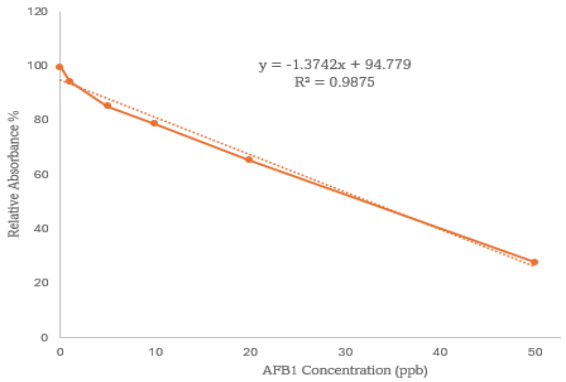

Figure 2: Standard curve for Aflatoxin B1 by competitive ELISA

Table 1 shows a summary of the occurrence and level of aflatoxin B1 in rice across the local government of Kogi state where rice is produced in significant quantities. Table 2 indicates that fresh samples from Omala, Yagba-west, Lokoja and Ibaji had lower levels ($p \leq 0.05$) of AfB1 compared to stored samples in those areas. Although the level of AfB1 in fresh

samples in Bassa was not significantly lower than that of the stored samples, higher levels were found in the stored samples.

Table 1: Aflatoxin B1 profile of Rice in Kogi State

Location	Sample type	Range (ppb)	Mean ± SD	Number of Positive samples (n/N)	% of Positive samples	% of samples above 2ppb
Bassa	Freshly Harvested	0.0135-7.6853	2.894±4.178	3/3	100	33.3
	Stored	4.3252-13.2465	9.921±3.963	4/4	100	100
Omala	Freshly Harvested	0.00-1.2344	0.560±0.560	2/4	50	0
	Stored	2.2210-12.4530	7.893±5.205	3/3	100	100
Ibaji	Freshly Harvested	0.000-0.000	0±0.00	0/1	0	0
	Stored	1.2234-3.7544	2.489±1.790	2/2	100	50
Yagba-west	Freshly Harvested	0.00-0.4565	0.105±0.186	3/7	42.9	0
	Stored	1.1123-4.3425	2.584±1.340	4/4	100	75
Lokoja	Freshly Harvested	0.00-2.2356	1.164±0.671	5/7	71.4	60
	Stored	0.8769-22.5674	7.437±4.560	9/9	100	77.8

n is number of positive samples, N is number of samples (composite) analysed

Table 2: Aflatoxin Levels in Stored and Freshly Harvested samples

	Bassa	Omala	Yagba-west	Lokoja	Ibaji
Freshly Harvested	2.894±4.178[a]	0.560±0.560[a]	0.105±0.186[a]	1.164±0.671[a]	0±0.00[a]
Stored	9.921±3.963[a]	7.893±5.205[b]	2.584±1.340[b]	7.437±4.560[b]	2.489±1.790[b]

Values on same column with different superscript letters are significantly different at $p \geq 0.05$, while those with same superscript letters are not significantly different $p \leq 0.05$.

Figure 3 shows the comparative levels of AfB1 in freshly harvested samples across the LGAs of Kogi state, indicating that Bassa LGA had the highest level while rice from Ibaji has undetectable level of AfB1. Figure 4 on the other hand shows the mycotoxin levels found in stored rice across the LGAs, thus indicating that Bassa LGA had the highest level of mycotoxin while Ibaji had the lowest level of AfB1.

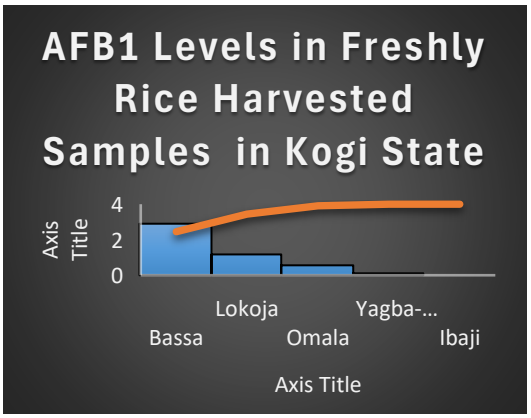

Figure 3: Aflatoxin levels in freshly harvested Rice across the zones

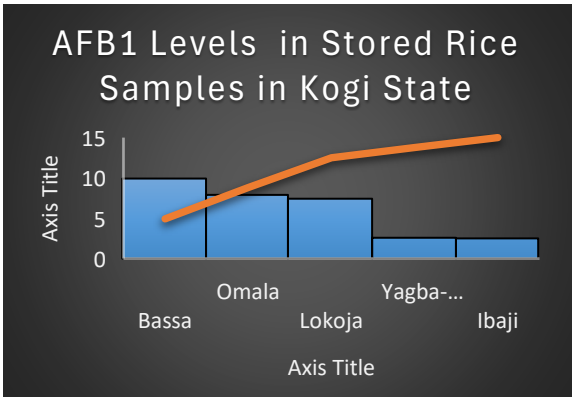

Figure 4: Aflatoxin levels in Stored Rice across the zones

DISCUSSION

This study assessed the occurrence, distribution, and influencing factors of aflatoxin B1 (AfB1) contamination in rice along the value chain in five rice-producing local government areas (LGAs) in Kogi State, Nigeria. The objectives included profiling aflatoxin levels at different value chain stages, evaluating the impact of storage practices, identifying cultural practices and geographical hotspots, and recommending mitigation strategies.

The data revealed widespread AfB1 contamination across the rice value chain, with a significantly higher incidence and concentration observed in stored samples compared to freshly harvested ones. This trend is consistent with prior studies which have established that the postharvest stage, especially during prolonged storage under non-ideal conditions, presents the greatest risk for aflatoxin buildup [4,5]. In this study, stored rice samples from Bassa, Omala, and Lokoja LGAs had mean AfB1 levels significantly exceeding the 2 µg/kg maximum limit set by the European Commission for cereals (European Commission Regulation EC No. 1881/2006) [9]. For instance, Bassa recorded a mean AfB1 concentration of 9.921±3.963 µg/kg in stored rice. This reinforces the assertion that poor storage conditions facilitate the proliferation of aflatoxigenic fungi such as *Aspergillus flavus* and subsequent aflatoxin biosynthesis [2].

The results clearly identified storage as the critical control point where aflatoxin levels tend to exceed safety thresholds. The significantly lower aflatoxin levels in freshly harvested rice (e.g., 0.105±0.186µg/kg in Yagba-West, 0.00 µg/kg in Ibaji) suggest that contamination is minimal at harvest but increases substantially with time under poor storage. This corroborates earlier findings that environmental conditions typical of Nigeria's tropical climate; high temperatures (25–37°C) and elevated relative humidity create ideal conditions for mycotoxin synthesis during storage [4,10].

Cultural practices observed in the field, such as drying rice on bare ground, using non-hermetic woven bags for storage, delayed threshing, and vending in open markets, are known to increase the risk of fungal infection and aflatoxin

contamination [11]. These practices are prevalent in all study zones, indicating the need for broad-based farmer education and infrastructural support.

Storage duration and conditions were found to be strong determinants of aflatoxin contamination. All stored rice samples in this study had AfB1 levels above or near international safety thresholds. This agrees with findings from West Africa where improper storage has been identified as a key driver of aflatoxin accumulation in rice and maize [5,12]. The widespread use of ambient, non-hermetic storage exposes rice to fluctuating humidity and temperature, facilitating *Aspergillus* growth and toxin production.

Spatial variation in AfB1 contamination was evident. Bassa consistently recorded the highest aflatoxin levels in both freshly harvested and stored rice, identifying it as an aflatoxin hotspot requiring urgent intervention. In contrast, Ibaji recorded undetectable levels of AfB1 in fresh samples and only modest levels in stored samples. While varietal resistance could be a factor, microclimatic differences and postharvest practices likely contribute significantly to these spatial patterns. This finding aligns with observations by Tang et al. (2019) [4], who emphasized regional variations in contamination risk based on ecological and socio-cultural conditions.

Given the findings of this study, the following mitigation strategies are recommended. Adoption of hermetic storage technologies (e.g., Purdue Improved Crop Storage [PICS] bags or metallic silos) to limit oxygen and moisture exposure. Training of farmers and traders in good postharvest practices, including rapid drying, proper threshing, and avoidance of ground drying. Routine screening for aflatoxins at the point of sale and during storage to inform handling decisions. Promotion of resistant rice varieties, especially those cultivated in low-contamination zones such as Ibaji. Government support and policy enforcement to ensure adherence to aflatoxin safety standards and incentivize improved storage infrastructure.

CONCLUSION

This study presents a comprehensive profile of aflatoxin B1 contamination in rice across the value chain in five major producing LGAs of Kogi State, Nigeria. The key findings are as follows: storage is the most critical stage for aflatoxin accumulation, with all stored samples exhibiting higher AfB1 concentrations than freshly harvested samples. Cultural and postharvest practices, including non-hermetic storage and open-air drying, are major contributors to contamination. Bassa LGA is identified as an aflatoxin hotspot, while Ibaji LGA appears to be a low-risk area, suggesting possible varietal or environmental resilience. The study emphasizes the urgent need for targeted interventions, including improved storage systems, farmer education, and regulatory enforcement, to reduce aflatoxin risks in rice. These findings contribute to national food safety strategies, support evidence-based policymaking, and can inform aflatoxin control initiatives in rice-producing regions of Nigeria and other sub-Saharan African countries.

Authors Contribution

AMA and ADO conceptualized the study. AMA, ADO, EY, AKA, and UL designed the study. AMA, ADO, EY, AKA, and UL participated in fieldwork and data collection. ADO performed the data analysis; AMA and ADO interpreted the

data. EY, AKA, and UL prepared the first draft and AMA and ADO reviewed the manuscript. All authors contributed to the development of the final manuscript and approved its submission.

Disclosure of Conflict of Interest

None

Ethics Approval and Informed Consent

This study did not use human or animal subjects. Therefore, ethical consideration was not applicable.

Disclosure of Funding

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