IMPACT OF FUNGAL CONTAMINATION ON NUTRIENT COMPOSITION OF RICE, MAIZE, AND SORGHUM IN NIGERIA: CORRELATION ANALYSIS AND IMPLICATIONS FOR FOOD QUALITY

HADIZA K. MUHAMMAD*[1,2], SUSAN B. SALUBUYI[1,2], IFEANYI F. OSSAMULU[1,2], FATIMA M. MADAKI[2], ANTOINE T. A. EDZILI[2], J. P. SHINGU[1,3], ADEKUNLE A. ADEYEMI[1] & PELUMI JOHN[1]

[1] Department of Biochemistry, Federal University of Technology, Minna.
[2] Africa Centre for Excellence for Mycotoxin and Food Safety, Federal University of Technology, Minna.
[3]National Biotechnology Research and Development Agency, Nigeria.

***Corresponding author:** hadiza.muhammad@futminna.edu.ng, 08035646027

ABSTRACT

This study assesses the effect of fungal contamination on the nutrient composition of staple cereals; rice (*Oryza sativa*), maize (*Zea mays*), and sorghum (*Sorghum bicolor*)—widely consumed in Nigeria. A total 23 samples of maize (7), rice (6) and sorghum (9) were analyzed for fungal colony-forming units (CFUs) via plate dilution method and nutrient composition (moisture, ash, fat, fiber, protein, and carbohydrate levels) was measured following Association of Analytical Chemists (AOAC) methods. Statistical analysis, including Spearman correlation, was applied using SPSS software. Maize showed the highest fungal contamination with a mean CFU of 4.0×10^5 CFU/g, followed by Sorghum at 3.7×10^4 CFU/g, while rice had the lowest at 2.7×10^4 CFU/g. Significant positive correlations were observed between fungal growth and moisture content in all grains, with correlation coefficients of 0.752 for rice, 0.806 for maize, and 0.550 for sorghum. Conversely, carbohydrate content showed a significant negative correlation in all samples, notably in maize (-0.860) and rice (-0.638), with (-0.462) for sorghum. Fat and fiber content showed a negative correlation in rice (-0.584) and maize (-0.488), while sorghum showed a positive correlation (0.413). Only rice showed a negative correlation for ash (-0.415) and protein (-0.136), while maize (0.354 and 0.220) and sorghum (0.258 and 0.384) showed a positive correlation. These findings underscore the nutrient losses due to fungal contamination, highlighting the necessity for enhanced post-harvest storage to mitigate contamination and preserve cereal nutritional quality.

Keywords: Fungi, Nutrient composition, Cereals.

INTRODUCTION

Cereals such as rice (*Oryza sativa*), maize (*Zea mays*), and sorghum (*Sorghum bicolor*) are essential staple foods worldwide, providing a primary source of calories and key nutrients for millions of people, especially in developing regions (Muitire *et al.*, 2021). These grains are not only foundational to food security but are also crucial in providing proteins, vitamins, and minerals necessary for balanced nutrition. However, cereal crops are highly susceptible to contamination by fungi during growth, harvest, and storage, which poses significant risks to both food safety and nutrient quality (Agriopoulou, 2021; Habschied *et al.*, 2021; Kumar *et al.*, 2021).

Fungal contamination in cereals is predominantly caused by several species such as *Aspergillus, Fusarium*, *Penicillium*, and *Alternata* species which thrive in warm and humid environments often associated with grain storage in tropical and subtropical climates (Chasna *et al.*, 2024; Cruz-Luna *et al.*, 2021). These fungi not only damage and decrease the shelf life of grains rendering them unfit for human consumption (Majumder *et al.*, 2013; Nešić *et al.*, 2021), but also produce mycotoxins, which are secondary metabolites that are toxic to humans and animals (Liu *et al.*, 2020). The damages caused by these microorganisms to cereals are estimated to be approximately between 20 to 40 % in Africa (Adégbola *et al.,* 2011). Mycotoxins, such as aflatoxins, ochratoxins, fumonisins, patulin, and Alternaria toxins, are well-known for their health risks, including neurotoxicity, carcinogenicity, and immunotoxicity. Beyond these health concerns, fungal contamination can lead to nutrient depletion in contaminated grains, as the microorganisms consume essential nutrients, impacting the grain's nutritional profile and, consequently, human health (Nishimwe *et al.*, 2020).

The impact of fungal contamination on the nutrient composition of rice, maize, and sorghum remains a crucial area of study. Understanding how fungi alter the levels of macronutrients (carbohydrates, proteins, fats) in these grains can inform agricultural practices, storage solutions, and mycotoxin management strategies. In this study, the effect of fungal contamination on the nutrient composition of rice, maize, and sorghum was examined and highlights the potential nutritional and public health implications of consuming contaminated cereals.

MATERIALS AND METHODS

Collection of samples

The use of sample materials in this study complies with relevant institutional, national, and international guidelines and legislation.

The grains of rice (6), maize (7), and sorghum (9) were obtained with permission from farms and stores; and purchased from markets in different agroecological zones in Nigeria.

Sample preparation

250 grams of each sample was milled into a fine powder using a mixer grinder. To avoid cross-contamination, cleaning and decontamination of the equipment was performed using methanol after each milling step. To also prevent further contamination, all samples were kept in the freezer.

Fungi isolation procedure

Fungi isolation was carried out using the plate dilution method as described by (Nevalainen *et al.,* 2014). One gram of the milled sample was weighed into a sterile tube suspended in 9 mL of distilled water and shaken to make a first dilution of 10-1. Three serial dilutions were carried out for maize to obtain 10^{-1}, 10^{-2}, and 10^{-3} dilutions, while two serial dilutions were carried out for rice and sorghum to obtain 10^{-1} and 10^{-2}. One milliliter of each diluent was plated onto potato dextrose agar (PDA). The plates were incubated for 2 days at room temperature. After incubation, the growth of fungi colonies was observed and counted, the number of colonies per gram of samples was expressed in colony forming unit per gram (CFU/g).

Proximate analysis of rice, maize and sorghum

Standard methods by the Association of Analytical Chemists (AOAC, 2005) were adopted in the analysis. The system consists of the analytical determination of moisture, ash, crude fat, crude fibre, crude protein and carbohydrate.

Determination of moisture content

Each of the samples were weighed, dried in a hot air oven at 105 ^{0}C for three hours, cooled in a desiccator and the final weight was measured.

Determination of ash content

Ash content was determined by weighing 2 g of sample into a crucible and incinerating at 500 ^{0}C for three hours using a muffle furnace.

The light grey ash obtained was cooled, and the final weight of the ash content was taken.

Determination of fat content

Fat content determination was done using the Tecator Soxtec system HT 1043 extraction unit. Fat extraction was done using petroleum ether.

After extraction, the solvent was allowed to evaporate, and the fat was dried in an oven at 105 ^{0}C for one hour, cooled in a desiccator, and weighed to determine the fat content.

Determination of fiber content

To determine the fiber content. The sample was gently boiled in 200 mL of 1.25 % sulfuric acid solution for 30 minutes, the solution was filtered, washed with boiling water until the filtrate was acid free. The residue was transferred back to the beaker and gently boiled in 200 mL of 1.25 % sodium hydroxide solution, followed by filtration and washing until the filtrate was alkali-free, with a final wash using 15 ml of 95 % ethanol.

The residue was then dried in an oven at 105 ^{0}C for 2 hours, cooled in a desiccator, and weighed.

Determination of protein content

The protein content was determined by micro-Kjeldahl using the Tecator Digestion System and Kjeltec Auto 1030 Analyzer.

Kjeldahl digesting system was used to digest the sample after which it was diluted with distilled water and NaOH was added to make the solution strongly alkaline.

The released ammonia was distilled into a receiving flask containing boric acid, the distillate was titrated against standardized hydrochloric acid (0.1 M). The nitrogen content was multiplied by a conversion factor (6.25) to get protein content.

Determination of carbohydrate content

The percentage carbohydrate content of the sample was determined by adding the percentage values of ash, fat, protein, and moisture content together (% Fat + % Ash + % Protein + % Moisture) and subtracted from 100.

Statistical analysis

Values were represented as mean ± standard deviation. Mean ± standard deviation and Spearman correlation of fungi concentration against nutrient composition were determined using SPSS software. The statistical level of significance was fixed at $p < 0.05$.

RESULTS

Colony forming unit per gram of rice, maize and sorghum

The result of the proximate analysis and the colony-forming units (CFU) of fungi in rice, maize, and sorghum are presented in Tables 1, 2 & 3.

Maize had the highest fungi load, the mean value for maize was 4.0×10^5 CFU/g, and the CFU count in some maize samples was as high as 1.2×10^6 CFU/g. In contrast, rice had the lowest fungi load, with a mean of 2.7×10^4 CFU/g, with CFU count in a sample as low as 6.7×10^1 CFU/g.

The mean value of fungi load in sorghum was 3.7×10^4 CFU/g, with a range of $1.3 \times 10^4 – 1.3 \times 10^5$ CFU/g for the lowest and highest values respectively.

Effect of fungi on nutrient composition of rice, maize, and sorghum

The nutrient analysis revealed correlations between contamination and nutrient content. There was a strong positive correlation for moisture in rice (0.752), maize (0.806), sorghum (0.550) and a strong negative correlation for carbohydrates in rice (-0.638), maize (-0.860), while sorghum exhibited a relatively weak negative correlation (-0.462).

This data strongly indicates potential loss of nutrients to the fungi present.

DISCUSSION

The findings of this study highlight the significant impact of fungal contamination on the nutrient composition of rice, maize, and sorghum. The higher CFU of fungi in maize compared to rice and sorghum aligns with the work of Garba *et al.* (2017), and Onyedum *et al.* (2020), this can be attributed to its higher susceptibility to fungal contamination (Mahmoud *et al.*, 2013).

The positive correlation between moisture content and fungal presence across all three grains suggests that higher moisture levels in grains may create a favorable environment for fungal growth, which accelerates nutrient degradation. This aligns with previous research that links fungal proliferation in cereals to moisture-rich environments (Nishimwe *et al.,* 2020). The observed negative correlation between fungal contamination and carbohydrate content, particularly in maize (-0.860) and rice (-0.638), indicates that fungi consume available carbohydrates, potentially impacting the energy value of the grains for human consumption. Interestingly, while protein content showed minimal negative correlation with fungal contamination in rice, it displayed a slight positive correlation in sorghum, suggesting variability in how fungi interact with nutrient types depending on the grain. These findings underscore the need for effective grain storage solutions that limit moisture accumulation and inhibit fungal growth, as well as the potential for further investigation into grain-specific fungal resistance mechanisms.

CONCLUSION

In conclusion, this study demonstrates that fungal contamination significantly affects the nutrient composition of rice, maize, and sorghum, with notable implications for food quality and safety. The positive correlation between moisture levels and fungal growth highlights the importance of proper grain drying and storage conditions to inhibit fungal proliferation. Additionally, the depletion of carbohydrates and varying effects on protein content across the different grains emphasize the nutrient losses and potential health risks associated with consuming contaminated cereals. These findings underscore the urgent need for improved post-harvest management strategies, particularly in regions with humid climates where fungal contamination is prevalent. Future research focusing on fungal-resistant grain varieties and advanced storage solutions could further enhance food security and nutritional quality in staple cereal crops.

Table 1: Nutrient Composition and Colony Forming Units (CFU/g) of Fungi in Rice

AEZ	Crop	Location	Moisture	Ash	Fat	Fiber	Protein	Carbohydrate	Mean Fungi load. (CFU/g)
MA	RM	T1	7.16 ± 1.18	2.44 ± 0.25	0.95 ± 0.02	1.78 ± 0.19	5.37 ± 0.94	73.7 ± 0.74	3.8×10^4
MA	RS	T1	7.51 ± 1.56	2.96 ± 0.52	1.1 ± 0.16	2.00 ± 0.39	5.57 ± 0.86	75.21 ± 2.11	1.2×10^5
SGS	RM	B1	16.47 ± 2.02	9.73 ± 0.93	2.47 ± 0.11	1.16 ± 0.02	2.26 ± 0.05	63.83 ± 0.79	5.4×10^3
SGS	RS	B1	13.04 ± 1.09	9.17 ± 0.06	2.5 ± 0.10	1.19 ± 0.03	2.30 ± 0.01	61.17 ± 1.03	1.4×10^3
SHS	RM	R1	8.83 ± 0.29	3.88 ± 0.09	6.33 ± 1.89	5.83 ± 0.77	10.36 ± 1.75	63.72 ± 2.75	6.7×10^1
SHS	RS	R1	13.17 ± 1.04	2.56 ± 0.36	7.67 ± 1.76	4.86 ± 0.17	11.08 ± 1.19	59.74 ± 4.67	1.2×10^3

AEZ: Agroecological zone, MA: Mid-Altitude, SGS: Southern Guinea Savannah, SHS: Sahel Savannah, RM: Rice from Market, RS: Rice from Store

Table 2: Nutrient Composition and Colony forming units (CFU/g) of Fungi in Maize

AEZ	Crop	Location	Moisture	Ash	Fat	Fiber	Protein	Carbohydrate	Mean Fungi load. (CFU/g)
NGS	MF	B2	12.54 ± 0.47	3.10 ± 0.10	2.24 ± 0.21	3.27 ± 0.02	10.32 ± 0.02	67.37 ± 0.04	3.2×10^5
NGS	MM	B2	11.07 ± 0.06	2.92 ± 0.07	2.61 ± 0.01	3.40 ± 0.10	10.22 ± 0.02	69.28 ± 0.03	2.8×10^5
NGS	MS	B2	12.48 ± 0.02	2.97 ± 0.12	2.22 ± 0.03	3.26 ± 0.02	9.87 ± 0.01	68.45 ± 0.01	7.6×10^5
MA	MM	T1	6.15 ± 0.49	2.45 ± 0.31	1.98 ± 0.11	1.24 ± 0.24	8.10 ± 2.40	75.01 ± 5.38	1.2×10^6
MA	MS	T1	6.51 ± 0.86	2.97 ± 0.16	2.14 ± 0.19	1.46 ± 0.44	8.30 ± 2.52	76.52 ± 4.8	1.1×10^5
RF	MM	A1	10.12 ± 0.44	1.25 ± 0.05	2.33 ± 0.05	2.48 ± 0.02	7.05 ± 0.45	76.81 ± 0.71	3.7×10^4
RF	MS	A1	10.12 ± 0.26	1.26 ± 0.14	2.18 ± 0.02	2.48 ± 0.17	7.27 ± 0.49	76.68 ± 0.71	5.7×10^4

AEZ: Agroecological zone, Northern Guinea Savannah, SGS: MA: Mid Altitude, RF: Rain Forest, MM: Maize from Market, MS: Maize from Store, MF: Maize from Farm

Table 3: Nutrient Composition and Colony forming units (CFU/g) of Fungi in Sorghum

AEZ	Crop	Location	Moisture	Ash	Fat	Fiber	Protein	Carbohydrate	Mean Fungi load. (CFU/g)
MA	SM	T1	6.26 ± 0.23	1.87 ± 0.16	0.82 ± 0.13	1.74 ± 0.24	6.94 ± 0.78	75.91 ± 6.35	2.0×10^4
MA	SS	T1	6.61 ± 0.61	2.39 ± 0.25	0.98 ± 0.22	1.96 ± 0.44	7.13 ± 0.88	77.42 ± 5.76	1.7×10^4
SS	SF	A1	18.26 ± 0.31	2.07 ± 0.21	2.43 ± 0.21	3.36 ± 0.11	9.21 ± 0.22	63.98 ± 0.48	1.8×10^4
SS	SM	A1	15.53 ± 0.25	2.87 ± 0.23	2.63 ± 0.13	3.58 ± 0.10	10.43 ± 0.21	64.00 ± 0.25	1.3×10^5
DS	SF	G1	12.54 ± 0.47	3.10 ± 0.10	2.24 ± 0.21	3.27 ± 0.02	10.32 ± 0.02	67.37 ± 0.04	1.3×10^4
DS	SM	G1	11.07 ± 0.06	2.92 ± 0.07	2.61 ± 0.01	3.40 ± 0.10	10.22 ± 0.02	69.28 ± 0.03	3.2×10^4
DS	SS	G1	12.48 ± 0.02	2.97 ± 0.12	2.22 ± 0.03	3.26 ± 0.02	9.87 ± 0.01	68.45 ± 0.01	3.2×10^4
SGS	SM	M2	8.00 ± 0.00	3.30 ± 0.00	2.43 ± 0.02	3.63 ± 0.03	10.81 ± 0.02	71.25 ± 0.01	3.5×10^4
SGS	SS	M2	10.4 ± 0.10	3.17 ± 0.06	2.52 ± 0.02	3.68 ± 0.01	10.41 ± 0.02	69.21 ± 0.03	4.1×10^4

AEZ: Agroecological zone, MA: mid-altitude, SGS: Southern Guinea Savannah, DS: Derived Savannah, SM: Sorghum from Market, SS: Sorghum from Store, SF: Sorghum from Farm

Table 4: Correlation of Fungi (CFU/g) against Nutrient Composition of Rice, Maize and Sorghum

	Moisture	Ash	Fat	Fiber	Protein	Carbohydrate
Rice	0.752	-0.415	-0.584	-0.301	-0.136	-0.638
Maize	0.806	0.354	-0.488	-0.272	0.220	-0.860
Sorghum	0.550	0.258	0.413	0.390	0.384	-0.462

REFERENCES

Adégbola, P. Y., Arouna, A., & Ahoyo, N. R. A (2011) Acceptabilité des structures améliorées de stockage du mais au Sud-Bénin in Bulletin de la Recherche Agronomique du Bénin—Numérospécial 2: Aspects économiques du stockage et de la conservation du mais au Sud-Béni, Septembre. 2011, 1-12.

Agriopoulou, S. (2021) Ergot Alkaloids Mycotoxins in Cereals and Cereal-Derived Food Products: Characteristics, Toxicity, Prevalence, and Control Strategies. *Agronomy*, 11(5), 931.

AOAC (2005). Official Methods of Analysis of Association of Official Analytical Chemists, 15 th ed. Washington D.C. USA.

Chasna, M. R. P., Rajawardana, D. U., & Amunugoda, P. N. R. J. (2024). An overview of the impact of climatic change on the occurrence of aflatoxins in cereals: Sri Lankan perspective. *YSF Thematic Publication 2024*, 19.

Cruz-Luna, A.R., Cruz-Martinez, H., Vasquez-Lopez, A. & Medina, D. I (2021) Metal nanoparticles as novel antifungal agents for sustainable agriculture: Current advances and future directions. *Journal of Fungi* (Basel), 7(12), 1033. doi: 10.3390/jof7121033

Habschied, K., Kanižai-Šarić, G., Krstanović, V., & Mastanjević, K. (2021) Mycotoxins—Biomonitoring and Human Exposure. *Toxins*. 13(2), 113.

Kumar, A., Pathak, H., Bhadauria, S., & Sudan, J. (2021). Aflatoxin contamination in food crops: causes, detection, and management: a review. *Food Production, Processing and Nutrition*, *3*, 1-9.

Liu, Y., Galani Yamdeu, J. H., Gong, Y. Y., & Orfila, C. (2020). A review of postharvest approaches to reduce fungal and mycotoxin contamination of foods. *Comprehensive Reviews in Food Science and Food Safety*, *19*(4), 1521-1560.

Mahmoud, M. A., Al-Othman, M. R., & Abd El-Aziz, A. R. (2013). Mycotoxigenic fungi contaminating corn and sorghum grains in Saudi Arabia. *Pakistan Journal of Botany*, *45*(5), 1831-1839.

Majumder, D., Rajesh, T., Suting, E, G., & Debbarma, A (2013) Detection of seed borne pathogens in wheat: recent trends. *Australian Journal of Crop Science*. 201337(4), 500-507

Muitire, C., Kamutando, C., & Moyo, M. (2021). *Building stress resilience of cereals under future climatic scenarios:'the case of maize, wheat, rice and sorghum'*. London, UK: IntechOpen.

Nevalainen, H., Kautto, L., & Te'o, J. (2014). Methods for isolation and cultivation of filamentous fungi. *Environmental Microbiology: Methods and Protocols*, 3-16.

Nešić, K., Habschied, K., & Mastanjević, K. (2021) Possibilities for the biological control of mycotoxins in food and feed. *Toxins*, 13(3), 198.

Nishimwe, K., Mandap, J. A. L., & Munkvold, G. P. (2020). Advances in understanding fungal contamination in cereals. *Advances in postharvest management of cereals and grains*, 31-66.