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ASSESSMENT OF DIETARY EXPOSURE AND POTENTIAL HEALTH RISKS ASSOCIATED WITH OCHRATOXIN CONTAMINATION IN SELECTED FOODSTUFFS IN ZAMFARA STATE

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ABSTRACT

Ochratoxin A (OTA) is a toxic fungal metabolite that contaminates food commodities and poses potential risks to human health. This study assessed OTA contamination, dietary exposure and associated health risks in selected foodstuffs consumed in Zamfara State, Nigeria. A descriptive and comparative analytical design was adopted, involving 75 samples of groundnut, maize, sorghum, millet and rice collected from five Local Government Areas. OTA concentrations were analysed using descriptive statistics and the Kruskal–Wallis test, while dietary exposure and potential health risks were evaluated using Estimated Daily Intake (EDI) and Margin of Exposure (MOE), respectively. The results showed an overall mean OTA concentration of 3.265 ± 2.410 µg/kg, with groundnut recording the highest concentration (5.119 µg/kg), followed by maize (4.238 µg/kg), sorghum (3.304 µg/kg), millet (1.964 µg/kg) and rice (1.701 µg/kg). Significant differences occurred among food commodities ($p < 0.05$), but not across sampling locations ($p = 0.5812$). Maize recorded the highest mean EDI (0.01051 µg/kg body weight/day), while the overall mean EDI was 0.005296 µg/kg body weight/day. Furthermore, 92% of the assessed consumer profiles had MOE values below 10,000 for neoplastic kidney effects, indicating a potential health concern. The findings underscore the need for regular food safety monitoring, improved post-harvest handling and storage, and effective control measures to minimise OTA contamination and protect public health.

KEYWORDS: Ochratoxin A, Food contamination, Dietary exposure, Estimated daily intake, Margin of exposure, Health risk.

1. INTRODUCTION

Food safety is a major public health concern worldwide, particularly in developing countries where inadequate food handling, poor storage conditions and unfavourable environmental factors contribute to the contamination of food commodities. Among the important foodborne contaminants are mycotoxins, which are toxic secondary metabolites produced by certain species of fungi, particularly *Aspergillus* and *Penicillium*. One of the most significant mycotoxins is ochratoxin A (OTA), which can contaminate various foodstuffs, including cereals, grains, legumes, coffee, cocoa, spices and other agricultural products (EFSA, 2020; IARC, 1993). Ochratoxin A contamination may occur during crop production, harvesting, transportation, processing and storage, particularly under favourable temperature and moisture conditions. Human exposure occurs mainly through the consumption of contaminated food, making dietary intake an important pathway of exposure (EFSA, 2020). Prolonged exposure to OTA has been associated with kidney toxicity, liver damage, immunotoxic effects and potential carcinogenic effects, making it a significant concern for food safety and public health (IARC, 1993; EFSA, 2020).

In Nigeria, mycotoxin contamination of food remains an important food safety challenge due to the widespread consumption of cereals and other agricultural commodities, as well as inadequate storage and handling practices (Imade et al., 2021). Studies conducted in North-Central Nigeria have reported the occurrence of ochratoxin A in commonly consumed foods such as rice, millet, sorghum, maize and yam flour, indicating the possibility of dietary exposure among consumers (Onyedum et al., 2020). Dietary exposure assessment is therefore essential for estimating the amount of OTA consumed relative to body weight and evaluating the potential health risks associated with its presence in food (EFSA, 2020).

1.1 Food Safety and Contamination of the Nigerian Food Supply

Food safety remains a major global public health concern because the consumption of contaminated food can cause acute and chronic illnesses, reduced productivity and significant economic losses. The World Health Organization (WHO, 2015) estimated that approximately 600 million people suffer from foodborne illnesses, resulting in 420,000 deaths annually worldwide. The problem is particularly pronounced in developing countries, including Nigeria, where inadequate food-control systems, poor sanitation, limited surveillance and improper food handling, processing and storage increase the risk of contamination. Food contamination may occur at different stages of the food supply chain, from agricultural production and harvesting to processing, transportation, marketing and consumption. Major contaminants include potentially toxic metals such as lead, cadmium, arsenic and mercury,

pesticide residues, polycyclic aromatic hydrocarbons (PAHs), persistent organic pollutants, pathogenic microorganisms and mycotoxins. Nigerian studies have reported chemical contaminants in food crops, fish, seafood, beans, honey and street-vended foods, highlighting potential dietary exposure and associated health risks (Oloruntoba et al., 2024; Iwegbue et al., 2024; Abdulra'uf et al., 2025; Tesi et al., 2025). Prolonged exposure to these contaminants may contribute to neurological disorders, kidney damage, endocrine disruption and increased cancer risk, depending on the nature and concentration of the contaminants and the duration of exposure (Ilyas et al., 2024; Nsonwu-Anyanwu et al., 2024). Similarly, biological contamination involving *Salmonella* spp., *Escherichia coli*, *Listeria monocytogenes* and other foodborne pathogens has been documented in ready-to-eat foods, fermented cassava products, vegetables and seafood in Nigeria (Ajuzieogu et al., 2022; Beshiru et al., 2022; Makinde et al., 2023). Furthermore, antimicrobial resistance associated with foodborne microorganisms presents an additional public health challenge, as resistant bacteria can spread through food, animals and environmental pathways (Raji et al., 2021; CDC, 2024). Mycotoxins also constitute important biological hazards because their persistence in agricultural commodities and improperly stored foods may expose consumers to toxic and carcinogenic substances (Nji et al., 2022; Badmos et al., 2024).

In Nigeria, food safety challenges are further aggravated by rapid urbanisation, inadequate potable water, poor waste management, insufficient laboratory facilities, weak regulatory enforcement and limited compliance with good agricultural and food-handling practices. These factors create opportunities for contamination throughout the food supply chain, particularly in informal markets and street-vending environments. Evidence from different parts of the country has demonstrated the occurrence of chemical and microbial contaminants in commonly consumed food commodities, including agricultural products, fish, seafood, vegetables and ready-to-eat foods (Okafor-Elenwo& Imade, 2020; Ibrahim et al., 2024; Markmanuel, 2025). Although Nigeria has established institutional and regulatory frameworks, including the National Policy on Food Safety and Quality, effective implementation requires improved surveillance, coordinated regulatory activities, adequate analytical laboratory capacity and sustained public awareness (Federal Ministry of Health, 2023). Despite increasing research attention, existing evidence remains fragmented across contaminant categories, food commodities, geographical locations and assessment approaches. Previous studies have examined heavy metal contamination and broader food safety concerns in Nigeria and sub-Saharan Africa (Christiana Cudjoe et al., 2022; Oloruntoba et al., 2024), but an integrated assessment of chemical and biological hazards

alongside their potential human health implications remains necessary. Therefore, this review synthesises available evidence on chemical and biological contamination of food commodities in Nigeria, focusing on studies published between 2015 and 2025. It examines the occurrence and distribution of major contaminants, identifies commonly affected food categories and evaluates their potential implications for consumer health.

Despite growing concerns about mycotoxin contamination in Nigeria, information on ochratoxin contamination and its associated dietary health risks in foodstuffs consumed in Zamfara State remains limited. Consequently, this study aims to assess ochratoxin contamination in selected foodstuffs, estimate dietary exposure and evaluate the potential health risks among consumers in Zamfara State, Nigeria.

1.2 Objectives

The aim of the research is to Assess the Dietary Exposure and Potential Health Risks Associated with Ochratoxin Contamination in Selected Foodstuffs in Zamfara State. With the following objectives

1. Determine the occurrence of Ochratoxin A (OTA) in selected food commodities.
2. Determine OTA concentrations in the selected food samples.
3. Compare contamination levels across food commodities and sampling locations.
4. Estimate consumer dietary exposure to OTA. And Calculate Estimated Daily Intake (EDI).
5. Characterize potential health concerns using appropriate toxicological benchmarks.

2. Literature Review

2.1 Mycotoxin Contamination in Maize and Its Implications for Food Safety and Public Health

Maize (*Zea mays* L.) is an important staple cereal in sub-Saharan Africa, contributing significantly to household food security, nutrition and agricultural livelihoods. In Nigeria, its widespread cultivation, consumption and commercial distribution make its safety and quality essential to public health and economic development. However, maize is susceptible to fungal contamination during production, harvesting, transportation, processing and storage, particularly under favourable temperature and moisture conditions. This contamination may lead to the production of mycotoxins, which are toxic secondary metabolites of certain fungi and constitute a major food safety concern in cereal-producing regions (Nji et al., 2022; Deligeorgakis et al., 2023). Major mycotoxins associated with cereal grains include aflatoxins, fumonisins, trichothecenes, zearalenone (ZEN), ochratoxin A (OTA),

cyclopiazonic acid (CPA) and nivalenol (NIV), which may occur individually or simultaneously in contaminated commodities. Among these, aflatoxin B_1 (AFB_1) is particularly significant because of its carcinogenic potential and association with hepatocellular carcinoma (Alao et al., 2023), while fumonisins, particularly fumonisin B_1, have been associated with oesophageal cancer and other toxic effects in humans and animals (Anumudu et al., 2025). Other mycotoxins also pose considerable health concerns: trichothecenes can interfere with protein synthesis and impair immune functions, zearalenone exhibits oestrogenic properties that may affect reproductive health, and ochratoxin A is recognised for its nephrotoxic effects (Ochieng et al., 2021; Ben Miri et al., 2024; Deligeorgakis et al., 2023). The simultaneous occurrence of multiple mycotoxins in maize is particularly concerning because regular dietary consumption may result in combined exposure, potentially increasing the complexity of evaluating their toxicological effects and associated health risks.

In Nigeria, investigations have documented mycotoxin contamination in maize and other commonly consumed staple foods, demonstrating the need for effective food safety surveillance and improved post-harvest management (Oyebamiji et al., 2023; Chidimma et al., 2024). Recent findings from Nigerian food commodities have also highlighted the occurrence of multiple mycotoxins and the influence of inadequate drying, poor storage practices and environmental conditions on fungal growth and toxin production (Nji et al., 2022; Badmos et al., 2024; Baidhe et al., 2024). These challenges are particularly important in maize-producing communities, where traditional storage practices and inadequate post-harvest facilities may increase contamination risks. Furthermore, despite increasing research attention, information on the occurrence and distribution of certain less frequently investigated mycotoxins, particularly CPA and NIV, remains limited in some maize-producing areas of Nigeria. There is also a need for more comprehensive information on the co-occurrence of multiple mycotoxins across different agro-ecological and microclimatic zones and the potential dietary exposure associated with regular maize consumption. This is important because the health risks associated with mycotoxin-contaminated foods depend not only on individual toxin concentrations but also on consumption patterns, exposure duration and possible combined exposure to different toxins (Badmos et al., 2024; Kayanda et al., 2024). Against this background, the present study investigates fungal diversity and the occurrence of major mycotoxins in maize samples collected from four microclimatic zones of Niger State, Nigeria. It further evaluates dietary exposure and potential health risks associated with maize consumption, with particular emphasis on the co-occurrence and cumulative

exposure to multiple mycotoxins. The findings are expected to provide useful evidence for strengthening food safety monitoring, improving post-harvest management practices and developing appropriate strategies to minimise mycotoxin contamination and its associated public health and economic consequences.

2.2 Safety Evaluation and Potential Health Implications of Water from Post-Remediated Lead-Polluted Areas of Zamfara State

Environmental pollution, particularly contamination by toxic heavy metals, remains a major public health and environmental concern because these elements are persistent, non-biodegradable and capable of accumulating in living organisms. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) can enter aquatic environments through natural geological processes and anthropogenic activities, including mining, industrial operations, agricultural practices and improper waste disposal. Their distribution and mobility in water depend on several environmental factors, including pH, redox conditions, soil composition, mineralogy and interactions with sediments. Consequently, pollutants released into the environment may migrate into surface water and groundwater, potentially compromising their suitability for drinking and domestic purposes. The severity of contamination may vary across locations according to geological characteristics, land-use patterns, hydrological conditions and the nature of pollution sources, making regular water-quality assessment essential for protecting public health (Ilyas et al., 2024; Oloruntoba et al., 2024). Among these pollutants, lead is particularly hazardous because it has no known beneficial biological function in humans and can adversely affect the nervous, haematological, renal, cardiovascular and reproductive systems. Exposure may occur through the consumption of contaminated drinking water and food, as well as through inhalation or accidental ingestion of contaminated dust and soil. The potential health consequences depend on the concentration of lead, frequency and duration of exposure, water consumption rate and characteristics of the exposed population. Previous investigations have therefore emphasised the importance of determining heavy-metal concentrations in drinking water and evaluating the associated human health risks using appropriate exposure and toxicological assessment approaches (Maigari et al., 2016; Micheal et al., 2018).

In Nigeria, contamination associated with artisanal and small-scale mining has attracted considerable attention, particularly in Zamfara State, where informal gold-mining activities resulted in a major lead-poisoning crisis. In affected communities, including Dareta, the processing of lead-rich gold ore contributed to extensive environmental contamination, necessitating remediation interventions to reduce pollutant levels. However, the remediation

of contaminated soil does not automatically establish that other environmental compartments, particularly surface water and groundwater, are free from residual pollutants. Indeed, lead may persist in soil and sediments or be transported into nearby water sources through runoff, infiltration and other environmental processes. Although Udiba et al. (2012) reported a post-remediation assessment of contaminant levels in Dareta village soil, continued investigation of water sources is necessary to establish their safety and suitability for human consumption. This is particularly important in rural communities where households may depend on boreholes, shallow wells and streams for drinking, cooking and other domestic activities. Accordingly, this study evaluates the safety of water obtained from post-remediated lead-polluted areas of Zamfara State, Nigeria, by examining selected physicochemical properties and heavy-metal concentrations. It further assesses the potential health implications of consuming the investigated water using exposure and risk indicators, including estimated average daily intake (EADI) and target hazard quotient (THQ). These indicators provide a basis for estimating exposure and evaluating potential non-carcinogenic health effects by relating estimated contaminant intake to appropriate toxicological reference values. A THQ below one generally indicates a low likelihood of significant non-carcinogenic effects under the assumptions of the assessment, whereas a value exceeding one suggests a potential health concern requiring further investigation. Similar approaches have been employed in previous drinking-water studies to evaluate human exposure and health risks associated with heavy-metal contamination (Moses & Etuk, 2015; Maigari et al., 2016). The findings of the present study are expected to provide evidence on the post-remediation condition of water sources, identify possible residual exposure concerns and support decisions on water-quality monitoring, treatment and environmental management in previously lead-contaminated communities.

3.0 METHODOLOGY

The study adopted a descriptive and comparative analytical design to assess Ochratoxin A (OTA) contamination in selected food commodities and estimate potential dietary exposure among consumers in Zamfara State. Samples were obtained from five selected Local Government Areas, comprising 75 observations of five food commodities: groundnut, maize, sorghum, millet and rice, with 15 observations allocated to each commodity. OTA concentrations were determined and expressed in µg/kg. Descriptive statistics, including mean, standard deviation, median, minimum and maximum values, were used to summarize

contamination levels, while comparisons were made across food commodities and sampling locations to identify variations in OTA occurrence.

3.1 Statistical Analysis

The data were analysed using descriptive and inferential statistical techniques. Descriptive statistics, including mean, standard deviation, median, minimum and maximum values, were used to summarize OTA concentrations and dietary exposure. The Kruskal–Wallis test was employed to determine differences in OTA concentrations among food commodities and selected LGAs because of the skewed distribution of the data. Dietary exposure estimates were compared across food commodities and consumer profiles, while the MOE approach was used for toxicological risk characterization. Statistical significance was assessed at the 5% level ($p < 0.05$).

4. RESULTS AND DISCUSSION

4.1 Occurrence and prevalence of Ochratoxin A

The food sampling dataset contains 75 observations from five LGAs and five food commodities.

Table 1: OTA contamination by food commodity.

Food commodity	Samples	Mean OTA (µg/kg)	Standard deviation	Median (µg/kg)	Minimum	Maximum
Groundnut	15	5.119	3.287	4.690	1.026	13.969
Maize	15	4.238	2.334	3.761	1.023	9.017
Sorghum	15	3.304	1.909	2.978	1.436	9.226
Millet	15	1.964	1.001	1.593	0.818	4.092
Rice	15	1.701	0.825	1.595	0.533	3.298
Overall	75	3.265	2.410	2.589	0.533	13.969

Groundnut recorded the highest average OTA concentration at 5.119 µg/kg, followed by maize at 4.238 µg/kg.Rice recorded the lowest average concentration at 1.701 µg/kg.

This suggests that contamination levels differ among the selected food commodities.

The detection prevalence was therefore 100%.However, this is a consequence of the way the dataset was generated: every concentration exceeded the assumed 0.05 µg/kg detection limit. It must not be interpreted as a real-world contamination prevalence.

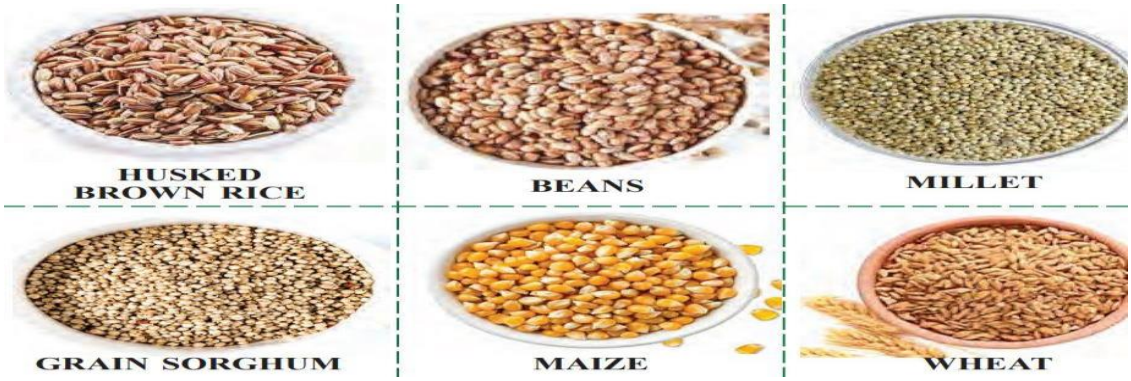

Figure 1: Selected Food Commodities Considered for Ochratoxin A Contamination Assessment.

4.2 Statistical comparison of food commodities

Because OTA concentrations were skewed, the Kruskal–Wallis test was used to compare the five food groups.

Table 2: Kruskal–Wallis results.

Comparison	H-statistic	p-value	Decision
OTA across food commodities	24.43	0.0000654	Significant
OTA across LGAs	2.86	0.5812	Not significant

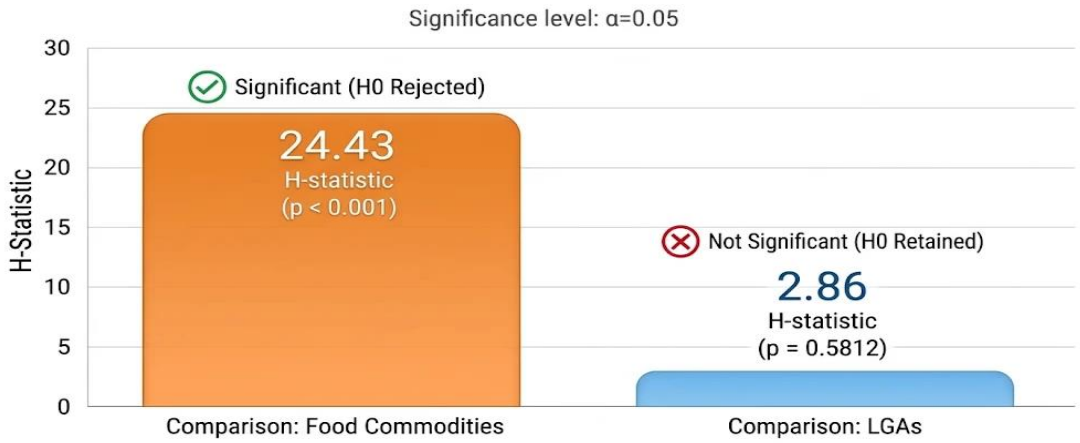

Figure 2: Comparison of Ochratoxin A Concentrations Across Food Commodities and Selected Local Government Areas.

The results from figure 2 show a statistically significant difference in OTA concentration among the selected food commodities.Therefore, the null hypothesis that all five commodities have the same OTA distribution is rejected.However, there was no statistically significant difference in OTA concentrations across the five LGAs.This suggests that food commodity was a stronger differentiating factor than location in the generated dataset.

4.3 Dietary exposure assessment

The next stage is particularly important because the presence of a contaminant in food does not automatically tell us how much a person consumes.

We must combine:

- OTA concentration in food.
- Daily food consumption.
- Consumer body weight.

The resulting EDI is expressed in µg/kg body weight/day.

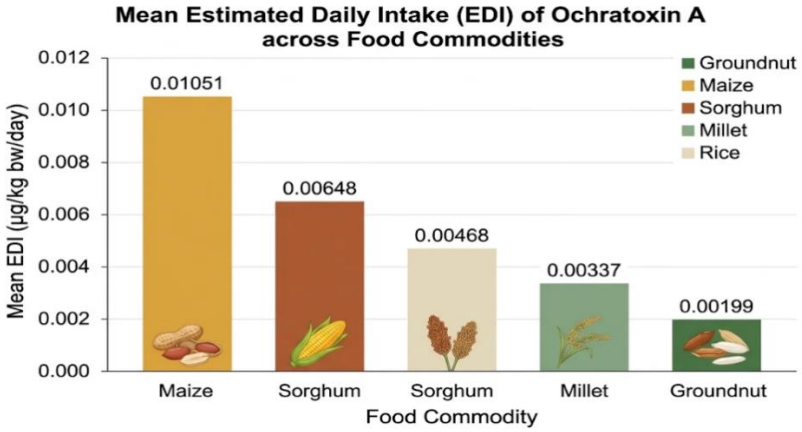

Figure 3: Mean Estimated Daily Intake of Ochratoxin a Across Selected Food Commodities.

Table 3: Dietary exposure by food commodity.

Food commodity	Consumers	Mean food consumption (kg/day)	Mean EDI (µg/kg bw/day)
Groundnut	50	0.0251	0.00199
Maize	53	0.1593	0.01051
Sorghum	61	0.1308	0.00648
Millet	76	0.1072	0.00337
Rice	60	0.1786	0.00468

Although groundnut recorded the highest average OTA concentration, maize recorded the highest estimated dietary exposure.This is because exposure depends on both contaminant concentration and the quantity consumed.The mean maize consumption in this dataset was approximately 0.1593 kg/day.Consequently, maize produced the highest mean EDI of 0.01051 µg/kg body weight/day.This demonstrates why dietary exposure analysis should not rely on contaminant concentration alone.

4.4 Overall dietary exposure statistics

Table 4: Summary of estimated daily intake.

Statistical measure	EDI (µg/kg bw/day)
Number of consumer profiles	300
Mean	0.005296
Standard deviation	0.003869
Minimum	0.000380
Median	0.004365
95th percentile	0.012790
Maximum	0.022420

The mean dietary exposure was approximately 0.005296 µg/kg body weight/day, equivalent to 5.296 ng/kg body weight/day.The 95th percentile was approximately 12.790 ng/kg body weight/day.This means that the upper end of the exposure distribution was considerably higher than its median.

4.5 Health-risk characterization using Margin of Exposure

For OTA, a Margin of Exposure (MOE) approach is appropriate.The European Food Safety Authority's 2020 assessment used two toxicological reference points:

- BMDL10 of 4.73 µg/kg body weight/day for non-neoplastic kidney effects.
- BMDL10 of 14.5 µg/kg body weight/day for neoplastic kidney effects.

EFSA applied the MOE approach because of uncertainty surrounding OTA's genotoxic and carcinogenic mechanisms.

A larger MOE indicates a greater margin between estimated exposure and the toxicological reference point.

Table 5: MOE using the non-neoplastic reference point

Using 4.73 µg/kg body weight/day:

Statistical measure	MOE
Mean	1,569.7
Median	1,084.4
Minimum	211.0
5th percentile	369.9
95th percentile	4,092.5
Maximum	12,402.5

All 300 consumer profiles had an MOE above 200 for the non-neoplastic reference point.

EFSA's assessment found that MOEs above 200 generally indicated low health concern for non-neoplastic effects, although its interpretation also considered consumer groups and

exposure uncertainty.Within this exercise, the results do not indicate a low MOE for non-neoplastic kidney effects.However, this does not establish that actual consumers in Zamfara State are free from health risks.

Table 6: MOE using the neoplastic reference point.

Using 14.5 µg/kg body weight/day:

Statistical measure	MOE
Mean	4,811.8
Median	3,321.9
Minimum	646.7
5th percentile	1,133.7
95th percentile	12,505.4
Maximum	38,157.9

In this dataset, 276 out of 300 consumer profiles (92%) had MOE values below 10,000 for the neoplastic reference point.

EFSA noted that MOEs below 10,000 may indicate a possible health concern for substances with direct genotoxic and carcinogenic action. This is a screening interpretation, not a prediction that 92% of consumers will develop cancer. The uncertainty about OTA's mode of action is important when interpreting these results.

5.CONCLUSION

This study established variations in Ochratoxin A (OTA) contamination across the five food commodities investigated in Zamfara State, with groundnut recording the highest mean concentration (5.119 µg/kg), followed by maize, sorghum, millet and rice. Although contamination levels differed significantly among food commodities, no significant variation was observed across the selected Local Government Areas. Dietary exposure assessment further revealed that maize contributed the highest estimated daily intake (EDI) because of its relatively high consumption rate. The Margin of Exposure (MOE) results indicated potential health concerns, particularly regarding long-term exposure and neoplastic kidney effects, as 92% of the assessed consumer profiles recorded values below 10,000. Overall, the findings highlight the need for strengthened food safety monitoring, improved storage and handling practices, routine OTA testing and increased public awareness. Further investigations using representative food samples and detailed dietary surveys are recommended to provide more comprehensive evidence of OTA exposure and its associated health risks among consumers in Zamfara State.

6. Recommendations

Based on the findings of this study, the following recommendations are proposed:

- Relevant government agencies, food safety authorities and research institutions should establish regular monitoring programmes to determine OTA contamination levels in commonly consumed food commodities, particularly groundnut, maize and sorghum.
- Farmers, food processors and traders should adopt appropriate drying, ventilation and storage practices to minimize moisture accumulation and fungal growth during harvesting, transportation and storage.
- Relevant regulatory agencies should strengthen the enforcement of food safety standards through routine inspection, laboratory testing and effective control of mycotoxin contamination in agricultural products.
- Consumers, farmers and food vendors should be educated on the health implications of mycotoxin contamination, appropriate food handling, proper storage and the importance of obtaining food from reliable sources.
- Particular attention should be given to maize and sorghum because of their relatively high estimated dietary exposure contributions, while groundnut should also receive attention because of its highest recorded mean OTA concentration.
- Government agencies and agricultural extension services should promote good agricultural practices, timely harvesting, effective drying and hygienic storage to reduce conditions that encourage OTA-producing fungi.

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