Scientific African 7 (2020) e00188

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Occurrence of major mycotoxins and their dietary exposure in North-Central Nigeria staples

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ARTICLE INFO

Article history:
Received 15 May 2019
Revised 29 September 2019
Accepted 4 October 2019

Editor: DR B Gyampoh

Keywords:
Total aflatoxin
Fumonisins
Ochratoxin A
Staples

ABSTRACT

Mycotoxins are natural contaminants of cereals and other food commodities throughout the world and they significantly impact human and animal health. This work determined the occurrence, co-occurrence and levels of total aflatoxin (AfT), fumonisins (Fums), and ochratoxin A (OTA) in six staples; rice, corn, millet, sorghum, cassava flake (garri) and yam flour in North-Central Nigeria. To achieve this, a total of 162 samples of the staples from field, market and stores from four microclimatic zones of Niger state were quantified for the mycotoxins by the enzyme-linked immuno-sorbent assay (ELISA) method. The result revealed that AfT, Fums and OTA showed deference to microclimatic zones. While AfT had 100% occurrence in all analysed samples within 2.1–248.2 µg/kg, Fums and OTA had lower occurrences and were found within 10–8400 µg/kg and 1.20–170.1 µg/kg, respectively. Rice (25.06 ± 52.39 µg/kg), sorghum (6198 ± 1046 µg/kg) and garri (45.87 ± 61.94 µg/kg) had the highest levels of AfT, Fums and OTA, respectively, while corn (13.83 ± 11.16 µg/kg), rice (119.4 ± 248.3 µg/kg) and sorghum (2.44 ± 1.78 µg/kg) were least contaminated with of AfT, Fums and OTA, respectively. AfT in the field, store and market staples ranged between 5.20 and 45.60 µg/kg, 0.01 and 55.40 µg/kg and 2.10 and 248.2 µg/kg, respectively. Fums was within 50–8400 µg/kg, 50–8150 µg/kg and 10–6150 µg/kg in field, store and market samples respectively. Also, OTA ranged from 3.67 to 5.60 µg/kg, 1.30 to 174.7 µg/kg and 1.20 to 106.1 µg/kg in field, store and market samples, respectively. Co-occurrence of various combinations of the three mycotoxins was evident. In rice co-occurrence was determined to be 24.32%, 37.88%, 64.86% and 24.32% for AfT/OTA/Fums, AfT/OTA, AfT/Fums, and OTA/Fums combinations respectively. Dietary exposure and risk characterisation study was further estimated for the mycotoxins. EDI and%TDI for AfT, Fums and OTA from root and tuber products were lower compared to that for cereals and grains. It is therefore concluded that the climate in North-Central Nigeria is favourable to AfT, Fums and OTA producing fungi. The levels of contamination of these staples with major mycotoxins is of public health importance, it should bring stakeholders together to review the food value chain from farm to folk and identify critical control points in managing this situation.

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https://doi.org/10.1016/j.sciaf.2019.e00188

Introduction

Cereals, roots and tubers are staples for about two third of the earth's population, providing 85% and 10% of the world's energy and protein food intake, respectively, [34]. Roots and tubers are the basic diets for about a billion people in the developing countries, accounting for 40% of food eaten by half the population of Sub-Saharan Africa [28]. There is considerable evidence that human food and animal feed commodities are frequently subjected to some form of contamination and spoilage such as growth of fungi exacerbated by subsequent production of toxins as secondary metabolites [42]. These secondary metabolites also called mycotoxins are low molecular weight toxic compounds produced by fungi and are known to pose a serious risk to human and animal health worldwide [25]. Of the over 300 elucidated mycotoxins, about 5 always make the list of most important mycotoxins, these mycotoxins that are distributed widely and have known toxic effects are the aflatoxins, ochratoxins, fumonisins, trichothecenes and zearalenone. Sufficient evidence of carcinogenicity from studies has shown that aflatoxins are known human carcinogens, while both fumonisins and ochratoxins are probable human carcinogens [24]. Cases of human aflatoxicosis have been reported sporadically, mainly in Africa and Asia [9,21]. Damages to the liver, bone marrow, adrenals and kidneys were reported in mice administered with fumonisin B1 (FB1) at gavage doses ranging from 1 to 75 mg/kg body weight per day for 14 days [37]. Ochratoxin A is a potent nephrotoxic mycotoxin in nature and displays other adverse effects such as hepatotoxicity, teratogenicity, and immunosuppression [59].

These make their study important to ensure food safety and food security. Mycotoxin contamination of cereals like rice, grains such as corn, sorghum, millet and groundnut continue to raise a lot of concerns, as these food items are not only eaten directly but mainly used as raw materials in the manufacture of other food products. Mycotoxin contamination of various foodstuffs and agricultural commodities is a major problem in the tropics and sub-tropics because the climatic conditions and agricultural and storage practices are conducive for fungal growth and toxin production [30]. Fumonisins, zearalenone, aflatoxins, citrinin, cyclopiazonic acid, sterigmatocystin, patulin, gliotoxin and different trichothecenes are some of the mycotoxins of greatest agro-economic importance [17,61]. This study was designed to investigate the occurrence and levels of total aflatoxin (AfT), Fumonisin (Fums) and Ochratoxin A (OTA) in rice, corn, millet, sorghum, cassava flakes (garri) and yam flour sampled from field, stores and markets in the four microclimatic zones of Niger state, Nigeria.

Materials and method

Sample collection and preparation

Samples of rice (62), corn (20), millet (20), sorghum (20), garri (cassava flakes) (20) and yam flour (20) making 162 samples were sourced from the four micro-climatic zones of Niger state, Nigeria. According to data sourced from Geography Department of Federal University of Technology Minna, The "Wettest zone" (Suleja and Tafa) has annual rainfall > 1400 mm, the "Wet zone" (Borgu and Magam) has between 1200 and 1400 mm, the "Dry zone" (Agaie, Agwara, Bida, Bosso, Edati, Gbako, Gurara, Katcha, Kontagora, Lapai, Lavun, Mashegu, Chanchaga, Mokwa, Munya, Paiko, Rijau, and Shiroro) has between 1000 and 1200 mm while the "Driest zone" (Mariga, Wushish and Rafi) has less than 1000 mm annual rainfall. Market, field and stored samples were collected in a plastic container with airtight lid and transferred to the laboratory of Biochemistry Department of Federal University Technology Minna for further processing. The representative samples were air dried and then ground using a Romer series II mill so that 75% will pass through a 20-mesh screen, then thoroughly mixed.

Mycotoxin quantification

Prior extraction, samples of garri which contain oil were deffated using the soxhlet method. ELISA grade methanol and distilled water was used for extraction of AfT, Fums and OTA. Various concentrations of the standard toxin were prepared in the extraction solution, and quantified by ELISA (STAT FAX Elisa Reader MODEL: 303 PLUS), the resultant peak area plotted against concentration became the basis for determining the concentration of toxin in a sample.

In all cases, 20 g of the respective samples were weighed; 100 ml of the extraction solution was added. In all cases, 100 µL of the resulting extract, dilution or standard was mixed with 200 µL of conjugate in dilution microtitre wells. A 100 µL portion of this mixture was added to antibody linked wells and incubated for 15 min. After which 100 µL of substrate were incorporated, the mixture was allowed for 5 min at room temperature. Following this, 100 µL of stop solution was added to the mixture. Absorbance measurements were performed immediately using two simultaneous wavelengths (450 nm and 630 nm) with a microplate reader (STAT FAX Elisa Reader MODEL: 303 PLUS). This was done according to the ELISA kit manufacturer manual (AgraQuant® Aflatoxin, AgraQuant® Ochratoxin, AgraQuant® Fumonisin; Romer Labs, Getzersdorf Austria). The conditions for quantification are presented in Table 1.

Estimation of exposure and risk characterisation

The estimated daily intake (EDI), and percentage tolerable daily intake (% TDI) values will be estimated for the staples. The method used by Rodríguez-Carrasco et al. [48] and pproved by JECFA was adopted in this study. The "Estimated daily intake" which estimates the amount of toxin that can be ingested daily (µg/kg bw/day) can be obtained by using the formula

Table 1
Assay conditions.

S/N	Parameter	Total Aflatoxin	Fumonisin	Ochratoxin A
1	Extraction solution	Methanol: water (70:30)	Methanol: water (80:20)	Methanol: water (50:50)
2	LOD	3 ppb	200 ppb	1.9 ppb
3	LOQ	9 ppb	600 ppb	5.7 ppb
4	Range of quantification	4–40 ppb	250–5000 ppb	2–40 ppb
5	Recovery rate	85 ± 15%	80%	90 ± 20%
6	Wavelength	450 nm and 630 nm differential filter	450 nm and 630 nm differential filter	450 nm and 630 nm differential filter

below:

$$\text{Estimated daily intake (EDI)} = \frac{\text{contamination level} * \text{consumption rate}}{\text{Body weight (kg/persons)}}$$

Where "Contamination level" refers to the average toxin level found in a certain foodstuff (μg/Kg) and "Consumption rate" is the amount of the foodstuffs ingested on daily basis (gram/day).

The health risk characterisation for the mycotoxin (%TDI) was estimated by dividing the EDI previously calculated with the tolerable daily intake (TDI) (μk/kg bw/day) of the respective mycotoxins (where available) as indicated in the equation:

$$\%\text{TDI} = (\text{EDI}/\text{TDI}) * 100$$

The EDI and %TDI will therefore be calculated based on the estimated daily consumption outlined in the WHO/GEMS database (2012). According to the database search result, Nigeria being among the cluster 13 nations consume an average of 23.6 g/day and 330.5 g/day of processed roots and tubers, and cereal grains and flours respectively. We have also earlier determined in another study the average weight of an adult to be 61 kg.

The toxicological guidance value for OTA was set as a "provisional tolerable weekly intake" (PTWI) value of 0.1 μg/kg bw/week [26], the TDI will then be estimated as PTWI/7. Guidance for Fums was set at a "provisional maximum tolerable daily intake" (PMTDI) value of 2 μg/kg bw/day [26].

Statistical analysis

IBM SPSS Statistics version 20 and Microsoft Excel 2013 packages were employed. Mean and standard deviations, and charts were used to present data.

Results and discussion

This study has generated data on the occurrence and levels of AfT, Fum, and OTA in rice, corn, millet, sorghum, garri and yam flour from North - Central Nigeria. The study showed a wide spread contamination of cereals and tubers with AfT, Fums, and OTA in the four microclimatic zones of Niger state North- Central Nigeria. The levels of these toxins found in the studied samples is not surprising since tropical climates such as those existing in Nigeria have been found to be quite conducive for mould growth and mycotoxin production. According to Mclean and Berjak [39], the two most important environmental components favoring mold growth and mycotoxin production are hot and humid conditions, hence, mycotoxigenic fungi are abundant in the tropics.

Aflatoxin contamination

Each of the 6 staples studied showed 100% occurrence of AfT (Table 2), rice which had the highest mean was contaminated between 2.10 and 248.20 μg/kg while corn which had the lowest mean level was contaminated between 2.70 and 41.70 μg/kg. Granados-Chinchilla et al. [20] had shown 10.8% occurrence of aflatoxin in Costa Rica food chain survey (2003–2015) within the range of 0.48–500 μg/kg, with semolina corn, semolina rice, white corn and sorghum having 100%, 100%, 38.6% and 0% prevalence, respectively. In Vienna Austria, Reiter et al. [46] had presented a different case with a lower range of contamination of rice by AFB1 (0.45–9.86 μg/Kg) in 18.5% of the samples. Wang and Liu [57] reported 70.3% occurrence of aflatoxins in corn samples. This study agrees with our previous finding [35] which demonstrated 100% aflatoxin contamination of rice sample in Niger State. Ezekiel et al. [16] reported 45% occurrence of total aflatoxin in uncooked flour/grain from rural Northern Nigeria (0.3–63.7 μg/Kg), which is within the range of finding in this report. The findings in this study are in line with the observations of Bankole and Mabekoje [6] who stated that corn seeds, in western Nigeria are constantly contaminated with aflatoxins. It is equally in agreement with Ezekiel et al. [15] who documented high levels of aflatoxins in millets from Plateau state. The higher rate of aflatoxin contamination may be due to high growth of aflatoxin producing fungi because aflatoxin producing fungi were reported to be the dominant fungi contaminants of rice samples in Niger State [36]. Aflatoxin levels in millet, sorghum and yam flour (4.80–248.20 μg/kg) were all elevated beyond the safe limit of 4 μg/kg set by European Commission [14] and only 5% of garri and corn, and 7% of rice were safe for consumption. In a recent report Al-Zoreky and Saleh [3] reported that aflatoxin concentration in rice sampled from Eastern Saudi Arabia were within

Table 2
Occurrence and concentrations (μg/kg) of total aflatoxin in 6 staples from the four microclimatic zones of Niger state.

Crop		ZONE I WETTEST	ZONE II WET	ZONE III DRY	ZONE IV DRIEST	TOTAL
Rice	Number of samples	11	14	14	19	58
	Occurrence (%)	100	100	100	100	100
	Mean	11.09 ± 6.23	28.96 ± 63.35	32.24 ± 53.63	17.36 ± 1.04	25.06 ± 52.39
	Range	2.10–18.10	2.20–248.20	4.10–212.80	14.95–21.90	2.10–248.20
	Safe (%)	18	7	0	5	7
Corn	Number of samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	13.50 ± 4.82	15.53 ± 10.91	21.35 ± 16.55	4.94 ± 1.36	13.83 ± 11.16
	Range	5.10–16.50	6.60–33.30	5.00–41.70	2.70–6.30	2.70–41.70
	Safe (%)	0	0	0	20	5
Millet	Number of samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	33.30 ± 10.10	17.64 ± 10.21	7.12 ± 1.46	6.66 ± 1.53	16.18 ± 12.94
	Range	17.50–45.60	4.90–33.50	5.10–8.60	4.80–8.20	4.80–45.60
	Safe (%)	0	0	0	0	0
Sorghum	Number of samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	12.44 ± 5.69	22.34 ± 12.72	19.68 ± 12.63	6.66 ± 1.53	15.31 ± 10.74
	Range	7.80–20.50	8.60–42.60	6.70–40.80	4.80–8.20	4.80–42.60
	Safe (%)	0	0	0	0	0
Garri	Number of samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	23.60 ± 23.09	28.85 ± 15.47	16.45 ± 0.35	5.35 ± 0.67	18.56 ± 15.64
	Range	2.60–55.40	16.70–49.85	16.10–16.80	3.85–7.20	2.60–55.40
Yam flour	Number of Samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	10.64 ± 6.31	25.95 ± 9.90	18.76 ± 9.75	10.68 ± 2.66	16.51 ± 9.66
	Range	5.00–18.50	17.60–39.45	6.70–32.90	7.95–14.41	5.0–39.45

Value expressed as Mean ± Standard Deviation.

EU and international legislations. The level of AFT reported in this study should attract a great concern since the ingestion of such-contaminated food by animals and human can be of enormous public health significance, of greatest concern is the relevance of these toxins in human hepatoma and oesophageal cancer [50,51]. Also, Continuous intake of small doses of aflatoxin could increase still-births and neonatal mortality, immunosuppression with increased susceptibly to infectious diseases such as pneumonia, stunted growth [7] and HIV/AIDS [31]. These unsafe levels of aflatoxin contamination will also reduce the market value of the food stuff and may render crops unmarketable. People's Daily Newspaper in 2014, reported that large quantity of Nigerian foods exported to European countries are being rejected due to high presence of aflatoxin. The newspaper also reported that, World Bank has estimated that nine African countries including Nigeria will have 64% of their annual export of nuts, fruits and cereals hitherto valued at about $64 million annually reduced as a result of rejection in overseas market due to mycotoxin contaminations.

Fumonisin contamination

Occurrence of fumonisin (Fums) was lesser than aflatoxins but the mean concentrations obtained for Fums appear to be higher in magnitude. Fumonisin (Table 3) has its highest occurrence in sorghum (100%) while garri had the least occurrence (55%). Levels of Fums in rice, garri and millet samples (10–2510 μg/kg) were all safe for consumption, because they were all within the safe limit of 4000 μg/kg for unprocessed food (JECFA, [27]), except for corn and yam flour with 85% and 65% safety level, respectively, and sorghum which was least safe (5%) having a range of 3700–8400 μg/kg. Adetunji et al. [2] and Chilaka et al. [10] reported the presence of Fums in Nigerian food, especially the occurrence of Fums in cereals and non-cereal food. Ezekiel et al. [16] reported 80% occurrence of Total fumonisin within 2.7–10,904 μg/kg in unprocessed flour/grain in rural Northern Nigeria, this is consistent with our current findings, Abdus-Salaam et al. [1] reported FB1, FB2 and FB3 in rice with occurrences and mean values of 39.5%, 21.1%, 18.4% and 18.52 μg/kg, 8.75 μg/kg, 5.54 μg/kg, respectively. From China, Xing et al. [58] reported Fumonisin B1 and deoxynivalenol as the primary mycotoxin of corn in 3 China provinces, they also reported 100% occurrence of fumonisin within 16.5–315.9 μg/kg. Also there are other reported cases of fumonisin B1, B2 and B3 in rice, corn, millet, sorghum and their derivatives in other hot temperate regions; Europe and Africa [53,60]. Fumonisin B1 is reported to be hepatotoxic, nephrotoxic, embryotoxic in laboratory animals [49]. These makes its presence in common staples of great interest hence it poses a public health concern.

Ochratoxin A contamination

Ochratoxin A (OTA) was found in all the 6 staples within 1.20 μg/kg–170.1 μg/kg (Table 4). However, garri and yam flour had 100% occurrence while rice had the least occurrence (53%). Mean level of 1.01 μg/kg at a 10% occurrence has also been

Table 3
Occurrence and concentrations (µG/KG) of fumonisin in 6 staples from the four microclimatic zones of Niger state.

Crop		ZONE I WETTEST	ZONE II WET	ZONE III DRY	ZONE IV DRIEST	TOTAL
Rice	Number of samples	12	15	17	18	62
	Occurrence (%)	67	67	47	56	60
	Mean	256.7 ± 387.3	50.00±45.83	98.23±201.8	105.6 ± 256.8	119.4 ± 248.3
	Range	10–1200	40–150	10–520	10–1000	10–1200
	Safe (%)	100	100	100	100	100
Corn	Number of samples	5	5	5	5	20
	Occurrence (%)	60	60	100	80	75
	Mean	1062 ± 1025	2760 ± 2553	252.0 ± 193.3	1192 ± 750.1	1317 ± 1609
	Range	1410–2300	3960–5110	110–570	1050–2010	110–5110
	Safe (%)	100	60	100	100	85
Millet	Number of samples	5	5	5	5	20
	Occurrence (%)	80	60	40	100	70
	Mean	64.00 ± 43.93	822.0 ± 882.0	20.00 ± 27.39	1706 ± 565.4	653.0 ± 853.1
	Range	50–110	700–2010	0–50	1050–2510	50–2510
	Safe (%)	100	100	100	100	100
Sorghum	Number of samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	6400 ± 1266	6080 ± 1651	6260 ± 118.2	6060 ± 866.6	6198 ± 1046
	Range	4800–8150	3700–8400	6260–6440	5100–7130	3700–8400
	Safe (%)	0	20	0	0	5
Garri	Number of samples	5	5	5	5	20
	Occurrence (%)	0	80	80	60	55
	Mean	0	54.00 ± 36.47	528.0 ± 656.0	490 ± 512.8	268.0 ± 456.0
	Range	–	10–100	50–1390	500–1200	10–1390
Yam flour	Number of samples	5	5	5	5	20
	Occurrence (%)	100	60	80	40	70
	Mean	5716 ± 943.9	728 ± 1029	1862 ± 2381	452 ± 621.5	2190 ± 2518
	Range	4870–7200	10–2200	120–5840	1050–1210	10–7200

Value expressed as Mean ± Standard Deviation.

Table 4
Occurrence and concentrations (µg/kg) of Ochratoxin A in 6 staples from the four microclimatic zones of Niger state.

Crop		ZONE I WETTEST	ZONE II WET	ZONE III DRY	ZONE IV DRIEST	TOTAL
Rice	Number of samples	9	16	14	18	57
	Occurrence (%)	56	13	57	83	53
	Mean	2.31 ± 2.33	0.25 ± 0.76	2.20 ± 2.30	6.73 ± 6.78	3.10 ± 4.79
	Range	2.90–5.85	0–2.90	1.70–6.30	1.2–16.90	1.20–16.9
	Safe (%)	89	100	86	56	81
Corn	Number of samples	5	5	5	5	20
	Occurrence (%)	100	100	60	100	90
	Mean	2.93 ± 0.62	4.46 ± 0.75	5.50 ± 6.73	3.60 ± 0.72	4.12 ± 3.29
	Range	2.10–3.75	3.70–5.60	0–16.50	2.80–4.40	0.00–16.50
	Safe (%)	100	80	40	100	80
Millet	Number of samples	5	5	5	5	20
	Occurrence (%)	80	100	100	100	90
	Mean	1.90 ± 1.85	5.50 ± 0.50	3.55 ± 1.30	5.02 ± 0.50	3.99 ± 1.81
	Range	0–3.80	4.80–6.20	1.80–5.20	4.60–5.70	1.80–6.20
	Safe (%)	100	20	100	60	70
Sorghum	Number of samples	5	5	5	5	20
	Occurrence (%)	60	60	80	100	75
	Mean	1.20 ± 1.23	2.30 ± 2.15	2.62 ± 2.05	3.65 ± 0.96	2.44 ± 1.78
	Range	1.40–2.90	3.20–4.50	1.7–5.60	2.80–5.20	1.40–5.60
	Safe (%)	100	100	80	80	90
Garri	Number of Samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	4.54 ± 2.00	78.36 ± 65.00	60.52 ± 70.29	67.20 ± 72.76	45.87 ± 61.94
	Range	1.60–6.90	1.30–165.4	1.70–174.7	4.20–170.1	1.30–170.1
Yam Flour	Number of Samples	5	5	5	5	20
	Occurrence (%)	100	100	100	100	100
	Mean	4.05 ± 1.30	4.75 ± 0.68	4.5 ± 2.35	2.44 ± 1.14	3.94 ± 1.65
	Range	1.85–5.20	3.80–5.45	1.80–8.20	1.20–8.20	1.20–8.20

Value expressed as Mean ± Standard Deviation.

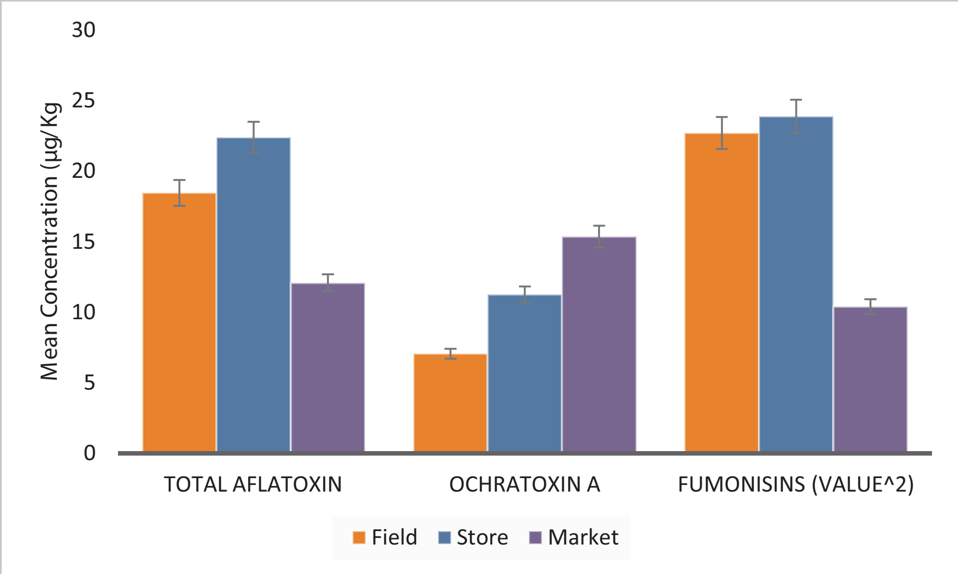

Fig. 1. Mean level of AfT, OTA and Fum in field, store and market.

reported in Nigerian rice [1]. In South-West Nigeria, an occurrence of 96% at low levels (0.01–2.18 μg/kg) was reported for OTA in rice [5]. However, Ezekiel et al. [16] did not find OTA in uncooked flour/grain of rural Northern Nigeria origin. In an Asian based study, Darouj et al. [12] reported 43.33% OTA contamination of cereal-based baby food having a mean value of 0.0095 μg/kg. In this study also, there were unsafe levels of OTA in all the six stable foods analyzed. OTA is considered as the most toxic member of the ochratoxin family and has been classified as a possible human carcinogen (group 2B) [24]. Ochratoxin is a potent nephrotoxic mycotoxin in nature and also displays other adverse effects such as hepatotoxicity, teratogenicity, and immunosuppression [59]. Several major mechanisms have been shown to be involved in the toxicity of ochratoxin: including inhibition of protein synthesis, interference with metabolic systems involving phenylalanine, promotion of membrane lipid peroxidation, disruption of calcium homeostasis, inhibition of mitochondrial respiration, and DNA damage [47]. Several studies indicate that OTA might be an Nrf2 inhibitor. OTA-induced inhibition of the activation of Nrf2 and gene transcription of Nrf2 in conjunction with OTA-induced Nrf2 protein depletion would harm the cell defenceless to compound-induced and physiological oxidative stress [32]. In animals, an increase in the occurrence of testicular cancer has been correlated with the ingestion of OTA [38].

Comparison of major mycotoxin level in field, store and market

Fig. 1 shows that the highest levels of AFT and Fums were found in the stored staples while market staples had highest mean level of OTA. This suggests an increase in susceptibility to mycotoxin contamination under storage conditions, and therefore insinuating a need for adherence to proper storage practices. Staples displayed in the market appear to have the lowest mean values for AfT and Fum, these may be because of sorting before displaying food items. Sorting has been in the discussion among the possible ways to reduce exposure to mycotoxins, many farmers carry out sorting and culling of visibly damaged and mouldy crops in order to realize the prize premium associated with cleaner and unspoiled grains, but such practices cannot guarantee mycotoxin reduction. The data revealed that there was 100% occurrence of aflatoxin in the field, market and stored samples ranging within 5.20–45.60 μg/kg, 8.20–55.40 μg/kg and 2.10–248.2 μg/kg, respectively. This high level of aflatoxin may be due to the fact that aflatoxin mitigating measures are not strictly practiced in Nigeria. Ochratoxin A from the field samples ranged from 3.67–5.60 μg/kg, while the store and market samples were 1.30–174.7 μg/kg, and 1.20–106.1 μg/kg, respectively. Fums in the market samples were lower than that found in the store and field samples except in rice.

Co-occurrence of mycotoxins

In various proportions, this study observed the joint occurrence of the studied mycotoxins in various samples; these include occurrence of AfT/OTA/Fums, AfT/OTA, AfT/Fums, and OTA/Fums. In rice samples, co-occurrence was determined to be 24.32%, 37.88%, 64.86% and 24.32% for AfT/OTA/Fums, AfT/OTA, AfT/Fums, and OTA/Fums, respectively. While that for Fums and AfT cut across all the zones, joint occurrence of others were only reported in zone III (dry zone) and IV (driest zone). Occurrence of mycotoxins in staple grains on retail outlets in Kaduna and Nasarawa states in Nigeria was reported by Mokogwu [41]. In his studies, high levels of aflatoxin, deoxinivalenol, ochratoxin and zearalenone were detected in corn,

Table 5
Exposure and risk characterisation of AfT, Fums and OTA in 6 staples.

Mycotoxin	Staple	Mean level (μg/kg)	Average daily intake (g/day)	Adult weight (kg)	EDI (μg/kg bw/day)	TDI (μg/ kg)	%TDI
AfT	Rice	25.06	330.5	61	135.80	NA	NA
	Corn	13.83	330.5	61	74.93	NA	NA
	Millet	16.18	330.5	61	87.66	NA	NA
	Sorghum	15.31	330.5	61	82.95	NA	NA
	Garri	18.56	23.6	61	7.18	NA	NA
	Yam flour	16.51	23.6	61	6.39	NA	NA
Fums	Rice	119.40	330.5	61	646.90	2.00	3.24
	Corn	1317.00	330.5	61	7136.00	2.00	35.68
	Millet	653.00	330.5	61	3538.00	2.00	17.69
	Sorghum	6198.00	330.5	61	33581.00	2.00	167.90
	Garri	268.00	23.6	61	103.70	2.00	0.52
	Yam flour	2190.00	23.6	61	847.30	2.00	4.24
OTA	Rice	3.10	330.5	61	16.80	0.014	11.76
	Corn	4.12	330.5	61	22.32	0.014	15.63
	Millet	3.99	330.5	61	21.62	0.014	15.13
	Sorghum	2.44	330.5	61	13.22	0.014	9.25
	Garri	45.87	23.6	61	17.75	0.014	12.42
	Yam flour	3.94	23.6	61	1.53	0.014	1.067

NA = Not Applicable.

groundnut, beans and yam. Occurrence of aflatoxin and fumonisin in sorghum from Egypt was reported by Osman et al. [44]. Geoffrey et al. [19] and Chilaka et al. [10] have also reported occurrence of ochratoxin, aflatoxin and fumonisin in sorghum in Sub-Saharan Africa. This shows that sorghum is a suitable microenvironment that can either support the growth of several mycotoxin producing fungi or one fungus with a potential to produce several mycotoxins. Also, Kimanya et al. [29] reported the occurrence of high levels of aflatoxins (158 μg/kg) and total fumonisin (11,048 μg/kg) in Tanzanian corn. Similarly, Adetunji et al. [2] reported high levels and co-occurrence of aflatoxin B1 (AFB1; max.: 6738 μg/kg), fumonisin B1 (FB1; max.: 10,447 μg/kg), and zearalenone (ZEN; max.: 2044 μg/kg) contamination in 67, 93, and 17%, of stored corn grains in Nigeria. Furthermore, aflatoxins (588 μg/kg), citrinin (16,773 μg/kg), Fums (2294 μg/kg) and ZEN (205 μg/kg) were reported in a batch of yellow corn used for the production of ogi (fermented corn gruel) [43] while FB1 was reported to also occur in corn and ogi from Nigeria at maximum concentrations of 8222 μg/kg and 1903 μg/kg, respectively [10]. Previous studies have also reported the occurrence of fumonisin, ochratoxin A and aflatoxins in cassava and yam products [11,34,54]. The occurrence of mycotoxins in these products may be attributed to the rudimentary processing, poor storage, and marketing practices used for these products. This co-occurrence of mycotoxins can affect both the level of mycotoxin production and the toxicity of the contaminated material [40]. Exposure to more than one mycotoxin has been proposed to have either potentiation, synergistic, antagonistic or additive effects on their toxicity. According to Ma et al. [33], the combined effect of mycotoxins on human and animal health need to be further investigated and taken into consideration when new regulations are set in the future, as the current regulations do not consider this.

Exposure and risk assessment

Table 5 summarises the exposure and risk characterisation of the 3 mycotoxins evaluated in adults within the study area. In all cases except with fumonisin from garri,%TDI values imply higher exposure related risks. The EDI of AfT from the non-staples garri and yam flour were the least being 7.181 μg/kg bw/day and 6.387 μg/kg bw/day respectively, while that from rice (135.8 μg/kg bw/day) was the highest. According to American Cancer Society, [4] even EDI level as low as 0.001 μg/kg bw/day may induce liver cancer hence, the levels of AfT in food should be As Low As Reasonable Achievable (ALARA) [13]. EDI of AfT between 0.00023 and 0.0106 μg/kg bw/day was reported in Ireland adult population through consumption of cereal products and seeds [18], also, AfT EDI values 0.00052 μg/kg bw/day was reported for adult Lebanese population consuming bread and toast [45]. Huong et al. [23] reported 0.0222 μg/kg bw/day AFB1 EDI in rice. These were much lower than values found in our work.

For fumonisins EDI values ranged from 646.9 to 33581.0 μg/kg bw/day in cereal and grains while it was between 103.7 and 847.3 μg/kg bw/day in root and tuber products. Sorghum presented the highest consumption risk with %TDI of 167.9% while garri and yam flour also presented the least consumption risk for with %TDI of 0.518% and 4.236%, respectively. Sprong et al. [55] reported Fums EDI of 0.0469 μg/kg bw/day through the consumption of breakfast cereals and dried fruits. In Catalonia regional population, cereal products were the main contributors of up to 5% TDI of Fums in their diet [8]. The EDI and%TDI of Fums from cereals and grains reported by the authors is not as high as that found in our work. The national evaluations performed by Brazil, China (including Hong Kong Special Administrative Region), France, Guatemala, Japan, Malawi, the Netherlands, Portugal, Republic of Korea, Spain, United Republic of Tanzania, Vietnam and Zimbabwe on food consumption and dietary exposure to fumonisin, showed the mean exposure to FB1 and total fumonisins in European countries to be below 0.250 μg/kg bw/day. High exposures to FB1 were reported for Zimbabwe [22] and China [56] with a maximum of 7.700 μg/kg bw/day for adults living in the rural province of Huaian.

EDI for OTA ranged from 13.22–22.32 µg/kg bw/day in cereals and grains and 1.524–17.75 µg/kg bw/day in root and tuber products. The %TDI of OTA ranged from 9.254% to 15.63% and 1.067% to 12.42% in cereals and grains, and root and tuber products, respectively. Sirot et al. [52] had reported %TDI of 0.01%–1% for OTA from consumption of breakfast cereal in France population.

In conclusion, this study has therefore shown that the consumers of rice, millet, corn, sorghum, garri and yam flour in North - Central Nigeria are not excluded from the risk associated with the consumption of Aft, Fums and OTA. The unsafe levels of contamination reported raises concerns with respect to the health of the individuals in this region. As a result, it should bring stakeholders together to review the food value chain from farm to folk and identify critical control points in managing the situation.

Declaration of Competing Interest

There is no conflict of interest in this publication.

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