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ORIGINAL RESEARCH ARTICLE

Natural Co-occurrence of Emerging and Minor Mycotoxins on Maize Grains from Abuja, Nigeria

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ABSTRACT

This study investigated the incidence of emerging, less investigated fungal metabolites in maize grains across the FCT Abuja, Nigeriausing Liquid Chromatography Tandem Mass Spectrometric (LC/MS-MS). For the first time, the presence of 19 emerging mycotoxins including beauvericin (BEAU), moniliformin (MON), nidurufin (NID), norsolorinic acid (NA), citrinin (CIT), macrosporin (MAC-A), sterigmatocystin (STER), macrosporin, alternariol methyl ether (AME) chanoclavine (CNV); agroclavine (AGV); elymoclavine (ECV) and brevianamid (BVD-F) were confirmed to be present as contaminant in maize grains in all the six zones of the Federal Capital Territory, Abuja. Up to 23 toxic non-regulated fungal metabolites were quantitated in a single sample, emphasising the great variety of mycotoxin co-exposure. Four out of these non-regulated metabolites which had incidence levels > 60% in maize were monoacetoxyscirpenol (MAS)—60% in maize, emodin (EMOD)—93.3%, 3-nitropropionic acid (3-NPA)—60% in maize and equisetin (EQUI)—96.7% in maize. This report could form the basis for the production of a maize mycotoxin road map in the FCT, Abuja, Nigeria.

KEYWORDS LC-MS/MS, emerging mycotoxins, maize grains, minor mycotoxins, Abuja-Nigeria

INTRODUCTION

Maize (*Zea mays* L.) are known for harbouring several fungal strains many of which produce mycotoxins[1]; although attempts are constantly being made to develop maize germplasm with reduced mycotoxin contamination and insect damage.[2] Sometimes extreme and inconsistent weather conditions aggravate mycotoxin contamination in grains either in the field or during storage.[3] Nigerians have maize as part of their dietary staples and the demand for maize grains is particularly fuelled by the increasing demand in the feed milling industry.[4] Food safety results only when microbial contaminants and chemical toxicants are present below tolerance levels in foods.

There are reports of a combination of many mycotoxins in maize seeds and grains[5,6] as well as in animal feed formulated.[7] The occurrence cuts across the sub-Saharan Africa.[8] Mycotoxins can have adverse impacts on the health of humans and other animals as well as negative economic impacts on agriculture and associated industries. In developing countries, most staples obtained from local markets are often consumed irrespective of quality due to food scarcity problems and shortage of mycotoxin analysis facilities.[9]

The economic implications of emerging mycotoxins are difficult to determine partly because of insufficient information on some of these less investigated metabolites.[9,10] Therefore, there is a need to understand the prevalence and level of concentrations of less investigated fungal metabolites in these crops across varied agro ecological zones to enable the consumers and policy makers to determine the potential risk of possible toxicants.[11,12] There are, however, limited data on the presence of other emerging mycotoxins and microbial metabolites in crop production and products in Nigeria due to the novelty and shortage of multi-mycotoxin LC-MS/MS facility for such analysis. Due to the presence of high concentrations of emerging mycotoxins in many food ingredients, there is a great interest on these toxins.

In developing countries like Nigeria, many individuals are ignorant of emerging mycotoxins as a biochemical hazard in their diet and how to control them from the field and after crop harvest.[13] Thus these vulnerable people are not only food insecure, but also are chronically exposed to high levels of mycotoxins.[14]

This study therefore investigated the incidence of less investigated fungal metabolites in maize grains across the FCT Abuja, Nigeria using Liquid Chromatography Tandem Mass Spectrometric (LC/MS-MS) System with a view to facilitating

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an informed national emerging mycotoxin policy for cereals.

MATERIALS AND METHODS

Chemicals and Reagents

Methanol (LC gradient grade) and glacial acetic acid (pa) were purchased from Merck (Darmstadt, Germany); acetonitrile (LC gradient grade) from VWR (Leuven, Belgium); and ammonium acetate (MS grade) was obtained from Sigma-Aldrich (Vienna, Austria). Water was purified successively by reverse osmosis, and an Elga Purelab ultra analytic system was used from Veolia Water (Bucks, UK). Standards of fungal metabolites were obtained as gifts either from various research groups or from various commercial sources such as Romer Labs (Tulln, Austria), Sigma-Aldrich (Vienna, Austria), Iris Biotech GmbH (Marktredwitz, Germany), Axxora Europe (Lausen, Switzerland) and LGC Promochem GmbH (Wesel, Germany). The purity of the solid substances was ≥95%.

Sampling and Samples

Surveys were conducted in the FCT, Abuja Nigeria (between Lat. 9° 40' N, Long. 7° 29' E and Lat. 8° 83'N, Long. 7° 17' E, 388–566m asl.) between January and February, 2014. The farmers' stores were located in the six Area Councils (Table 1, Fig. 1).

A total of 30 maize grains samples were collected from farmers store in the six area councils of the FCT namely Abuja Municipal Area Council (AMAC), Abaji, Bwari, Gwagwalada (GWA), Kuje and Kwali. The sampled locations and number of sample types collected from each district were uneven as the number of stores for each type of grain in the respective zone varied. Only samples threshed/shelled and stored for less than 30 days after harvest were collected. Each sample was collected as a bulk sample (1.8–2.0 kg) and comprised of four subsamples of 0.5 ± 0.05 kg each. The subsamples were obtained from random points in farmer's basins or other storage containers and mixed to form an aggregate sample. The samples were comminuted and quartered such that 100–150 g of representative samples was obtained from each bulk. Representative samples were stored at 4°C until they were analysed for multiple microbial metabolites.

Table 1 Samples of maize grains collected and sampling points in the FCT Abuja, Nigeria.

Area council	Total no. of maize samples/ Area council	Ward
Abaji	5	Abaji Central, Pandagi, Sabongari
AMAC	6	Gwagwa, Kabusa, Karshi, Karu and Orozo
Bwari	4	Bwari Central, Byazhin, Ushafa
Gwagwalada	6	Gwako, Paiko and TunganMaje
Kuje	6	Chibiri, Gaube, Saaji, Chukuku, Kuje Central and Kwaku
Kwali	3	Kilankwa, Kwali Central and Yangoji
Total	30	

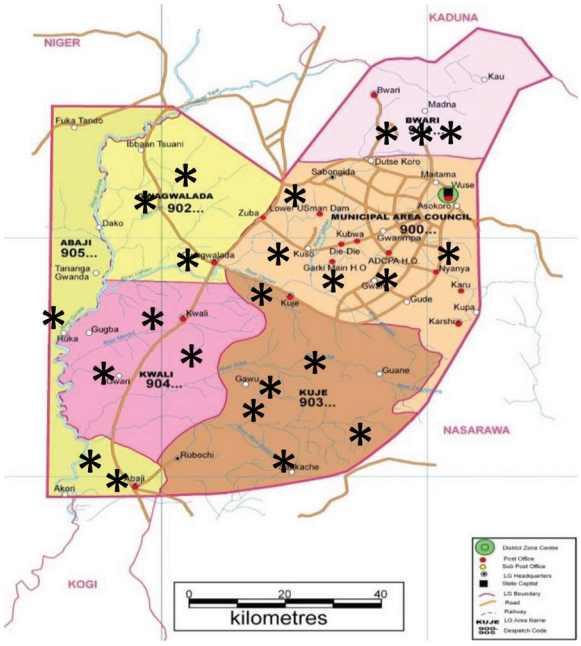

Fig. 1 Location of maize grains sampling sites (*) in the Federal Capital Territory (FCT) Abuja (Source: Dept. of Planning & Survey, FCDA, Abuja, Nigeria).

Sampling Area

The sampling areas were 46 locations (Table 1) in the six Area Councils of the Federal Capital Territory (Fig. 1). And 263 questionnaires were distributed and retrieved from the farmers and the marketers in the FCT, Abuja (Fig. 1).

LC-MS/MS Determination

To 5 g of milled sample, 20 mL of extraction solvent (acetonitrile/water/acetic acid 79:20:1, v/v/v) was added. Extraction, dilution, and analysis were performed as described by.[15] Briefly, LC-MS/MS screening of target fungal and bacterial toxins and metabolites was performed with a QTrap 5500 LC-MS/MS System (Applied Biosystems, Foster City, CA) equipped with a TurboIon

Spray electrospray ionization (ESI) source and an 1290 Series HPLC System (Agilent, Waldbronn, Germany). Chromatographic separation was performed at 25°C on a Gemini C_{18}-column, 150 × 4.6 mm i.d., 5 µm particle size, equipped with a C_{18} 4 × 3 mm i.d. security guard cartridge (all from Phenomenex, Torrance, CA). The chromatographic method as well as chromatographic and mass spectrometric parameters for the investigated analytes was as described by Malachova et al.[15] The ESI-MS/MS was performed in the time-scheduled multiple reaction monitoring (MRM) mode both in positive and negative polarities in two separate chromatographic runs per sample by scanning two fragmentation reactions per analyte. The MRM detection window of each analyte was set to its expected retention time ±27 and ± s in the positive and the negative mode, respectively. Confirmation of positive analyte identification was obtained by the acquisition of two MRMs per analyte (with the exception of moniliformin (MON) and 3-nitropropionic acid (3-NPA) that exhibit only one fragment ion). Quantification was based on external, 1/x weighed calibration in connection with correction for apparent recoveries that were obtained during method validation for maize. The accuracy of the method is verified on a routine basis by participation in proficiency tests.

Statistical Analysis of Data

Median, mean, standard deviation (SD) and detectable range were calculated for concentrations of all toxins and metabolites. Pictorial representation of prevalence level was carried out using Excel package 2007. Scatter plots visualising the co-occurrence of fungal toxins concentration (using the logarithmic scale) in the highly loaded samples were constructed.

RESULTS

Contamination Levels of Emerging and Minor Fungal Metabolites in Maize Grains in the Investigated Areas

The percentage of contaminated samples, the mean, median and maximum contamination level of the emerging and unregulated minor mycotoxins in maize from the FCT, Abuja is as shown in Table 2. The emerging mycotoxins and further secondary metabolites were evaluated and a total of 19 occurrences were observed in the maize samples. These emerging mycotoxins common to both samples and have been in the focus of European Food agency Agency (EFSA) were 11 and includedbeauvericin (BEA), moniliformin (MON), sterigmatocystin (STER) and citrinin (CIT) among others. Others that have not been in the focus of EFSA are norsolorinic acid, nidurufin, macrosporin, fusaproliferin, agroclavine (AGV), chanoclavine (CNV), festuclavine (FEST) and elymoclavine (ECV).

BEA was the most prevalent emerging mycotoxin (100%) in the maize samples at the concentration of up to 329 µg/kg. Next to the prevalence of beauvericin was moniliformin which occurred in 66% of the maize and with maximal concentration of 1387 μgkg^{-1}. This is the first report concerning the contamination of Abuja, FCT-Nigeria maize samples with the emerging *toxigenic fungi* mycotoxins and also with a total of 46 non-regulated metabolites (Table 2). Thirty-three non-regulated microbial metabolites was detected on maize. Up to 23 toxic non-regulated fungal metabolites were quantitated in a single sample, emphasising the great variety of mycotoxin co-exposure. Four out of these non-regulated metabolites which had incidence levels of >60% in maize were monoacetoxyscirpenol (MAS)—60% in maize, emodin (EMOD)—93.3%, 3-nitropropionic acid (3-NPA)—60% in maize and equisetin (EQUI)—96.7% in maize.

The prevalence of nonatin—a *Streptomyces* bacterial metabolite was 16.7%. This was relatively low and therefore most probably not a source of concern.

The co-occurrence of toxins and metabolites in the six highest contaminated samples of maize were pictorially shown as scatter plots in Fig. 2.

The co-occurrence of toxins and metabolites in the six highest contaminated samples of maize is pictorially shown as scatter plots in Fig. 2.

DISCUSSION

Maize harvested, stored or marketed in most north central States of Nigeria has been shown over many seasons to be contaminated with agriculturally important toxins.[17] This might be linked to favourable climatic and crop storage conditions which are frequently conducive to fungal growth and mycotoxin production, as much of the population relies on subsistence farming or on unregulated local markets. The occurrence of many of these emerging mycotoxins in same matrices is a source of concern as co-occurrence may result in synergistic deleterious effect on the human and animal consumers.[18–20]

Occurrence of Emerging Mycotoxins

Consideration was given to metabolites without any existing regulation despite their established toxicity. Among the emerging toxins under evaluation by international organisations such as the EFSA - European Food Safety Authority[21] and the Food and Agriculture Organisation of the United Nations (FAO), beauvericin (BEAU), moniliformin (MON), citrinin (CIT), sterigmatocystin (STER), macrosporin, alternariol methyl ether (AME) were detected in maize from all the six zones of the Abuja, FCT Nigeria. However, NID was detected in 36.7% of the composite maize samples respectively; NA in 50.0% of the maize; CIT in 40.0 % of the maize; and

Table 2 Occurrence and concentrations of emerging mycotoxins and minor secondary microbial metabolites contaminant detected in maize grains from the FCT, Abuja, Nigeria, by LC-MS/MS.

Toxin/Metabolite	%. positive in maize (n=30)	Maize contamination level (μg kg^{-1})			
		Median	Maximum	Mean	SD[a]
Emerging mycotoxins					
Diacetoxyscirpenol (DAS)	40	5.9	6.59	2.24	2.06
Altertoxin-I (ATX-I)	6.7	2.6	2.8	2.6	0.2
Tentoxin(TNTX)	8.0	0.3	3.5	1.3	1.4
Alternariol (AOH)	7	0.4	0.8	0.5	0.2
Alternariol methyl ether(AME)	40	0.2	0.8	0.2	0.2
Fusaproliferin (FUS)	7.1	0.3	1.3	0.6	0.6
Sterigmatocystin(STER)	43.3	1.9	548	75.6	162
Lysergol (LSG)	20	0.6	0.8	0.6	0.1
Moniliformin (MON)	66	25.3	1387	146	333
Beauvericin (BEAU)	100	2.5	329	25	76.1
Minor secondary microbial metabolite					
FumonisinB_4 (FB_4)	96	461	2716	765	808
Aflatoxin M1 (AFM_1)	36.7	183	477	172	169
Aspercolorin (ASP)	16.7	5.6	32.4	13.8	15.4
Norsolorinic acid (NA)	50.0	0.5	5.9	1.8	2.2
Nidurufin (NID)	36.7	1.3	8.7	2.4	3.0
Macrosporin A (MAC-A)	18.0	1.6	196	25.7	61.2
Averantin (AVRN)	43.3	3.4	32.3	7.5	11.1
Chanoclavine (CNV)	29.0	0.4	45.0	2.2	8.3
Agroclavine (AGV)	4.0	0.3	0.6	0.3	0.2
Festuclavine (FEST)	5.0	0.3	1.1	0.5	0.5
Elymoclavine (ECV)	10.0	0.2	1.2	0	0.6
Averufin (AVER)	63.3	12.8	385	67.7	114
Averufanin (AVF)	50.0	8.4	56.3	16.4	20.3
Versicolorin C (VER-C)	40.0	15.5	126	34.3	44.4
Versicolorin VER-A	43.3	2.8	23.2	7.1	8.3
Monoacetoxyscirpenol (MAS)	60.0	3.4	8.7	4.1	2.2
Emodin (EMOD)	93.3	2.3	163	11.8	30.9
Pestalotin (PEST)	93.3	9.6	60.9	14.8	14.3
Skyrin (SKY)	93.3	1.3	38.6	6.9	10.3
Rugulosin (RGS)	23.3	22.2	117.7	41	40.7
Andrastin A (AND-A)	26.7	7.6	25760	5517	9401

(*Continued*)

Table 2 Continued

Toxin/Metabolite	%. positive in maize (n=30)	Maize contamination level (μg kg^{-1})			
		Median	Maximum	Mean	SD[a]
Curvularin (CURV)	13.3	81.6	170	83.7	94.7
Aurofusarin (ARF)	10.0	6.5	10.9	6.4	4.6
Bikaverin (BIK)	10	7404	47210	19132	2443
Hydrolysed Fumonisin B_1 (H-FB_1)	100	885	19928	1989.5	3697
Fusaric acid (FA)	90	90.6	612	171	168
Fusarinolic acid (FUS-AC)	96.7	392	3152	951	964
Siccanol (SCN)	56.7	1294	166400	21886	44690
Equisetin(EQUS)	96.7	18.4	619	49.5	117
Fusarin C(FUS-C)	46.7	3586	37960	8201	1123
Monocerin (MONO)	43.3	0.6	480	54.3	133
DON-3-Glucoside (DON-3-G)	6.7	2.9	4.8	2.9	2.7
Zearalenon-4-sulfate(ZEN-4-S)	16.7	0.1	2.7	0.6	1.2
Nivalenol (NIV)	33.3	5.1	50.8	10.1	14.9
Aspterric acid (A-A)	43.3	246	2481	657	796
Nitropropionic acid (3-NPA)3-	60	81.4	2501	426	775
Terphenyllin (TPL)	13.3	200	1322	456	580
[d]Radicicol (RDC)	12.1	147	1541	343	127
Tenuazonic acid (TEN-A)	28.3	33.2	1540	390	635
Physcion (PHYS)	10.0	131	139	95.2	68.7
Tryptophol (TRYP)	19.0	28.5	70.6	30.4	13.5
Brevianamid F(BVD-F)	26	10.7	54.4	13.4	11.1
Aflatoxin G_2(AFG_2)	6.7	22.0	34.3	22.0	17.5
Penicillide (PCD)	6.7	3.6	7.1	3.6	4.9
Kojic acid (KA)	33.3	272	582	294	163
Cyclopiazonic acid(CPZ-A)	23.3	302	1000	368	298
Methylsterigmatostin (MSTER)	33.3	3.8	78.6	15.7	25.2
Malformin C (MAL-C)	20	1.7	173	53.6	81.8
Malformin A (MAL-A)	20	9.9	536	99.7	214
Malformin A_2 (MAL-A_2)	4	0.7	22.7	6.1	11.1
Aurasperon B (ASP-B)	10	7407	47210	19133	24425
Aurasperon C(ASP-C)	10	2216	19180	7583	10052
Aurasperon G(ASP-G)	5	12810	143600	44148	60551
Monactin (MONC)	6.7	0.4	0.7	0.4	0.4

[a]Standard deviation; [b]Below limit of detection; [c]Bacterial (*Streptomyces*) metabolite; [d:] *radicicol metabolite produced by other fungi: Pochoniachlamydosporia, Cylindrocarpon destructans, Nectria radicicola.*[16]

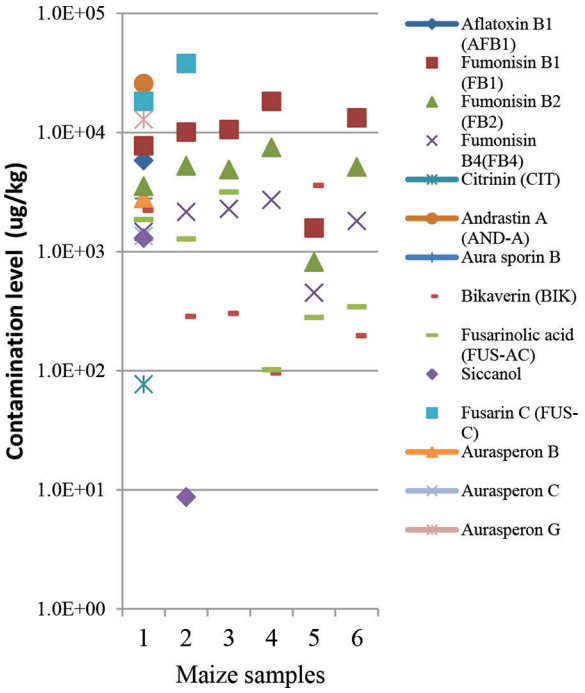

Fig. 2 Scatter plots visualising the co-occurrence of fungal metabolites in the six highest contaminated samples of maize from the FCT, Abuja Nigeria. Different colour pattern represents each type of metabolite.

STER in 43.3% of the maize grains. Jestoi[22] reported that limited data on emerging, less reported mycotoxins might be due to their late recognition especially because of the late understanding of their role as mycotoxins., a notable Alternaria toxin, is fetotoxic and teratogenic in mammals.[21] The main producers of emerging *Alternaria* metabolites are *A. alternata*, *A. dauci*, *A. cucumerina*, *A. solani*, and *A. tenuissima*, *A. citri* and it is also commonly found in wheat, rice, rye, olives, sorghum, tobacco, apples, peppers, sunflower seeds, oilseed rape, pecan nuts, tomatoes and mandarins.[23]

The incidence of emerging *Fusarium* mycotoxins has been reported in different cereal and cereal products samples such as maize,[24] wheat and barley,[25] rice,[26] grain-based products[27] and breakfast, infant cereals.[28] Beauvericin and moniliformin were the two most prevalent minor mycotoxins in the all evaluated maize grains in the territory understudied.BEA is produced by different *Fusarium* species such as *F. avenaceum, F. subglutinans, F. oxysporum F. proliferatum, F. poae and F. Tricinctum.*[29] Abdus-Salaam *et al.*,[30] reported from their analysis of Nigerian rice that beauvericin were detected with maximum value of 131 µg/kg while Sulyok et al.[31] reported up to 800 mgkg^{-1} BEAU in maize samples investigated.

The incidence and contamination level of BEA was specifically high, thus the toxic effects of BEA and other emerging metabolites should be considered as there is high consumption of maize in Nigeria. Blesa[32] reported that BEA, a *Fusarium* emerging hexadepsipeptide secondary metabolites, has been less frequently investigated by routine methods. A public health threat cannot completely be ruled out due to their widespread co-occurrence with other mycotoxins and fungal metabolites in cereal grains. Though reports are not yet available for the synergistic interactions of these additional metabolites, effects of independent administrations have been reported. For example the peptide, BEAU is genotoxic to human lymphocytes and to brine shrimps[33] while MON can induce cytotoxicity in many mammalian systems.[20]

In our study, moniliformin were detected in 100% of maize samples and 146.0 µg/kg level of MON was found in all the maize samples. This is far above the EU maximum acceptable limit of 15–135 µg/kg in maize and maize products. MON occurred in 75.30% of maize was 66.0% but with a concentration level as high as 1387 µg kg^{-1}. Moniliformin has been detected in maize, wheat, rye, triticale, oats and rice, and co-occurrence with FUMs has been reported.[34] MON is sodium or potassium salt of 3-hydroxycyclobut-3-ene-1, 2-dione and produced by several species of *Fusarium* including *F. avenaceum, F. tricinctum* and *F. proliferatum.*[35] Nazari *et al.*[36] reported that there was no detectable level of MON found in the analysed Iranian rice samples.

*Fusaproliferin (*FUS) was detected in only 33.3% of the Nigerian maize samples with a mean concentration of 0.6 **µg/kg**. Koppen[23] reported that FUS is commonly found in, corn, barley, bread mill, oat flour and rice. In a study in Morocco, Mahnine *et al.*[28] reported that one rice-based infant cereal was contaminated to FUS at the concentration level. In this study, enniatins (A, A_1, B, B_1) were not detected in maize samples. Vaclavikova et al.[37] detected enniatins in small grains from Czech Republic but they disappeared after being processed into beer and bread making. Up to 4260 µg/kg of citrinin were detected in maize. Also up to 547.8 µg/kg of STER were detected in maize. Abdus-Salaam et al.,[30] evaluated emerging toxins in processed Nigerian rice and detected that citrinin and sterigmatocystin (STER) had maximum values of 207 and 125 µg/kg respectively. Aflatoxin precursors such as norsolorinic acid (NA), nidurufin (NID) were detected.

In this study, the presence of clavines ergot alkaloid in most samples of maize which indicate contamination of the cereals with *Claviceps purpurea*, *C. africanana*, *C. fusiformis*, *C. fusiformis*, *C. paspali*, *Neotyphodium coenophialum* and it is commonly found in wheat, rye, hay, barley, millet, oats, sorghum and triticale. Mean concentration of agroclavine was as low as 0.3 µg/kg in the maize and only in 4.0% of them. This is the first report in which maize samples are contaminated by this clavine-type ergot alkaloid in Abuja Nigeria. Souza et al.,[38] reported a low level of agroclavine (7. 20 µg/kg) in maize samples in Brazil and also Ezekiel et al.[39] reported from the study of maize-based poultry feed in other parts of Nigeria that Claviceps metabolites were found at concentrations

of up to 350 μgkg^{-1}, with agroclavine (AGV) having the highest concentration although elymoclavin (ECV) was the most prevalent. Adetunji[40] reported from the studies on the mycotoxins load on Nigerian stored maize that festuclavine (FEST) and AME occurred only in one sample (1.7% contamination) each at concentrations of 3.2 and 106 μgkg^{-1} respectively

Robinson and Panaccione[41] reported that chemically, the difference between agroclavine and festuclavine is the presence of the 8, 9-double bond in agroclavine. Cheng,[42] earlier found that Ergot alkaloid-producing fungi in the Trichocomaceae typically produce festuclavine as a key intermediate to more complex ergot alkaloids, whereas most ergot alkaloid-producers in the Clavicipitaceae use agroclavine as a substrate for future modifications.

The mean concentration of chanoclavine was relatively low in maize (2.2 **μg/kg**) and the alkaloid is prevalent in 29.0% of the maize. From investigations on Norwegian grains samples, it was found that 40% of the barley contained chanoclavine at a median level of 0.1 μg/kg with the maximum concentration of 0.2 μg/kg. 18% of the wheat contained the metabolite at a median level of 0.1 μg/kg with the maximum concentration of 0.9 μg/kg while no chanoclavine was found in the oats samples. From the study of ergot alkaloid produced by endophytic fungi, Guerre[43] reported that oxidoreduction of chanoclavine is necessary to obtain agroclavine. It was further reported that the oxidation of agroclavine leads to the formation of elymoclavine, which is known to be more potent than agroclavine in the prolactin reduction assay and then oxidation of elymoclavine leads to d-lysergic acid. Regardless of the low-to-moderate levels of ergot alkaloids in our samples, there is an impending danger in the continuous consumption of this potent group of non-regulatory toxins.

CONCLUSION

The HPLC-MS/MS method used in this study showed an ultra-large mycotoxin spectra, good sensitivity, rapidness, and applicability to complex matrices for detecting the emerging and other minor microbial metabolites in crop produce such as cereal grains. For the first time, the presence of 19 emerging mycotoxins including beauvericin BEAU), moniliformin (MON), nidurufin (NID), norsolorinic acid (NA), citrinin (CIT), macrosporin (MAC-A), sterigmatocystin (STER), macrosporin, AME chanoclavine (CNV); agroclavine (AGV); elymoclavine (ECV) and brevianamid (BVD-F) were confirmed to be present as contaminant in Abuja Nigerian maize grains. There is an indication from the present study that the potential health threat due to the contamination of maize with some non-classic mycotoxins which might be neglected in conventional mycotoxin monitoring. This report could be basis for the production of road map for emerging and minor mycotoxins and its mitigation with regards to maize for the country.

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Core tip: This study investigated the incidence of emerging, less investigated fungal metabolites in maize grains across the FCT Abuja, Nigeria using a multi-mycotoxin analysis facility. For the first time, the presence of 19 emerging mycotoxins including beauvericin (BEAU), moniliformin (MON), nidurufin (NID), norsolorinic acid (NA), citrinin (CIT), macrosporin (MAC-A), sterigmatocystin (STER), macrosporin, alternariol methyl ether (AME), chanoclavine (CNV); agroclavine (AGV); elymoclavine (ECV) and brevianamid (BVD-F) were confirmed in Abuja Nigerian maize grains. Up to 23 toxic non-regulated fungal metabolites were quantitated in a single sample, emphasising the great variety of mycotoxin co-exposure. Four out of these non-regulated metabolites which had incidence levels >60% in maize were monoacetoxyscirpenol (MAS)—60% in maize, emodin (EMOD)—93.3%, 3-nitropropionic acid (3-NPA)—60% in maize and equisetin (EQUI)—96.7% in maize.

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Author contribution: Anjorin Toba Samuel contributed towards data collection and article writing; Fapohunda Stephen prepared the samples for analysis and proof read the manuscript'; Sulyok Michael analysed the samples in the laboratory and collated the data, Krska Rudolf assisted in the analysis of data.

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Dedication: The article is dedicated to all those who ignorantly consume contaminating microbial toxins in their food.

Disclaimer: Any views expressed in this paper are those of the authors and do not reflect the official policy or position of the Department of Defense.