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Review on the Aflatoxins' Contamination of Foods and Public Health Effects among Nigerian Population

Baha'uddeen Salisu[1,2], Siti Marwanis Anua[3*], Wan Rosli Wan Ishak[4] and Nurzafirah Mazlan[5]

[1]Environmental and Occupational Health Program, School of Health Sciences, Health Campus, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia. Email: bahauddeens@student.usm.my, Tel: +601164394458

[2] Department of Microbiology, Umaru Musa Yar'adua University, PMB 2218, Katsina, Nigeria. E-mail: bahauddeen.salisu@umyu.edu.ng

[3] Environmental and Occupational Health Program, School of Health Sciences, Health Campus Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia. Email: smarwanis@usm.my, Tel: +6097677827.

[4]Nutrition and Dietetics Program, School of Health Sciences, Health Campus, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia. Email: wrosli@usm.my, Tel: +6097677649

[5] Department of Diagnostic and Allied Health Sciences, Faculty of Health and Life Sciences, Management and Science University, University Drive, Section 13, 40100 Shah Alam, Selangor, Malaysia. Email: nurzafirah_mazlan@msu.edu.my, Tel: +603-55216481

*Corresponding author: smarwanis@usm.my; +6097677827

Abstract

Aflatoxin in foods and feeds need adequate monitoring on account of their severe toxicity and carcinogenicity to both humans and animals. This review was aimed at examining the public health risks attributed to chronic exposure of aflatoxins in foods within Nigeria. Both the reported cases of aflatoxins in foods and biomarkers in Nigeria signified increase in dietary exposure. Aflatoxins contamination levels ranges from 1.3 ng/g to 51,192ng/g in foods with an estimated dietary exposure of 0.00017 ng/kgbw/day to 9, 880.56 ng/kgbw/day. The percentage incidence of primary liver cancer cases (PLCC) attributable to the dietary aflatoxin exposure for every 100,000 Nigerians per year ranges from 0.0024 to 708.13% between 1998 to 2008 which increases to 0.0046 to 45,602% between 2009 to 2018. The percentage incidence of PLCC signified by urine aflatoxin M1 (AFM1) levels in adults was around 0.23 - 1.29% per 100,000 population per year. In children, the estimated PLCC and stunting due to aflatoxin exposure via breast milk were 0.0019 to 237.71 cancers per 100,000 populations per year and mild to severe stunting with height-for-age z-score (HAZ) value above -3 HAZ reductions. Hence, there is need for additional monitoring of the marketed foods and implementing more stringent control and prevention strategies that reduce dietary exposure levels in Nigeria.

***Keywords**: Aflatoxins, Immuno-suppression, Stunting, Liver cancer*

INTRODUCTION

Aflatoxins are a group of low molecular weight toxic proteins compounds produced as secondary metabolites by fungi of the genera *Aspergillus*. Specie of *A. flavus* that grow under favourable conditions are excellent source of Aflatoxins(Salisu and Almajir, 2020). Several fungi were known to contaminate foods/feeds and consequently produce wide array of toxic metabolites and mycotoxins (Oliveira *et al.*, 2017; Reddy *et al.*, 2010; Uhlig *et al.*, 2013; (Zaki, Shaheen and Rizzi, 2012; Berthiller *et al.*, 2013; Alshannaq and Yu, 2017). Such metabolites and mycotoxins causes cancer, encephalopathy, pulmonary haemorrhage, central nervous system(CNS) depression, as well as hematologic and immunologic suppression (Andrea, 2013; Magnussen and Parsi, 2013; Moreno, 2015; Liew and Mohd-Redzwan, 2018; Negash, 2018).

Globally, aflatoxins contaminate about 25% of the worlds food supply (EAC Policy, 2018b). An estimated 4.5 billion of the world's population is exposed to aflatoxins which accounted for one-sixth of the global deaths annually as Africa recorded more than half-billion cases (CDC, 2012). Increased exposure to aflatoxins is generally associated with acute or chronic toxicities depending on the amount and length of exposure, and often death in humans, other mammals, birds, and fishes (Völkel *et al.*, 2011). Being highly lipophilic, the primary target organ of aflatoxins is the liver which may spread to other organs like kidneys, lungs, heart, and brain (Gurav and Medhe, 2018). Generally, aflatoxicosis lead to hepatocellular carcinoma (liver cancer), chronic hepatitis,

cirrhosis, jaundice, and deficient nutrient conversion(Wild and Gong, 2010).
It can also lead to genotoxicity, birth defects, and stunted growth in children (EAC Policy, 2018a; JECFA, 2018). The cases are more likely to occur in African countries due to hot and humid climatic conditions coupled with poor storage practices (eg. Use of stores with leaky roofs and /or with poor ventilation) which promote the proliferation of aflatoxigenic fungi (Gong *et al.,* 2016). This lead to the serious contamination of foods and feeds accordingly. Globally, Africa has the highest record of liver cancer (40% out of the estimated 25,200–155,000 annually) attributed to aflatoxins contamination (Liu and Wu, 2010). This, therefore, called for intensive reviews that summarize the past and present aflatoxins risks in Africa. This review will analyze the primary liver cancer cases (PLCC) and stunting attributed to chronic exposure to aflatoxins in foods and feeds within Nigeria.

AFLATOXICOSES IN NIGERIA

In Nigeria, several cases of aflatoxicosis have been occurring but only a few were documented (Atanda *et al.,* 2013). One of the most serious outbreaks of acute aflatoxicosis occurred in the late 1900s in which 40 children reportedly died at the Obafemi Awolowo Teaching Hospital complex, Ile-Ife, Nigeria (Oyelami*et al.,* 1995; 1997). Aflatoxins were detected in 81% (30 out of the 40 children) following the autopsy of the brain tissues of the children (Oyelami *et al.*, 1995). Among the 30 aflatoxin positive children, 15 have kwashiorkor which is a sign of chronic aflatoxicosis while the remaining showed other symptoms (Oyelami *et al.*, 1995). Aflatoxins were also detected in the lung and kidney specimens of another set of 32 children during autopsyamong which 18 suffered from kwashiorkor (Oyelami *et al.*, 1997).. It was concluded that kidney and cardiac failures were the major cause of death among such children(Oyelami *et al.*, 1997, 1998). Many other deaths due to acute aflatoxicosis have been occurring in various parts of Nigeria(Atanda *et al.,* 2013). Aflatoxins were found in various tissues and biological fluids such as semen, blood, and urine of liver cancer patients in Nigeria (Atanda *et al.,* 2013). According to a report from National Hospital, Abuja, many post mortem examinations on liver cancer were linked to aflatoxins effects(Atanda *et al.,* 2013). In addition, according to reports from many specialist hospitals in Nigeria, several cases of aflatoxicosis and other mycotoxicoses have been recorded (Atanda *et al.,* 2013).

The effect of chronic exposure to aflatoxins is aflatoxin-induced hepatocellular carcinoma (HCC) which is mostly associated with hepatitis B or C virus (Lizárraga-Paulín*et al.,*2012). Generally, aflatoxin exposure is the second largest environmental risk factor for cancer development worldwide (McCullough and Lloyd, 2019). In Nigeria, an estimated 7,761 out of 10,130 annual liver cancer cases are attributed to Aflatoxin contaminated maize and groundnuts (Adetuniji *et al.*, 2014). This has led to the loss of about 5,000 lives and $155 million (Olayinka, 2018) This therefore signifies the need for more preventive interventions and control strategies to reduce the exposure levels.

Another debilitating exposure effect to aflatoxins is their ability to devitalize the immune system through modulation of cytokines, cell-mediated immune suppression, T-cells, B- cells and natural killer cells activities suppression (Bammler*et al.,* 2000; Sayo, 2015). Many studies in Africa showed strong association between exposure to aflatoxins and a high risk of HCC, immunodeficiency, and development of infectious diseases, and as vaccine failure (Qazi and Fayyaz, 2006; Ogodo and Ugbogu, 2016; Mupunga, Mngqawa and Katerere, 2017). It has been shown that there is a strong association between unsafe sex and development of aflatoxicosis in HIV endemic areas (Lizárraga-Paulín, Moreno-Martínez and Miranda-Castro, 2012).This suggestedpossible role of aflatoxins in AIDS-related immunosuppression and deaths which might be the reason for higher prevalence of aflatoxicosis. In Nigeria, HIV prevalence is 1.4%, accounting for about 1.9 million people living with HIV with about 160, 000 AIDS-related deaths in 2016 alone(UNAIDS, 2017, 2019). These data suggest a possible correlation between aflatoxin exposure and the AIDS.

Many studies have shown strong affiliation between aflatoxin exposure and stunting in children (Turner *et al.*, 2007; Shuaib *et al.*, 2010; Watson *et al.*, 2018).Generally, aflatoxin exposure is more common in low-income families who cannot afford good quality food (Ahlberg *et al.*, 2018). According to the 2019 global child malnutrition estimate, about 149 million children under the age of five are stunted and the majority of which are found in Africa and Asia (UNICEF/WHO/World Bank Group, 2019). A study on exposure to aflatoxins among children with severe acute malnutrition was recently conducted in Nigeria (McMillan *et al.*, 2018). The median concentration of AFB1-lysin adducts detected in the serum samples was 2.6 pg/mg albumin with values ranging from 0.2pg/mg to 59.2 pg/mg albumin (McMillan *et al.*, 2018). Such AFB1-lysine was significantly higher in stunted children

(4.6 pg/mg albumin) and children with severe acute malnutrition (4.3pg/mg) when compared to non-stunted (1.2 pg/mg albumin) and the controls (0.8 pg/mg). This AFB1-lysine was also found to be significantly higher in kwashiorkor children (median = 6.3 pg/mg albumin) compared to children with severe marasmus (median = 0.9 pg/mg). Several studies have established a strong link between aflatoxin exposure and kwashiorkor which is a severe form of protein-energy malnutrition (PEM), as well as increased morbidity in children. As observed by (McMillan *et al.*, 2018), the highest level of the serum aflatoxin was found in children with kwashiorkor. Similarly, significantly higher levels of aflatoxins were detected from the autopsy of liver specimens of some Nigerian and South African kwashiorkor children (Lamplugh and Hendrickse, 1982).

A cross-sectional study of aflatoxins in the food plates, serum and urine samples of 36 kwashiorkor children (KC), 29 marasmic kwashiorkor children (MKC), 13 marasmic children (MC) and 33 healthy age-matched control subjects from the 3 agroecological zones of Nigeria was conducted (Ogbadu and Onyemelukwe, 2012). Aflatoxins were detected in 93.1% of MKC, 88.9% of KC, 76.9% of MC, and 63.6% of the healthy controls, with the corresponding levels of AFB1 in the food plates as 82.4%, 69.4%, 53.8%, and 42.4% respectively. The median concentration of aflatoxins in the 3 groups of malnourished children is significantly higher than those in the control subjects for both serum/urine (p=0.013) and food plates (p=0.007), indicating that children in Nigeria are continuously being exposed.

BIOMARKERS OF AFLATOXIN EXPOSURE IN NIGERIA AND THEIR HEALTH SIGNIFICANCE

Biomarkers of aflatoxin exposure include both the aflatoxins and their metabolites that can be detected in the body tissues and fluids or excretory products (Polychronaki *et al.*, 2008). The major validated aflatoxin biomarkers include hydroxylated aflatoxin M (AFM) found in milk and often in urine and faeces(Wild and Turner, 2002). Others are serum aflatoxin protein adducts (Af-albumin, AF-lysine) and excretory metabolites such as aflatoxin-DNA adduct (AFB1- N7-guanine) and AFM1 found in urine (Wild and Turner, 2002; Jager *et al.*, 2014).

Summary of some major reported biomarkers from the body fluids of Nigerians for the last 2 decades (1998 – 2018) is shown in Table 1.From the table, most of the biomarkers reported before the beginning of the 21st century were detected in lower quantities and the overall percentages of positive samples in each study were less than 50%. This may probably be due to the type of detection techniques used in those periods which are generally characterized by less sensitivity and precision compared to modern techniques such as HPLC-FD (Bhanot, 2015; Patil, 2018a, 2018b; Smith, 2018). In the recent reports, from 2012 to 2018, both the percentage of positive samples and the rate of detection of biomarkers from the samples were very high. In most of the studies, biomarkers were detected in more than 80% of the samples tested at higher levels ranging from 0.00349 to 149 ng/ml of samples and up to 361ng/ml in kwashiorkor children (Table 1).

Inferencially, the higher levels of biomarkers, signifies high dietary exposure to AFB1 in Nigeria. As can be seen from Table 1, multiple studies have reported these aflatoxin biomarkers in maternal blood, babies cord blood, jaundiced neonates and mothers, breast milk of lactating mothers, urine and serum of malnourished children, as well as urine samples of healthy adults. This is a strong indication of the extent to which Nigerians are exposed to dietary aflatoxins and the manifestations of the chronic effects of the aflatoxins in Nigeria. Apart from the apparent health effects in children, other chronic effects of aflatoxin exposure such as stunting and hepatocellular carcinoma can also be hypothetically estimated from the levels of the most recently reported biomarkers.

The summary of the hypothetical health implications represented by the most recently reported biomarkers of aflatoxin exposure in Nigeria is provided in Table 2. Given that AFM1 is 10 times less carcinogenic than AFB1 (Ahlberg *et al.*, 2018). The primary liver cancer cases signifies by the reported levels of AFM1 in breast milk ranges from 0.0019 to 237.71 cancers per 100,000 population of children per year with an estimated percentage incidence of 0.014 to 1,694.87 liver cancers per 100,000 population per year out of the estimated 12,047 total primary liver cancer cases in males and female Nigerians (WHO, 2014). Similarly, the hypothetical estimate of stunting that could result based on the level of AFM1 consumption in breast milk by the children will range from mild to highly severe stunting with height-for-age z-score (HAZ) value above -3 HAZ reduction, given that AFM1 in milk (ng/kgbw/day) has a significant reduction effect ($\beta = -0.3$, at $p = 0.01$) on height-for-age z-score of childhood growth provided all other growth determinant factors are disregarded (Mahdavi *et al.*, 2010; Ahlberg *et al.*, 2018). This further explains the numerous reports of severe childhood malnutrition in Nigeria (Onyemelukwe *et al.*, 2012b; McMillan *et al.*, 2018).

On the other hand, the primary liver cancer cases signified by the reported urine AFM1 level ranges from 0.036 to 0.18 cancers per 100,000 population per year as calculated using the regression equation of Zhu *et al.*, (1987), AFM1 in Urine = -0.042 + 0.0026AFB1 (R^2 = 0.65), thereby contributing to an estimated 0.23 to 1.29% of liver cancers per 100,000 population

Table 1: Biomarkers of Aflatoxin Exposures in Nigeria

Place	Number and Type of Subjects Tested	Type of Aflatoxin Biomarker	% of Positive Samples	Level of contamination (ng/ml)	Reference
Enugu State	78 Healthy Men	TAF	NS	R= 0.02 - 3.1	(Denning *et al.*, 1988)
Jos / Plateau	77 maternal blood 78 babies cord blood	Serum Aflatoxins	21% 12%	NS	(Lamplugh *et al.*, 1988)
Ibadan/ Oyo State	625 babies cord blood	Serum Aflatoxins	14.6%	NS	(Maxwell *et al.*, 1994)
Ibadan/ Oyo State	320 jaundiced neonates (jn) 80 mothers of jn (mjn) 60 control neonates (cn) 7 mothers of controls (mc)	Serum Aflatoxins	- 27.4% of jn - 17% of mjn - 16.6% of cn - 14.4% of mc	NS	(Sodeinde *et al.*, 1995)
Zaria / Kaduna State	Cord blood of 37 jaundiced neonates (jn) Cord blood of 40 non-jn Serum of 64 jn Serum of 60 control babies	Serum Aflatoxins	37.8% 22.5% >50% 0%	NS	(Ahmed *et al.*,1995)
Ogun State	Breast milk from 50 lactating mothers	Mycotoxins	AFM1 obtained in 82%	- M = 0.0159	(Raiola, 2012)
South-western Nigeria	Breast milk from 120 lactating mothers	AFM1	14.1%	R= 2 - 187	(Oluwafemi , 2012)
Three AEZs of Nigeria	36 kwashiorkor children (kc) 29 Marasmic kc 13 arasmus 33 controls	Total Serum Aflatoxins	88.9% 93.1% 76.9% 63.6%	MD = 0.1656 MD = 0.2284 MD = 0.2343 MD = 0.0207	(Onyemeluk we *et al.*, 2012b)
Three AEZs of Nigeria	13 kwashiorkor children (kc) 20 Marasmic kc 11 arasmus 31 controls	Total Urine Aflatoxins	84.6% 60% 81.8% 90.9%	MD =79 MD = 43.8) MD = 14.4 MD = 42.6	(Onyemeluk we *et al.*, 2012b)
Ogun State	Breast milk from 50 lactating mothers	AFM1	82%	M = 0.015	(Adejumo *et al.*, 2013)
Northern Nigeria	120 subjects from eight rural communities	-Urine Mycotoxins -AFM1	- 50.8% (61/120) - 14.2% (17/120)	Mean AFM1 = 0.3;SD = 0.4	(Ezekiel *et al.*, 2014)
Ogun State	84 rural and Semi-urban Subjects	Urine AFM1	99% (83/84)	(M = 0.027)	(Ezekiel *et al.*, 2018)
Nigeria	children suffering from severe acute malnutrition	Serum aflatoxin-lysine	100%	[a] R= 0.2 - 59.2 (MD= 2.6)	(McMillan *et al.*, 2018)

[a]Concentration expressed in pg/mg albumin
AEZs = Agro-ecological Zones; NS = Not stated; M = Mean; MD = Median; R = Range; AFM1 = Aflatoxin M1

per year out of the estimated 12,047 total primary liver cancer cases in males and female Nigerians as reported by (WHO, 2014), (Table 3). As a matter of fact, the same value was obtained, when the estimated cancer risk calculated using the regression equation of (Zhu *et al.*, 1987) was compared with the cancer risk calculated using the direct level of AFB1 reported in the food consumed by the subjects. i.e.

-Mean AFB1 in the food obtained from the subjects = 2.4µg/kg (Ezekiel *et al.*, 2014), thus, estimated exposure in ng/kgbw/day = AFB1 (2.4µg/kg) x 57g/person/day (average food consumed per day per person) devided by weight of average adult Nigeria (60.okg) (Adetunji *et al.*, 2017) = 2.28 ng/kgbw/day.

- And, the primary liver cancer = exposure (ng/kgbw/day) of AFB1 (2.28) X average potency (0.0825) =0.188 per 100,000 population/year

The above value (0.188) is equal to the estimated value calculated from the mean AFM1 (0.3) in the urine of subjects as shown in Table 2.

Table 2: Hypothetical Health Effects of Aflatoxin reported biomarkers from Nigeria between 2012 to 2018

Type of sample	Level of AFM1 in the sample (ng/ml)	Estimated AFM1 Exposure Via Breast Milk		Estimated Dietary AFB1 Exposure		[e] EHCC (Cases per 100, 000 population /year)	[f] % Incidence of HCC/ 100, 000 population /year	g Estimated Growth Reduction (Stunting) (0.1cm)	Reference
		[a]ng per day	[b]ng/ KgBW per day	[c]ng per day	[d]ng/kg bw/ day				
Breast Milk	M = 0.0159	2.40	0.25	-	-	0.0021	0.015	-0.075	(Raiola, 2012)
Breast milk	R = 2 to 187	302 to 28,237	30.82 to 2,881.3	-	-	0.25 to 237.71	1.78 - 1,694.87	-9.246 - 864.40	(Oluwafemi , 2012)
Breast Milk	M= 0.015	2.27	0.23	-	-	0.0019	0.014	-0.069	(Adejumo *et al.*, 2013)
Urine	M =0.30	-	-	131.54	2.19	0.18	1.29	-	(Ezekiel *et al.*, 2014)
Urine	M = 0.027	-	-	26.54	0.44	0.036	0.23	-	(Ezekiel *et al.*, 2018)

Note: HCC = Hepatocellular carcinoma, EHCC = Estimated HCC, M = Mean, R= Range

[a]Values were calculated by multiplying the AFM1 (ng/ml of breast milk) with the average daily intake of breast milk by Nigerian infants (151ml/kgbw) (Marko *et al.*, 2018).

[b]Values were calculated by dividing the daily exposure with the average body weight of Nigerian children aged 12-24 months, 9.8Kg (Ojuri *et al.*, 2018).

[c]Values were calculated using the regression equation of Zhu *et al.*, (1987), AFM1 in Urine = -0.042 + 0.0026AFB1, $R2 = 0.65$

[d]Values were calculated by dividing the daily exposure with the average body weight of adult Nigerian population, 60.0Kg (Adetunji *et al.*, 2017)

[e]Calculated based on the average Nigerian population potency estimate of 0.0825 cancers/100,000 population/year per ng/kg bw/day(Adetunji, Atanda and Ezekiel, 2017): EHCC = exposure (ng/kgbw/day) of AFB1 X average potency. In case of AFM1 which is 10 times less carcinogenic than AFB1 (Ahlberg *et al.*, 2018), the estimated HCC was calculated as EHCC = exposure to AFM1 (ng/kgbw/day)÷10 X average potency.

[f] Values were calculated by multiplying the average liver cancer incidence in Nigeria = 7.13/100,000 population/year (WHO, 2014) with EHCC.

[g]Estimated growth reduction (stunting) to the nearest 0.1cm values were calculated by multiplying the AFM1 exposure (ng/kgbw/day) by the growth reduction effect (ß = -0.3) on height-for-age z-score as reported by Mahdavi *et al.*, (2010) and (Ahlberg *et al.*, 2018).

AFLATOXIN CONTAMINATION OF STAPLE FOODS IN NIGERIA ANDTHE ESTIMATED LIVER CANCER RISKS

The levels of aflatoxins in Nigerian staple foods and their attributed cancer risks for the last 2 decades (1998 – 2018) were summarised in Table 3. According to the various literature cited in this review, family cereals have the highest level of contamination by aflatoxins ranging from 1.3 ng/g – 51,192ng/g. This is followed by maize (0.002 – 15,489.6 ng/g), sweet potatoes (2,180 – 2,208 ng/g), meat (2.9 – 1,464), tomatoes (0.57 – 1,430 ng/g), Peanuts and their products (0.9 – 646.0 ng/g), rice (0.01 – 372 ng/g), spices (0.7 – 156.0 ng/g), edible mushroom (5.0- 100.1 ng/g), Bread (14.0 – 48.59 ng/g), millet (<4.0 – 40.30), fish (0.0 – 40.0 ng/g), sorghum (2.7 – 36.13 ng/g), Vegetables (2.41 – 33.49), yam (0.4 – 30ng/g), Cassava (0.0 – 29.4 ng/g), Wheat (17.01 – 20.53 ng/g), and milk and other dairy products that have the least contamination level (2.04 – 4.0 ng/g).

On the other hand, the dietary exposure risks to aflatoxins (ng/kgbw/day) per 100, 000 Nigerian population showed that maize consumption has the highest attributable dietary exposure risk having an estimated dieatary exposure levels ranging from 0.00017 ng/kgbw/day to 9, 880.56 ng/kgbw/day; followed by family cereals (8.65 – 4, 223.34 ng/kgbw/day), rice (1.28 – 628.49 ng/kgbw/day), sweet potato (428.04 – 433.53 ng/kgbw/day), peanuts and their products (0.55 – 396.75 ng/kgbw/day), tomatoes (1.57 – 259.78 ng/kgbw/day), yam (1.54 – 110.72 ng/kgbw/day), cassava (0.0 – 104.74 ng/kgbw/day), vegetables (6.63 – 73.4 ng/kgbw/day), sorghum (4.93 – 65.99 ng/kgbw/day), meat (1.11 – 56.1 ng/kgbw/day), millet (<5.84 – 58.89 ng/kgbw/day), fish (0.0 – 31.23 ng/kgbw/day), wheat (1.53 – 18.75 ng/kgbw/day), spices (0.035 – 7.8 ng/kgbw/day), bread (1.39 – 5.05 ng/kgbw/day), edible mushroom (0.029 – 0.58 ng/kgbw/day), and milk and other dairy products having the least dietary exposure levels (0.075 – 0.15 ng/kgbw/day). Consequently, these exposure values could account for an estimated % incidence of primary liver cancer cases per 100,000 population in Nigeria ranging from 0.087 to 0.17% , 0.034 to 0.67%, 1.54 to 5.89%, 0.035 to 8.97%, 17.95 to 21.74%, 0.0 to 36.19%, 1.29 to 64.945% <6.13 to 68.16%, 5.75 to 76.30%, 7.71 to 84.99%, 0.0 to 121.18%, 1.82 to 128.05%, 1.82 to 300.59%, 0.65 to 459.05%, 495.23 to 501.68%, 9.96 to 4,233.39% and up to 0.0024% to 45,602% due to consumption of milk and dairy products, edible mushroom, bread, spices, wheat, fish, meat, millet, sorghum, Vegetables, cassava, yam, tomatoes, peanuts and their products, sweet potato, rice, family cereals, and maize respectively. Overall, the estimated percentage incidence of primary liver cancer cases attributable to dietary aflatoxin exposure per 100,000 Nigerian population ranges from 0.0024 to 708.13% between 1998 to 2008 and 0.0046 to 45,602% between 2009 to 2018 with a mean range of 160.60 to 176.44% and 84.03 to 1,052.50% respectively; indicating a significant increase in the level of dietary exposure to aflatoxins in Nigeria. Hence, there is need for implementation of more stringent control and prevention strategies to reduce the high dietary exposure level of Nigerians to aflatoxins in staple foods and feeds because of their serious negative effects on health and the economy of the nation. Recently, over 120 Nigerian food products were rejected by the European Union from 2013 to 2016 due to their poor quality (Sokefun, Ayepola and Olasehinde, 2018).

Table 3: Cancer Risks Attributable to Dietary Aflatoxin Exposure in Nigeria

Place	Number and Type of Food Samples	% of Positive Samples	Level of Aflatoxins (ng/g)	[1] Estimated Dietary Exposure to AFB1 (ng/kgbw/day)	[2]Attributable Primary Liver Cancer (HCC)/100,000 people/year	[3] % Incidence of the HCC per 100,000	Reference
Ilisha, Nigeria	48 Maize-based gruel	NS	R = 0.002 - 19.716	[c] 0.002 - 19.72	0.00017 - 0.13	0.0024 - 1.82	(Oyelami *et al.*,1996)
Ogun and Oyo States	77 dried yam chips	AFB1 - 22%	[a] R =5 - 30	[d] 19.27 - 110.72	1.59 - 9.13	22.3 - 128.05	(Bankole and Mabekoje, 2004)
Lagos, Ibadan &Ogbomosho	150 brown breads	TAF = 11 samples	R= 14 - 41	[e] 1.39 - 4.071	0.11 - 0.34	1.54 - 4.77	(Efuntoye, 2004)
Southwestern Nigeria	106 dry roasted ground nuts	AFB1 = 64.2%	[a] M= 25.5	[f] 15	1.24	17.39	(Bankole *et al.*, 2005)
Niger State	196 mouldy rice	AFB1- 49.49%	M+SD = 200.19 + 320.98	[g] 323.91	26.72	374.75	(Makun *et al.*, 2007)
Ogun State	human and cow milk, yoghurt, "wara", ice cream and "nono"	AFM1	[b] R=2.040 to 4.0	[h] 0.075 - 0.15	0.0062 - 0.012	0.087 - 0.17	(Atanda *et al.*,2007)
Three AEZs of Nigeria	Maize samples	AFB1 AFB2	H= 612 H= 193	[c] 612	50.49	708.13	(Atehnkeng *et al.*, 2008)
Seven Southern Nigerian States	Wheat Millet Guinea corn Breadfruit Groundnut	AFB1= 100% in all samples	R=17.01-20.530 R=34-40.3 R=27.22-36.13 R=40.060-48.59 R=74.030-82.12	[j] 1.53 - 18.75 [k] 31.05 - 58.89 [L] 49.72 - 65.99 [e] 4.15 - 5.05 [f] 45.47 - 50.44	- 1.28 - 1.55 - 2.56 - 4.86 - 4.10 - 5.44 - 0.34 - 0.42 - 3.75 -4.16	- 17.95 - 21.74 - 35.90 - 68.16 - 57.50 - 76.30 - 4.77 - 5.89 - 52.59 - 58.35	(Odoemelam and Osu, 2009)
Oyo State/ Nigeria	40 fresh meat 40 dried meat	TAF = 100% TAF =100%	-R=2.9 to 85.2 -R= 3.1 to 74.1	[m] 1.11 - 32.66	0.092 - 2.69	1.29 - 37.73	(Olufunmilayo *et al.*, 2010)
Bayelsa State	Edible Mushroom	AFB1	M= 5.0	[n] 0.029	0.0024	0.034	(Jonathan et al.,2011)
Niger State	21 rice samples	TAF= 100%	R=28 - 372	[g] 47.31 -628.49	3.90 - 51.85	54.70 - 727.21	(Makun et al.,2011)
South-Western and South-Eastern Nigeria	41 rice 39 Maize 17 Cocoa Seeds 22 processed cocoa 25 Cocoa Powder	TAF = 87.8% TAF = 94.9% TAF = 88.2% TAF = 72.7% TAF = 44%	M=0.76, SD=3.1 M=10.24SD=24.9 M=1.12, SD = 1.7 M=6.05, SD =4.98 M=2.99; SD =2.63	[g] 1.28 [c] 10.24	0.11 0.84	1.54 11.78	(Augustina, 2011)

Table 3 continue Plateau State, Nigeria	16 fonio millet 17 sesame samples	AFs = 81% 0.0%	< 4.0	[K]<5.84	<0.48	<6.73	(Ezekiel et al., 2012)
Southwestern Nigeria	100 samples of yam flour	- AFB1 - AFB2	-M = 0.4 -R= < LOD - 3.5	[d] 1.54	0.13	1.82	(Somorin et al., 2012)
5Nigerian Markets	29 peanut cake samples	AFB1 & AFB2 = 86%	-H= 2.82	[f] 1.73	0.143	2.01	(Ezekiel et al., 2012)
Oyo State	12 Maize samples	AFB1= 58% AFB2 = 41.66%	[a] R=4.1 - 19.407 [a] R=1.46 -7.67	[c] 4.1 - 19.407	0.34	4.77	(Onilude et al., 2012)
Lagos Ogun, Oyo, Niger Kaduna	47 Peanut cakes	AFB1= 100%	M=385.1 M=1428 M=588.4 M=557.3 M=151	[f] 236.52 [f] 877.28 [f] 361.38 [f] 342.28 [f] 92.74	-19.51 -72.38 -29.81 -28.23 -7.65	-273.63 -1015.15 -407.8 -395.93 -107.29	(Warth et al., 2012)
Lagos State	34 dried edible Mushroom	- AFB1 - AFB2	M =100 M=96.9	[n] 0.58	0.048	0.67	(Samson et al., 2013)
5 AEZs Nigeria	70 samples of stored maize	AFB1	26.5 - 15,489.6	[*] 26.99-9,880.56	*8.10 - 2,964.16	*124.62 - 45,602	(Adetuniji et al., 2014)
Ogun State	34 breakfast cereals and pastas	TAF	[a]R=0.8-3.5 (M= 1.3)	[o] 8.65	0.71	9.96	(Ezekiel and Sombie, 2014)
Kaduna State	260 peanut kernels	28.84%	R= 6 -28.75	[f] 3.69	0.30	4.21	(Wartu et al., 2015)
Ibadan/ Nigeria	Stockfish samples	NS	0.0 to 40	[p] 31.23	2.58	36.19	(Ogunleye and Olaiya, 2015)
Nigerian Markets	Sweet Potatoes Tubers and leaves	NS	M=2,208 M=2,180 ppb	[q] 433.53 [q] 428.04	- 35.77 - 35.31	- 501.68 - 495.23	(Oyewale, 2015)
6 Geopolitical Zones of Nigeria	Maize, Bitter, cocumber, Pepper, Bush mango and peanut	100%	MR= 3.2 ± 0.12 to 63.4 ± 1.79	[o] 21.28 -421.61	1.76 - 34.78	24.68 - 487.80	(Williams et al., 2015)

Table 3 continue

5 AEZ, Nigeria	38composite local rice	-AFB1 = 18.5% -TAF= 36.9%	M = 5	[g] 8.45	0.70	9.82	(Rofiat et al., 2015)
3 southwestern Nigerian States	24 Raw peanuts 24 Roasted Peanuts	89.6%	-AFB1: M = 60.2 -TAF:M = 112.9	[f] 36.97	3.05	42.78	(Afolabi et al., 2015)
Katsina	Spices and condiments	57%	0.7 to > 20ppb	[i] 0.035 to >1	0.0029 to >0.0825	0.041 to >1.16	(Haruna et al., 2016)
Port Harcourt	wheat, groundnut and their products	TAF	M=1.73±0.09 to 37.23±3.66	[o]11.50 - 247.58	0.95 - 20.43	13.32 - 286.54	(Felagha I, 2016)
Sokoto State	63 peanut kernels	TAF= 82.5%	0.9-646	- [f]0.55 - 396.75	- 0.046 - 32.73	- 0.65 - 459.05	(Salau et al., 2016)
Three AEZs, Nigeria	110 sorghum 87 millet samples	AFB1 - 3% AFB1 - 7%	MSD = 2.7 ± 253 MSD = 11 ± 55.4	[L] 4.93 [k] 16.07	- 0.41 - 1.33	- 5.75 - 18.65	(Hertveldt, 2016)
Ibadan / Nigeria	Dried Okra	AFB1 - 100% AFB2 - 100%	R=26.69-33.49 R=0.7 - 3.73	[s] 73.4	6.06	84.99	(Okigbo and Anene , 2017)
Minna	72 cow liver 50 goatliver	AFM1= 83.3% AFM=58%	M=1,464 M= 425	[m] 56.1 [m] 16.29	4.63 1.34	64.94 18.85	(Shamsudin et al., 2017)
9Northern States,Nigeria	78 ear rot infected maize samples	AFB1 = 63%	M = 0.8	[c] 0.8	0.066	0.93	(Ogara et al., 2017)
Ibadan / Nigeria	Dried Tomatoes	AFB1 - 100% AFB2 - 100%	R=853 - 1,430 R=472 -878	[t] 154.96 - 259.78	12.78 - 21.43	179.24 - 300.59	(Okigbo and Anene, 2017)
Nsukka	cold paps of maize and guinea corn, peanut butter	AFB1 = 100% AFB2 = 100%	MR=1.48 ± 0.24 to 2.31±0.6	-[o] 9.84 - 15.36 - [o] 9.44 - 14.43	- 0.81 - 1.27 - 0.78 - 1.19	- 11.36 - 17.81 - 10.94 - 16.69	(Onyeke et al., 2017)
Minna (Niger State)/ Nigeria	50 Pumpkin	AFB1 - 12% AFB2 - 2%	R=2.48 - 10.66 R= 0.00 - 3.44	- [s] 6.82 - 29.32	- 0.56 - 2.42	- 7.85 - 33.94	(Suleiman et al., 2017)
Three AEZs, Nigeria	373 processed cassava products	TAF	-R= 0.00-29.4	[r] 0.00 - 104.74	- 0.00 - 8.64	- 0.00 - 121.18	(Abass et al., 2017)
Minna (Niger State)/ Nigeria	25 Dried Bitter Leaf	AFB1 - 40% AFB2 - 44%	-R= 2.41 - 9.51 -R= 1.45 - 16.45	- [s] 6.63 - 26.15	- 0.55 - 2.16	- 7.71 - 30.29	(Suleiman et al., 2017)
Minna /Niger	25 Fresh Bitter leaf	AFG1 - 20%	-R=0.00 - 3.86	- [s] 0.00 - 10.62	- 0.00 - 0.88	- 0.00 - 12.34	(Suleiman et al., 2017)

Table 3 continue

Lagos	31 dry and 89 rainy season ginger	- AFS = 46% - AFs = 89%	-M= 3.13 -M=1.18	-i 0.16 - i 0.059	- 0.013 - 0.0014	- 0.18 - 0.02	(Lippolis et al., 2017)
Nigerian Markets	55 dried chilli sample	-AFB1= 96%	-H = 156	-[i] 7.8	0.64	8.97	(Singh and Cotty, 2017)
Minna (Niger State)	25 Dried Tomato	-AFB2 - 20%	-R= 0.72 - 8	-[t] 1.98 - 22	0.0014 - 1.82	0.02 - 25.53	(Suleiman et al., 2017)
Kaduna State	40 dried vegetables	-TAF	- R= 6.5 - 31.6	-[s] 17.88 - 86.9	1.47 - 7.17	20.62 - 100.56	(Nafisa *et al.*, 2017)
Minna /Niger	25 Fresh Tomato	-AFB2 - 24%	- R= 0.57 - 7.13	-[t] 1.57 - 19.61	0.13 - 1.62	1.82 - 22.72	(Suleiman *et al.*, 2017)
Four AZEs	84 peanuts	AFs = 39%	H=2.076; M= 216	-[f] 132.66	10.94	153.44	(Oyedele *et al.*, 2017)
Minna (Niger State)/ Nigeria	25 Spinach	AFB1 - 10% AFB2 - 14%	- R= 0.08 - 1.49 - R= 0.07 - 7.32	-[i] 0.004 - 0.075	0.00033 - 0.0062	0.0046 - 0.087	(Suleiman et al., 2017)
Lagos/ Nigeria	-27 roasted cashew nut -15 peanut samples	70.37% (19/27) 100%	R=0.1 to 6.8 R= 29 - 33.78	[f] 17.81 - 57.60	1.47 - 4.75	20.62 - 66.62	(Modupeade et al.,2018)
Lagos and Ogun states	family cereal, peanut butter, Tom bran, ogi and infant formula	AFB1 AFM1	MR = 2.4- 83.4 MR=9 - 5.4	* 2.5-51,192	0.21 - 4,223.34	2.95 - 4,886.75	(Ojuri et al., 2018)
Nigeria	53 household formulated, 84 industrial-processed complementary foods	69.8% 36.9%	- M ± SD= 72 ±14.4 - M ± SD = 4.1 ± 3.5)	* 641	52.88	741.65	(Ojuri *et al.*, 2019)

Note: Reported levels of AFB1 in foods (Mean or range) were used in computing the estimated primary cancer attributable to aflatoxins exposure/100,000 population. Where the level of AFB1 was not given, the levels of total aflatoxins or AFM1 were used. However, places where AFM1 was used, the values were divided by 10 since AFM1 is 10 times less carcinogenic than AFB1 (Ahlberg et al., 2018).

Where: AFB1 = Aflatoxin B1; AFB2 = Aflatoxin B2; AFG1 = Aflatoxin G1; AFG2 = Aflatoxin G2; AFM1 = Aflatoxin M1; AFP1 = Aflatoxin P1; H= Highest contamination value; M = Mean; MD = Median; MR = Mean Range; NC = Information of specific consumption data of the stated food per capita was not obtained; NS = Not stated; R = Range; SD = Standard deviation; TAF = Total aflatoxins;

[1] Estimated Level of dietary Exposure to AFB1 (ng/kgbw/day) = [level of contamination in food (ng/g) x Daily amount of food consumed perperson (g/day)] ÷ (Average Body weight (kg-bw)

[2]Attributable Primary Liver Cancer (HCC) per 100,000/year = Estimated Level of dietary Exposure to AFB1 (ng/kgbw/day) x the average Nigerian population potency estimate of 0.0825 cancers/100,000 population/year per ng/kg b.w./day (Adetunji, Atanda and Ezekiel, 2017)

[3]% Incidence of the HCC per 100,000 = Attributable Primary Liver Cancer (HCC) per 100,000/year X average liver cancer incidence in Nigeria = 7.13/100,000 population/year (WHO, 2014).

***** Exposure data was provided by the author; [a] Concentration expressed in ng/L; [b] Concentration expressed in ng/mg albumin

[c] to [v] represent information of average population's daily consumption of the stated food item per person (g/person/day) as follows:

c maize = 60g (Ranum et al.,2014);[d] Yam = 231.23g (Felix, & Aidoo, 2013);[e] Bread = 6.22g (Kilby);[f] Peanut = 36.85g (World Atlas, 2018);[g] Rice = 101.37 (Nzeka, 2018);h Milk = 22g (Knoema, 2019c);iSpices = 3g (Knoema, 2019d);j Wheat = 54.79g (USDA Foreign Agricultural Services, 2012); k Millet = 87.67g (FAOSTAT, 2015);[L] Guinea corn (Sorghum) = 109.58g (FAOSTAT, 2015);[m] Meat = 23g (Knoema, 2019b);[n] Mushroom = 0.35g (Adedokun and Okomadu, 2017);[o] Cereals = 23.8g (Knoema, 2019a);[p] Fish = 46.85g (Helgilibrary, 2013a);[q] potato = 11.78g (Helgilibrary, 2013b);[r] Cassava = 213.76g (FAO, 2004);[s] Vegetable = 165g (Knoema, 2019e);[t] Tomatoes = 10.9g (Adeoye et al., 2017).

CONCLUSION

Both the dietary aflatoxins and aflatoxin biomarkers from Nigeria signifies an increase in dietary exposure to aflatoxins. Hence, there is need for additional monitoring of marketed foods and the implementation of more stringent control and prevention strategies to reduce the high dietary exposure level to aflatoxins in the country.

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