

## An Overview of Mycotoxin Contamination of Foods and Feeds

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### Abstract

Mycotoxins contamination of foods and feeds remain a great challenge to food safety and of public health and economic significance. Mycotoxins occur in various foodstuffs, from raw agricultural commodities to processed foods with varying impacts on food processing. The major group of mycotoxins that contaminate foods and feeds include aflatoxins, fumonisins and patulin. Several studies conducted to reveal the metabolism of mycotoxins in the body are reviewed. Health implications of mycotoxins upon consumption of adequate doses are diverse. They include sub-acute mycotoxicosis, immune suppression, carcinogenicity, genotoxicity, morbidity and mortality in animals and humans as well as interaction with nutrient assimilation. Mycotoxicity of foods have tremendous effect on international trade, resulting in huge losses. There are regulations, though not in all countries, aimed at preventing and controlling Mycotoxins which operate only on industrially processed foods and those meant for exports but not locally processed ones. A number of strategies for preventing mycotoxins have been proposed but the awareness for implementation is very low. The use of media to create awareness is a viable option.

**Keywords:** Food; Feeds; Mycotoxins; Contamination; Mycotoxicity; Mycotoxin metabolism; Prevention

### Introduction

Mycotoxins are secondary metabolites produced by moulds which contaminate foods and have toxic effects on the health of humans and animals. Mycotoxins are produced primarily by the fungi which belong to *Aspergillus*, *Penicillium* and *Fusarium* genera. Fungi proliferate to produce secondary metabolites under favorable environmental conditions, when temperature and moisture are suitable. Fungi are a normal part of the micro flora of standing crops and stored feeds, but the production of Mycotoxin depend upon the fungi present, agronomic practices, the composition of the commodity and the conditions of harvesting, handling and storage [1]. The amount of toxin produced will depend on physical factors (moisture, relative humidity, temperature and mechanical damage), chemical factors (carbon dioxide, oxygen, composition of substrate, pesticide and fungicides), and biological factors (plant variety, stress, insects, spore load).

Several fungal metabolites which are toxic in experimental systems abound, however, there are only five that are of major agricultural importance: aflatoxin, produced by *Aspergillus flavus* and *A. parasiticus*; deoxynivalenol, produced by *Fusarium graminearum* and *F. culmorum*; fumonisin, produced by *Fusarium verticillioides* (ex-moniliforme); ochratoxin, produced by *Aspergillus ochraceus* and *Penicillium verrucosum*; and zearalenone, produced by various *Fusarium* species [2]. These toxins produced by fungal species remain stable throughout the processing periods and cooking of feeds and foods (aflatoxin [3], ochratoxin [4], fumonisin [5], deoxynivalenol [6]. Fungal infection and subsequent production of Mycotoxin can occur at the field during crop growth or harvesting, and may continue during storage. The occurrence of this Mycotoxin at a considerably high level of concentration in foods can cause toxic effects ranging from acute to

chronic (mutagenic, teratogenic, carcinogenic) manifestations in humans and animals [7]. Animals that have been fed with Mycotoxin-contaminated feeds release products which can be dietary sources of some Mycotoxin [8].

Human diseases arising from Mycotoxin cut across a large part of the globe without boundaries. There are thousands of fungal secondary metabolites currently known, but only a few groups are reported to be important from the safety and economic points of view; namely aflatoxins (AFs), mainly produced by *Aspergillus* species; ochratoxin A (OTA), produced by *Aspergillus* and *Penicillium* species, and zearalenone (ZEA), fumonisins (FUM) and trichothecenes (TCTs) (especially deoxynivalenol (DON)), primarily produced by many *Fusarium* species [9-11].

The economic impact of Mycotoxin is diverse, from loss of human and animal life to reduced livestock production, disposal of contaminated foods and feeds and investment in research [12]. As a result of deleterious effects of Mycotoxin on humans and farm animals, a good number of countries in the world have implemented several regulations which prescribe the limits of Mycotoxin in several food commodities intended for consumption. In 1993, the WHO-International Agency for Research on Cancer evaluated the carcinogenic potential of AFT, OTA, TCT, ZEA, and FUMs [13,14].

So many efforts have been made towards control and reduction of mycotoxin contamination of foods but the ubiquitous nature of toxigenic fungi enables their wide occurrence. It is also noted that in most rural areas of the world, no effort is made towards the control of toxigenic fungi in food contamination. The aim of this work is have a general overview of Mycotoxins contamination of foods.

### Foods implicated in mycotoxins contamination

Mycotoxins are reported to have occurred in many agricultural products ranging from raw to process, hence, becoming a worldwide

issue [15]. They have the capacity to remain stable during processing of foods [16], indicating difficulty of getting rid of them. Reports that mycotoxin is naturally fairly distributed as contaminants of many cereals, (Table 1) as well as other food commodities [17] and feeds [18,19] along the food chain. While AFB1 and OTA are among the most frequently observed mycotoxin in foods [20], the other types are occasional contaminants depending on the factor prevailing on their occurrences where they are located. Several authors indicated the prevalence of aflatoxigenic and ochratoxigenic mould growth and toxin production [21,22].

<b>Cereals</b>	Corn (grains, gluten); Rice; Wheat; Barley; Oats; Rye; Sorghum; Millet
<b>Cereal products for human consumption</b>	Cracked grains; Cereal cleanings; Wheat bran
<b>cereal feed products</b>	Corn bran; Rice bran

**Table 1:** Cereals contaminated by OTA [52,53].

### Major groups of mycotoxin in foods

**Aflatoxins:** These are the most prominent mycotoxins produced by species of *Aspergillus* [23-25] which are subdivided into AFB1, B2, G1 and G2 [26]. Aflatoxins are major contaminants of foods especially in the tropical region where the climatic factors favor their production. They are common among food commodities, such as: maize, spices, cereals, peanuts, pistachios, cotton and groundnuts. Of all these crops, they appear to be more common in cereal products for reason yet to be fully investigated. Cereal products are very popular foods in Nigeria which are processed into different types of drinks, fruits and snacks. The susceptibility of these foods, the aflatoxin contamination [27,28] is therefore of public health significance. Speijars and speijars, [20] reported a co-existence of AFB1 and OTA in food commodities indicating that foods may be contaminated by multiple mycotoxins at a time. Several factors may be responsible for the mixed growth of mycotoxin producing fungi occurring simultaneously in foods. There are reports that AFB1 is frequently found contaminating food while AFM1 is hardly present in foods except from animal feeds [29,30]. AFB1 which also contaminates feed stuffs are being transformed by lactating cows through the hepatic microsomal cytochrome P450 to AFM1 from where they find their way into the milk [31], this makes consumer of raw milk highly susceptible. There is a correlation between the level of AFB1 in feeds and AFM1 in milk [32]. AFM1 can be dictated in milk within 24 hours after consumption AFB1 infested feed [33]. AFM1 binds to casein where it is highly stable in the curd. The level of AFM1 in cheese can be affected by the technology applied in cheese production [34,35]. Since AFM1 is contaminants of milk, invariably, it can contaminate many dairy products [36-38]. The processing methods and ripening periods of cheese have not been found to reduce mycotoxins [39,40]. This is why the risk remains, not

only in commercially available milk but also other derived dairy products. Though, AFM1 concentration in cheese may vary based on cheese, water content and production technologies [32,37]. AFM1 contamination in animal feeds from different countries of the world has been reported [41-44]. AFM1 contamination of feed stuffs may be more divergent than is being reported. Ochratoxin A which was discovered in South – Africa in 1965 [45] has derivatives A, B and C [46-48] and are well documented as global contaminant of variety commodities and stable foods. Humans are directly and indirectly exposed to OTA through the food chain where contamination of the ingredient and food stuffs or through contamination of the feeds for animals meant for human consumption [49,50]. Toxins like citrines produce by *Penicillium citrinum* is now produced by several species of *Penicillium* and *Aspergillus* some of which are found in feeds [51]. From the foregoing there seems to be the existence of new forms of mycotoxins yet to be identified in feeds and foods.

**Patulin:** Patulin (PAT) was discovered in 1943 in relation to *P. griseofulvum* and *P. expansum*. The molecule was first studied as a potential antibiotic, but the subsequent research demonstrated its toxicological properties [54,55]. Patulin is a toxin produced by, *Aspergillus*, *Penicillium*, and *Paecilomyces* fungal species. *P. expansum* is a common contaminant of spoiled fruits and vegetables, as well as rotting apples and Figs [56,57]. These mycotoxins can be found in different food products and raw materials, but apples and apple by-products are of greatest concern regarding PAT accumulation: the frequency of contamination in other food resources and products is much lower than in apple processing [58].

**Fumonisin:** A product of *Fusarium* species, notably *F. verticillioides*, *F. proliferatum*, *F. anthophilum*, *F. nygamai* as well as *Alternaria alternata* [59-61]. Fumonisin found in food are produced mainly in the field before harvesting. Fumonisins remain stable during this period due to temperature and moisture conditions which are important factors for *Fusarium* infection and toxin production [61]. Fumonisin, like other mycotoxins, infect corn-based foods and feeds and their occurrence has also been reported in other products, such as: rice and sorghum [62].

Fumonisin B1 and B2 have been reported in “black oat” feeds from Brazil and forage grass in New Zealand. FB1 and FB2 have been found in rural areas of South Africa, in homegrown corn produced and consumed by the people living in those areas. Commercial corn based human foodstuff from retail outlets in several countries contain fumonisins [63].

### Biosynthesis of mycotoxins

Table 2 shows mycotoxigenic fungi and their related mycotoxins among which the biosynthesis of mycotoxins by the major toxigenic species (Table 3) are selectively discussed.

<b>Mycotoxin</b>	<b>Produced species</b>	<b>Commodities</b>
Aflatoxins	<i>Aspergillus flavus</i> , <i>A. parasiticus</i> , <i>A. nomius</i> , <i>A. bombycis</i> , <i>A. ochraceoroseus</i> , <i>A. pseudotamari</i>	Nuts, spices, Cereals, maize, soybean, rice
Ochratoxin A	<i>Penicillium verrucosum</i> , <i>P. aurantiogriseum</i> , <i>P. nordicum</i> , <i>P. palitans</i> , <i>P. commune</i> , <i>P. variabile</i> , <i>Aspergillus ochraceus</i> , <i>A. melleus</i> , <i>A. niger</i> ,	Cereals, fruits, spices, coffee, Food of animal origin

	<i>A. carbonarius, A. sclerotiorum, A. sulphureus</i>	
Citrinin	<i>Penicillium citrinum, P. verrucosum, P. viridicatum, Monascus purpureus</i>	Oats, rice, corn, beans, fruits, fruit and vegetable juices, herbs and spices
Zearalenone	<i>Fusarium graminearum, F. sporotrichoides, F. culmorum, F. cerealis, F. equiseti, F. incarnatum</i>	Maize, soybean, cereals
Deoxynivalenol	<i>Fusarium graminearum, F. culmorum, F. crokwellense</i>	Maize, soybean, cereals
Alternariol, alternariol monomethyl ether	<i>Alternaria alternata, A. brassicae, A. capsici-anui, A. citri, A. cucumerina, A. dauci, A. kikuchiana, A. solani, A. tenuissima, A. tomato, A. longipes, A. infectoria, A. oregonensis</i>	Vegetables, fruit, cereals, soybean
Tenuazonic acid	<i>Alternaria alternata, A. capsici-anui, A. citri, A. japonica, A. kikuchiana, A. mali, A. solani, A. oryzae, A. porri, A. radicina, A. tenuissima, A. tomato, A. longipes</i>	Vegetables, fruit, cereals, soybean
Fumonisin	<i>Fusarium proliferatum, F. verticillioides</i>	Maize, soybean, cereals

**Table 2:** Mycotoxigenic fungi and mycotoxins [64-72,80].

Aflatoxin	Zearalenone	Deoxynivalenol		Fumonisin	Ochratoxin A
Tested samples	11,967	15,533	17,732	11,439	7,495
Positive samples	3,142	5,797	9,960	6,204	1,902
Percentage of positives	26%	37%	56%	54%	25%
Average positives (µg/kg)	57	286	1,009	1,647	14
Median positives (µg/kg)	11	85	453	750	2.6
1 <sup>st</sup> quartile positives (µg/kg)	3	43	234	332	1.1
3 <sup>rd</sup> quartile positives (µg/kg)	40	225	972	1,780	6.2
Maximum (µg/kg)	6,323	26,728	50,289	77,502	1,589
Sample origin	Myanmar	Australia	Central Europe	China	China
Sample type (analysis year)	other feed (2012)	silage (2007)	wheat (2007)	finished feed (2011)	finished feed (2011)

**Table 3:** Summary of the global survey of mycotoxins [73].

Trichothecenes pathway begins with an enzyme trichodiene synthase which cyclize farnesyl pyrophosphate (FPP) to trichodiene. The enzyme possesses sub-units molecular mass of 45 kDa and usually isolated from *Fusarium sporotrichoides* [73]. The subsequent pathway

involves esterification and oxygenation of trichodiene diacetoxyscirpenol, T-2 toxin and 3-cetyldeoxynivalenol [74]. The genes involved are: tri 5; Tri 4 and Tri 3 [75].

Fungal species	Mycotoxins
<i>Aspergillus flavus; Aspergillus parasiticus</i>	Aflatoxins
<i>Aspergillus flavus</i>	Cyclopiazonic acid
<i>A. ochraceus; Penicillium viridicatum; P. cyclospium</i>	Ochratoxin A
<i>P. expansum</i>	Patulin
<i>Fusarium culmorum; F. graminearum; F. sporotrichoides</i>	Deoxynivalenol
<i>F. sporotrichoides; F. poae</i>	T-2 toxin
<i>F. sporotrichoides; F. graminearum; F. poae</i>	Diacetoxyscirpenol
<i>F. culmorum; F. graminearum; F. sporotrichoides</i>	Zearalenone

<i>F. moniliforme</i>	Fumonisin
<i>Acremonium coenophialum</i>	Ergopeptide alkaloids

**Table 4:** The major toxigenic species of fungi and their principal mycotoxins [81].

Fumonisin is synthesized by the condensation of the amino acid alanine to an acetate-derived precursor. Structurally, they possess C-20 diester of propane-1, 2, 3 tricarboxylic acid and peritahydroxylcosane with primary amino group. The enzyme adenosyl methionine transferase is attached to the C-12 and C-16 of the branched chain methyl group [76], though, the isolation of this enzyme has not been documented [77].

The biosynthetic pathway of Aflatoxin has been well documented [78-80]. A polyketide synthase converted to norsolorinic acid by a fatty acid synthase. Conversion of enzymes occurs up to 12-17 ways with series of intermediates in polyketide. Then, AFB1 and AFG1 are produced after the formation of versicolorin B. Several enzymes that occur in aflatoxin and sterigmatocystin biosynthetic pathway are: O-methyl transferase; fatty acid synthase; polyketide synthase; desaturase; versicolorin B synthase; versicolorin hemiacetal acetate reductase; and norsolorinic acid reductase. The genes involved in aflatoxin are: fas1A, fas 2A; pksA; nor1, norA, avA; avf1, vbs, ver B; ver1A; afls; omtA and ordI. For sterigmatocystin biosynthesis are: stc J and stc K; stc A; stcE; stc F; stcI; stcN; stcL; stcS; stcU and stcP [81,82]. Different enzymes involved in aflatoxin biosynthesis have been documented [83,84]. The global summary of mycotoxin production by fungi is presented on Table 4.

### The metabolism of mycotoxins

Coker [85] reported that metabolism of aflatoxin B1 can be used to give an illustration with regards to the metabolic process in determining mycotoxin toxicity, and also as a means of determining exposure to mycotoxins, by measuring; mycotoxin-macromolecular conjugates, the parent mycotoxin and a biochemical change initiated by the mycotoxin, respectively.

**Metabolism of aflatoxin:** Much of the studies carried out to determine the metabolic fate of aflatoxins both *in vivo* and *in vitro* with the use of animal tissues have been conducted mainly on aflatoxin B1. Studies involving the measurement of aflatoxin B1, and its metabolites, in blood, urine, milk and isolated tissues are limited. Metabolism has been studied in many species and under many different conditions [86,87]. Under natural conditions, exposure to the aflatoxins may occur by ingestion of food contaminated and by the inhalation of contaminated dust particle contaminated with the fungal toxin. In addition to these natural routes, intraperitoneal (ip), intravenous (iv) and dermatitis administration have been used under experimental conditions. The completeness of absorption of aflatoxin B1 after oral exposure have been shown using radiolabelled aflatoxin B1 in rats and monkeys which demonstrated little difference in the distribution and excretion of the toxin after either oral or intraperitoneal administration [86-88]. Aflatoxin B1 can also be absorbed rapidly, by passive diffusion, from the small intestines (especially the duodenum) into the mesenteric venous blood. The composition of the intestinal epithelium is an important criterion since aflatoxin B1 is lipophilic in nature. Although the liver is regarded as the main site of aflatoxin transformation, gastrointestinal metabolism will reduce the exposure of the liver to aflatoxin B1 and, in terms of

hepatic toxicity, is an important means of detoxification [89,90]. After absorption, aflatoxin B1 is transformed resulting in the activation and detoxification of the toxin and the process is known to occur in two phases [91]. The toxin is first transformed to a selection of metabolites and, then the metabolites are converted to either water soluble conjugates or macromolecular adducts [92]. Several factors including the genetic make-up of the species, nutritional and health status, and exposure to metabolic modifiers in foodstuffs affect the modulation of the transformation process [93].

The major metabolites of aflatoxin B1 includes aflatoxin B1-8,9-epoxide, -8,9-dihydro-8,9-diol; the aflatoxins-B2a, -P1, M1-Q1; aflatoxicol, aflatoxicol H1 and aflatoxicol M1 [94,95]. However, not all metabolites have been identified in all species.

Aflatoxin B1 gets activated in the liver where the toxin is seen to interact with both DNA and protein to elicit the carcinogenic and acutely toxic effects of aflatoxin, respectively. Initially, aflatoxin B1 is converted, by cytochrome P450, to the highly reactive aflatoxin B1-8,9-epoxide which in turn may be converted to aflatoxin B1 -dihydrodiol [85,96,97]. Aflatoxin B1 is converted to at least seven metabolites, including a proposed unstable metabolite, the aflatoxin B1 -8, 9-epoxide, which is the so called ultimate carcinogenic form [89,98]. The carcinogenicity of aflatoxin B1 arises from interaction with guanine moiety of DNA, to produce the aflatoxin-N7-guanine adduct [96], while the acute toxicity of aflatoxin B1 arises from interaction between the dihydrodiol and protein amino groups to produce Schiff base adduct [99]. The 8,9-dihydro-8-9-diol; the aflatoxins -B2a,- P1, M1, - Q1; aflatoxicol, aflatoxicol H1 and aflatoxicol M1 are the major metabolites of aflatoxin B1 [94,100]. However, not all metabolites have been identified in all species. Aflatoxicol is a major aflatoxin B1 in rat plasma [101]. It is reported as having equivalent carcinogenic potency as aflatoxin B1 [102,103], and about 70% the mutagenicity [104,105]. This aflatoxicol may act as a reservoir for aflatoxin B1, *in vivo*, thereby prolonging the lifetime of the toxin in the body since aflatoxicol can be readily converted back to aflatoxin B1.

### Health implications of mycotoxins

**Subacute chronic toxicity and growth faltering:** Subacute mycotoxicoses which are toxic effects by mycotoxins occur with a lot of symptoms in humans and they include moderate to severe liver damage, reproductive problems, appetite loss, digestive tract discomfort, diarrhoea, growth faltering, immune suppression, increased morbidity, and premature mortality [106]. Aflatoxin is also implicated in the degenerative diseases childhood hepatic cirrhosis and Reye's syndrome [107]. Aflatoxins have been shown to pass from mother to fetus through the placenta, thus having the potential to affect prenatal infant development [108].

**Immune suppression: Increased morbidity and mortality in animals and humans:** In 1993, the International Agency for Research on Cancer reported that Aflatoxin B1 is hepatotoxic in humans and animals and is nephrotoxic and immunosuppressive in animals. Experimentally exposing animals to a chemical family of Fusarium



toxins called trichothecenes causes severe damage to actively dividing cells in bone marrow, lymph nodes, spleen, thymus, and intestinal mucosa [109]. These trichothecenes can be immune suppressive at lower doses [101]. Miller and Trenholm [106] concluded that mycotoxins are likely to be immunotoxic to humans as well following their studies on animals. Pestka and Bondy [101] dismissed the problem for the developed world with the reason that the high doses of mycotoxins might be most likely encountered in animal feed that is not inspected for interregional or international commerce. However, human food is regulated at the low parts per billion ranges in Canada, the United States, and most developed countries because of potent hepato carcinogenicity of aflatoxins. Thus, vigilant monitoring should minimize the potential for aflatoxin-induced immune suppression in humans." Monitoring is effectively done in the developed world. In the developing world, except in cases of exports of vulnerable commodities such as groundnuts or coffee to the developed nations, monitoring of internal food supplies is rarely implemented [109].

**Interaction with nutrient assimilation:** Hendrickse [110] reported that protein–energy malnutrition, kwashiorkor, and aflatoxin exposure appear to be seasonally linked in tropical regions where aflatoxins are present. However, research has shown that there is no specific cause-and-effect relationship between aflatoxin and kwashiorkor, but children with kwashiorkor who had tested positive for aflatoxin in blood and urine had statistically significantly longer hospital stays and suffered from more infections [111,112]. Thus, aflatoxin acted in conjunction with kwashiorkor, possibly by immune suppression, to worsen the prognosis [113]. Vitamins are thought to ameliorate genotoxicity, and aflatoxin B1 interacts with assimilation of vitamins A and E.

**Carcinogenicity and genotoxicity:** To underscore the correlation between cancer and aflatoxin, the incidence of primary liver cancer and the intake of aflatoxins in the same population groups has been demonstrated in Swaziland [114] and corroborated by data from Mozambique [115]. In China, maize was the major source of aflatoxin exposure hence a correlation was established in mortality rate from liver cancer in high risk area with food contamination recording 372/100,000 as against low risk area with 33/100,000 [116].

Human exposure to ochratoxin primarily occurs from whole grain breads, although coffee and wine are also implicated when fungi infect the berries and grapes. Marasas [117] suggested that levels of 100–200 ppb would be safe for humans consuming large amounts of contaminated maize.

Acute aflatoxicosis (severe aflatoxin poisoning) occurs in poultry, swine, and cattle consuming feeds contaminated with aflatoxins. The same can appear in humans, and cases of lethal toxic hepatitis attributed to consumption of aflatoxin-contaminated maize have occurred [107,117,118]. Large-scale acute human toxicoses due to consuming wheat and rice contaminated with deoxynivalenol have occurred in modern times in India [119] China, and Korea, among other countries [120].

### Effect of food mycotoxicity on international Trade

All EU member states have regulations for 12 mycotoxins. In Africa, 15 countries have regulations. That means most countries in Africa have no regulations even when such regulations are needed. Having no regulation is not that mycotoxin problems do not exist. On the other hand, regulations for small-scale and subsistence systems is a complete failure. Considering export compliance with food safety and quality

standards, a total of USD1.2 billion was observed to be involved. The World Bank estimate of losses in trade amount to USD450 million. In an effort to meet standard, some countries put in place relevant institutions for regulations and export the best quality produce while the poor quality ones are domestically consumed. This in itself compromises food safety regulations. Imported products with high risk of mycotoxin contamination include maize, cereals, coffee, spices, peanuts, pistachio nuts and other nuts spread through many continents. However, prevalence rate differ from one part of the world to the other.

**Regulation and prevention of mycotoxins:** The world's food crops have been significantly contaminated with mycotoxins. Significant losses due to mycotoxins and their impact on human and animal health have been linked with national economic implications and all these factors have combined to make mycotoxins important worldwide [74]. Many international agencies are trying to achieve universal standardization of regulatory limits for mycotoxins. Currently, over 100 countries are said to have regulations regarding mycotoxins in the food industry [121] which is a good development for all the nations of the world to do the same. From the studies of food-based mycotoxins in the last century, limits are being set. Hence, statutory levels of a range of mycotoxins permitted in food and animal feed are set by a range of European directives and EC regulations [25,48,122] in consultations with the Scientific Committee for Food, based on the analysis of scientific data collected by EFSA and the Codex Alimentarius (Table 5). This has resulted in the establishment of aflatoxins limits in many other countries to protect consumers from harmful mycotoxins that can contaminate foods. The Commission Regulations is of the opinion that the maximum levels should be set at a strict level which is reasonably achievable by following good agricultural and manufacturing practices and taking into account the risk related to the consumption of food. Such good agricultural and manufacturing practices require strict monitoring for improvement in compliance. Health protection of infants, young children and immune-compromised who belong to the vulnerable group of consumers require establishing the lowest levels of mycotoxins, which can be achieved through selection of raw material ingredients used for foods production. With the development of international trade, there is corresponding progress in research focused on mycotoxin food contamination and their toxicological properties. This has resulted in modified changes in the mycotoxin-related legislation across the European Union. The Commission Regulation 466/2001 [123] setting the maximum levels for certain contaminants in foodstuffs has been substantially amended many times to cope with recent understanding of mycotoxins contamination of foods and feeds. Currently, reports indicate that maximum levels for mycotoxins in foods are specified by the Commission Regulation EU 1881/2006 and the Commission Regulation EU 105/2010 as regards OTA, the Commission Regulation EU 165/2010 as regards aflatoxins, and the Commission Regulation EU 1126/2007 as regards *Fusarium* toxins [124-126]. Similarly, maximum levels for aflatoxins, *ochratoxin A*, *patulin*, and *Fusarium* toxin (fumonisin, deoxynivalenol, zearalenone) in different products: nuts, cereals, dried fruit, unprocessed cereals, processed cereal-based food, coffee, wine, spices, and liquorices are established. Many raw and processed foods not listed may also be contaminated by mycotoxins. Regarding total aflatoxins (i.e., sum of AFB1, AFB2, AFG1, and AFG2) in human food, EU maximum limits are 4 g/kg for peanuts and other oilseeds, tree nuts, dried fruits, cereals, and processed products thereof, intended for direct human consumption or use as ingredient in foodstuffs; 10 g/kg for tree nuts, dried fruits, maize and rice subjected

to sorting, or other physical treatment, before human consumption as well as spices, dried figs, almonds, pistachios, apricot kernels, hazelnuts, and Brazil nuts intended for direct human consumption; and 15 g/kg for peanuts and other oilseeds, almonds, pistachios, apricot kernels, hazelnuts, and Brazil nuts subjected to sorting, or other physical treatment, before human consumption [124]. The FDA action level is 20 g /kg for total AFs in peanuts, Brazil nuts, pistachios, and

other foods for direct human consumption [127]. Though all the limits set by the regulatory bodies followed the results of intensive research over the years, there is no doubt that constant review of these mycotoxins maximum limits in foods is important because of the development of mutant strains of fungi likely to produce more potent toxins.

Toxin	Product	Maximum limit (µg/kg)
Aflatoxin	Peanuts, oilseeds, cereals, processed products	4
	Tree nuts, dried fruits, maize, rice, spices, almonds, pistachios, hazel nuts	10
Fumonisin	Processed cereal-based foods	200
	Infant baby foods	400
	Unprocessed maize	800
Trichothecenes	Processed cereal-based foods	200
	Pasta	750
Ochratoxin A	Processed cereal-based foods	0.5
	Wine, grape juice, grape nectar/must	2
	Roasted/ground coffee beans	5
	Spices	20
Patulin	Apple juice	10
	Solid apple products	25
	Spirit drink, cider	50
ZEA	Bread, pastries	50
	Biscuits, cereals, snacks	75

**Table 5:** European Commission maximum limits for mycotoxins in foods [124,127].

The EC and the FDA have at times variable mycotoxins limits for the same food commodity. This position need to be harmonized since maximum limits of mycotoxins in foods and feeds all bother on issues of human health and safety. This can be done by having inter agency committees to generally assess all maximum limits from various agencies and adopting a common position.

### Strategies for prevention of mycotoxins

Many control strategies for mycotoxins contamination of foods have been proposed and implemented with varying degrees of successes. Suggested strategies include good agricultural practices (GAP), good manufacturing practices (GMP), biological control and transgenic approaches. These approaches are designed for mycotoxins control programs that will have economic impact as well as health improvement in the region. Many developing countries are gradually getting to know that reducing mycotoxin levels in foods will improve international trade advantages with a concomitant long-term health benefit to the local population. In most countries of the world, there is lack of understanding about mycotoxins contamination of foods. The focus on mycotoxin research should be centered on toxicity, exposure, mitigation impact and analytical aspects. A public private partnership to achieve this focus has been advocated. Under this arrangement, there should be a science driven body with volunteering scientists and public interest that will have a scientific discussion on the way forward for the control of mycotoxins in food and feeds. This is based on the fact that improvement of scientific knowledge in mycotoxins exposure

and mitigation of contaminants in foods will ensure safer food products. Public health must be maintained through adversary on the scientific knowledge of mycotoxins and the extent of the impact of their potential risk to health. This scientific framework when developed should not be localized but exchanged and reviewed as frequently as possible to handle issues of analytical methods and emerging mycotoxins

Advocating good manufacturing practices is quit broad and it involves the physical food processing methods which are believed to reduce mycotoxins to a reseanable extent. Such methods include sorting, dehulling, milling, dewatering, enzymatic and microbial activities like malting processes in the brewery operations, fermentation etc. These are areas that require further investigations on how they reduce the risk of mycotoxins contamination.

Natural products have also been proposed to reduce mycotoxins. Eugenol has been found to inhibit aflatoxin production but does not affect fungal growth. It acts at the transcriptomic level, thereby blocking the biosynthetic pathway which occurs at the early stage. Many more natural products of plant or animal origin may be evaluated in this same direction.

Biotransformation can be used to mitigate mycotoxins by identifying the metabolites formed during biotransformation and verify that that the metabolites are non-toxic.

Education and extension services where regular programs on radio and televisions on mycotoxin hazards and discussion on the issue should feature regularly on daily newspapers and magazines has been proposed [79].

There are diverse opinions on the use of chemicals to control mycotoxins. Some researchers said seed fumigation with ethylene oxide and methyl formate was found to significantly reduce the incidence of fungi including toxigenic species on stored groundnuts and melon seeds. Bankole [128] and Kavita and Reddy [129] reported that sodium chloride (2.5, 5.0 and 10.0%), propionic acid (1.0, 2.5 and 5.0%), acetic acid (1.0, 2.5 and 5.0%) inhibited aflatoxin B1 production in *A. flavus* inoculated groundnuts and maize kept in gunny bags. FUMs contamination could be reduced by application of fungicides that have been used in control of Fusarium head blight, such as prochloraz, propiconazole, epoxyconazole, tebuconazole cyproconazole and azoxystrobin [130]. On the other hand, application of fungicides has been shown to effectively control the AF producing *Aspergillus* species [131]. Chemical reduction of FUM toxicity can be achieved through the use of allyl, benzyl and phenyl isothiocyanate in model solution and in food products [132]. The BEA reduction varied from 10% to 65% in wheat flour and was dose-dependent with allyl isothiocyanate [133]. A contrary opinion to all these indicate that chemical detoxification lead to potential toxic metabolites, reduction in nutritional value and changes to food products.

Biological control programs using microorganisms to detoxify mycotoxins are other measures that are widely used. The International Institute for Agricultural Research (IITA) has pioneered this technique in Nigeria, by the development of its product called Aflasafe. Aflasafe has proven successful and is being tried on a number of crops [134]. Other reports of biological control is the introduction of a toxigenic strains of *A. flavus* and *A. parasiticus* to soil of developing crop resulting in 74.3 to 99.9% reduction in aflatoxin contamination of peanuts in the US [135] and 68-87% reduction in aflatoxin contamination in cotton seed [136]. *Saccharomyces cerevisiae* reduced the AFB1 concentration in peanuts by 74.4% [137,138]. Control of FUM-producing fungi by endophytic bacteria has also been reported [139]. *Trichosporon mycotoxinivorans* used as an OTA deactivator in broiler feeds has been recently reported [140]. Lactic acid bacteria, such as *Bifidobacterium bifidum* and *Lactobacillus rhamnosus*, are suggested to be a promising biological control strategy for PAT in aqueous solutions [141]. Fungal strains of *Trichoderma* have also been shown to control pathogenic fungi through mechanisms, such as competition for nutrients and space, fungistasis, antibiosis, rhizosphere modification, mycoparasitism, bio fertilization and the stimulation of plant-defense mechanisms [142].

Generally, mycotoxin contamination of agricultural products can be prevented using

#### 1. Pre-harvest methods:

- a. using resistant varieties
- b. field management
- c. use of biological and chemical agents
- d. harvest management

#### 2. Post-harvest methods:

- a. improved drying methods
- b. good storage conditions

- c. use of natural and chemical agents
- d. irradiation.

#### Other methods include

- Collection of a database of predominant fungi and mycotoxins in Nigeria.
- Construction of a Mycotoxin Occurrence Map to know the areas prone to Mycotoxin contamination.
- Establishment of a permanent culture collection center.

Good Agricultural practices (early planting and use of recommended crop production practices, irrigation to reduce drought stress, early harvesting, prevention of kernel damage during harvesting), Storage (adequate drying and proper storage below 13% moisture, and keeping storage facilities clean and dry) and Good Manufacturing Practices.

#### Conclusion

Mycotoxins contamination of food commodities remain a worldwide menace. Prevalence rate on foods and feeds differ from one region to another due to geographical factors that affect the growth of fungi and subsequent toxin production. Mycotoxins have occurred in many foods largely unknown to a number of consumers. Mycotoxins contamination of foods has adversely affected human health and international trade. Till now, not many countries have legislation on mycotoxin contamination of foods which does not mean absence of mycotoxins on foods in those countries. Several control strategies have been suggested through research but not fully implemented by the public. The use of media to create the much needed awareness is a good strategy for control and reduction of mycotoxin contamination of foods and feeds.

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