PREGLEDNI RAD / REVIEW

Occurrence of aflatoxins in Nigerian foods: a review

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Abstract

Aflatoxins are a family of poisonous, mutagenic, and carcinogenic mycotoxins that contaminate a wide range of foods and agricultural goods. Aspergillus species, such as Aspergillus flavus, and Aspergillus parasiticus are the most common producers. Aflatoxin generation can occur at any point of the food chain, including pre-harvest, drying, storage, transit, processing, and handling, if conditions are favourable for fungus to create toxins. It is classified into six main types which are Aflatoxin B1, Aflatoxin B2, Aflatoxin G1, Aflatoxin G2, Aflatoxin M1 and Aflatoxin M2. In Nigeria, Aspergillus species that produces aflatoxin has been isolated from agricultural products such as cereals, spices, locally fermented food, oil-seeds, and animal products. Aflatoxin contamination is high due to poor storage of food crops and lack of awareness of aflatoxins contamination among farmers, marketers and the consumers of these goods. Locally fermented foods such as ogiri, ugba, ogi-baba, and iru have been said to be contaminated by aflatoxin. Preventive measures should be carried out by the policy-making bodies to create awareness and sustain ongoing measures to effectively manage aflatoxin contamination in Nigeria so as to reduce the health risk of aflatoxins on the people and economy of the country.

Keywords: aflatoxins, mycotoxins, food

Introduction

The most studied mycotoxin found in agricultural products is aflatoxins (AFs). Aflatoxins are a family of poisonous, mutagenic, and carcinogenic mycotoxins that contaminate a wide range of foods and agricultural goods, with a particular predilection for grains and nuts. Aspergillus species such as Aspergillus flavus, Aspergillus parasiticus and Aspergillus nomius are the most common producers. In humans, aflatoxins (AFs) have been reported to cause hepatic toxicity, nephron toxicity, and immunological suppression (Liu et al., 2022). Aflatoxins are chemically and biologically active secondary metabolites produced by moulds that grow in soil, cereals, nuts, fruits, decaying vegetation, hay, and grains, with an unknown role in fungal development (Iram et al., 2016). Aflatoxin generation can occur at any point of the food chain, including pre-harvest, drying, storage, transit, processing, and handling, if conditions are favourable for fungus to create toxins. The 'dry chain' refers to the stages of the value chain responsible for suppressing aflatoxin-producing fungus after harvest while preserving appropriate conditions, particularly low humidity (Massomo, 2020a). Aflatoxin synthesis in agricultural products is also known to be enabled by plant immune compromising variables such as drought stress, damage, pest infestation, and poor fertilization. Aflatoxins are crystalline furanocoumarin molecules. Although 20 compounds have been identified as aflatoxins, the term aflatoxins usually refers to four compounds from the group of bis–furanocoumarin metabolites generated by A. flavus and A. parasiticus known as B1, B2, G1 and G2, and found in agricultural products (Sumon et al., 2021). Aflatoxin M1 is a 4–hydroxyl derivative of AFB1 and aflatoxin M2 is a 4–dihydroxyl derivative of AFB2. It is also a metabolite seen in the milk of humans and animals who consume aflatoxins B1 and B2. Aflatoxin B1 (AFB1), aflatoxin G1 (AFG1), aflatoxin M1 (AFM1), aflatoxin B2 (AFB2), and aflatoxin G2 (AFG2) are among the 20 distinct varieties that have been identified (Kumar et al., 2017). B-type AFs are pentanone derivatives that fluoresce brightly blue when exposed to UV light. The G-series AFs, on the other hand, are six-membered lactones that glow yellow-green, when exposed to UV light, hence the B and G names (Bennett and Klich, 2003). Aflatoxin G2 and B2 are congeners of Aflatoxins G1 and B1 that lack the 8, 9-double bond in the furan ring and are consequently only found in pairs (Chun et al., 2007). Aflatoxins M1 and M2 are blue-violet fluorescent metabolic products of B1 and B2 that are commonly seen in urine and milk of animals fed AFB1-contaminated meals. Aflatoxins are mutagenic, genotoxic, immunosuppressive, carcinogenic, and teratogenic in the order AFB1, AFB2, AFG1, AFG2 and AFM1 (Kumar et al., 2017). Aspergillus species may grow at temperatures ranging from 6 to 54 ºC. Temperatures of 35 to 37 °C are ideal for growth. The ideal temperature for the synthesis of fungal toxin is 28 to 33 °C. Water activity (aw) of 0.78 to 1 is optimal for Aspergillus species, with a maximum of 0.95. Aflatoxigenic species can produce toxins of 0.83 to 0.97 with 0.90 to 0.95 being the optimum water activity for toxin formation. Aspergillus flavus thrives in temperate and semi–warm, moist environments, while Aspergillus parasiticus thrives in warm, moist environments. Aspergillus flavus is more dependent on higher plants, while Aspergillus parasiticusis is more dependent on soil (Aliyu et al., 2016).
Although Aspergillus section Flavi individuals have been isolated from soil, air, and other natural environments, their taxonomic position and precise identification have been a source of debate (Razzaghi-Abyaneh et al., 2010; Agustina and Dinorah, 2020). Aflatoxin risk models could help large aggregators establish these relationships by lowering the risk of buying from farmers in low-risk areas. Traders in developing countries earn two-thirds of the value of farm commodities, and they bear the brunt of spoilage losses. As a result, traders must be addressed in any aflatoxin intervention, despite the fact that the harvesting and storage circumstances in which the items are received are the key determinants of fungal development throughout transportation. Focusing early in the supply chain is optimal, especially as the financial cost of investing in storage, drying, and testing equipment has been proven to be covered by the recovery of postharvest loss (Massomo, 2020a). To detect high-risk aspects in the supply chain, a

well-integrated holistic process for aflatoxin control is required (Keller et al., 2021).

Aflatoxin contamination rates can be particularly high across the African continent (Darwish et al., 2014) with studies showing that 90% of maize samples in East Africa and as high as 99% of samples in West Africa have evidence of high levels of aflatoxins during the time periods assayed (Massomo, 2020).

Occurrence of aflatoxins in foods

Aflatoxin has been thoroughly investigated in agricultural products such as cereals (sorghum, barely, maize, rice, and wheat), spices (turmeric, coriander, ginger, black pepper, and chili), and fat-containing crops such as tree nuts (Brazil nuts, pistachios, almonds, and walnuts), peanuts, and oilseeds (soybean, sesame, cotton, and sunflower). Aspergillus species, which create aflatoxins, have a strong affinity for grains and oilseeds. Peanuts, in particular, are very sensitive to Aspergillus growth (Perrone and Gallo, 2017)and at the moment comprises 339 known species. It is one of the most important economically fungal genus and the biotechnological use of Aspergillus species is related to production of soy sauce, of different hydrolytic enzymes (amylases, lipases. The most common foods linked to aflatoxicosis include corn, peanuts, and cotton. The largest rates of Aspergillus infection in these materials occur during pre–harvest, harvest, and storage. Under high water pressure, high ambient temperatures, mechanical damage during harvest, insect stings, rain during harvest, and storage under hot and humid circumstances, the risk of aflatoxin contamination in grains is significant. Mould growth is easier on damaged grains (due to mechanical damage during harvesting or insect damage). Mould grows faster in a warm, damp atmosphere (Golge et al., 2013)a total of 182 chilli samples were collected from two provinces of Turkey and checked for aflatoxins (AFs. Aflatoxins have been found in a variety of foods, according to several researches. Furthermore, aflatoxin indicators have recently been discovered in serum and urine samples (Hatem et al., 2005; Jager et al., 2016), providing further information for measuring aflatoxins exposure in Nigeria (Habibi et al., 2019). Aflatoxin has been found practically in every region of the country in Nigeria. Aflatoxin contamination is most common in peanuts, cereals, spices, locally fermented foods, and their food products.

Occurrence of aflatoxins in maize

Cereals are the primary source of nutrition for a vast section of the global population (Awika et al., 2011). In America and Asia, wheat accounts for up to 14.1 and 24.3% of total calorie intake, respectively, whereas rice accounts for up to 28.5% of total calorie intake in Asia (Andrade and Caldas, 2015). Wheat and maize provide 30% of daily energy for Africans. Cereals also make up a substantial component of newborn formulae around the world (Nicklas et al., 2020). Cereals also account for a major component of animal feed in all parts of the world (Alvarado et al., 2017). Aflatoxin contamination is unfortunately common in cereals and cereal-based goods. Maize (Zea mays) is one of the principal human-exposure vectors to aflatoxin because of its widespread production and consumption. Several occurrences of aflatoxicosis have been linked to tainted maize (Muthomi et al., 2009). As a result, dietary data relating to maize is an important part of many aflatoxin risk and exposure evaluations. Maize, being a staple meal in countries where climatic conditions are favourable for fungal growth and aflatoxin formation, maize-induced human and animal aflatoxin exposure remains a serious food safety risk. Aflatoxin contamination of maize and maize-based products has been reported in practically every country on the planet (Hyun and Han, 2012). Aflatoxin contamination in maize begins in the field, when the kernels become infected with aflatoxin-producing fungus, and continues to build up as the goods proceed through the value chain. For example, Kamika and Tekere (2016) have found that aflatoxin incidence rate increased as maize travelled through the value chain, from 32% at pre-harvest to 100% at the retail level of the 52 samples in a research to analyse aflatoxin occurrence in the maize supply chain in Congo. They have also discovered that aflatoxin levels climbed from 3.1 g/kg to 300 times higher than the Codex Alimentarius maximum limit of 10 g/kg for total aflatoxin. Tasie et al. (2019) reported the co-occurrence of aflatoxin and fumonisin in the maize value chain in Southwest Nigeria.

Occurrence of aflatoxins

According to Ikoma (2016), aflatoxin has been reported as the cause of liver damage in rats fed with varying doses of dietary protein. In his report, the young rats were fed with AFB1 in low or high protein diets for 6 months. The high protein diet was found to be related with hyperplastic activity in the liver, comparable to that seen in rats developing AFB1–induced hematomas. During the same time period, the rats fed the low protein diet with AFB1 showed no precancerous–like changes. This model was used to examine the sensitivity of several liver function tests to the dietary–induced variation in liver reactivity to AFB1 feeding. The serum enzymes lactic dehydrogenase and alkaline phosphatase were significantly increased in rats with precancerous–like lesions, with the former being the most susceptible. Although serum glutamate–oxalate transaminase and serum glutamate–pyruvate transaminase was both elevated in rats with precancerous–like lesions, they were much lower than lactic dehydrogenase and alkaline phosphatase. Aflatoxin metabolites in the urine were also tested. Following the feeding of AFB1, AFM1 and AFB1 were both discovered. AFB1 excretion increased steadily over the feeding period, whereas AFM1 increased briefly in the second and fourth months before declining. When compared to rats on a high protein diet, rats on a reduced protein diet produced a lower ratio of AFM1 to AFB1. The ratio significantly decreased after 6 months, particularly in rats with precancerous–like lesions. Lactic dehydrogenase, alkaline phosphatase, and the ratio of AFM1 to AFB1 urinary excretion were found to be beneficial in a diagnostic approach for AFB1–induced precancerous liver alterations that may be seen in human trials.

Occurrence of aflatoxins in oilseeds and oilseed products

Aflatoxin contamination affects oilseed crops such as peanuts, sunflowers, soybeans, canola, rapeseed, flaxseed, mustard seed, sesame, cottonseed, almonds, pistachios, walnuts, chestnuts, apricots, and Brazil nuts (Filazi and Sireli, 2013; Duman, 2010). Aflatoxin pollution affects oilseed crops such as peanuts, sunflowers, soybeans, canola, rapeseed, flaxseed, mustard seed, sesame, cottonseed, and their products (Filazi and Sireli, 2013). Aflatoxin contamination can also be found in almonds, pistachios, walnuts, chestnuts, apricots, and Brazil nuts (Duman, 2010). Peanuts are the most sensitive oil crops to aflatoxin contamination. The invasion of toxigenic fungus on peanut plants, followed by aflatoxin contamination of the nuts, is a severe food safety risk in peanut-producing countries around the world (Waliyar et al., 2015). Peanuts, which are both a cash and a staple crop in West Africa, contribute significantly to aflatoxin dietary exposure among consumers (N'dede et al., 2012). Toxigenic fungus proliferation and aflatoxin generation in peanuts are favoured by the sort of soils, environmental, and agricultural circumstances under which they are generally farmed (Bankole and Adebanjo, 2004). The maximum allowed limit for aflatoxins in foodstuffs has been established in several countries, with different specifications for AFB1 alone or total aflatoxins (AFB1, AFB2, AFG1 and AFG2) (Kumar et al., 2021; Miklós et al., 2020).

Occurrence of aflatoxins in spices and herbal products

Spices and herbs are commonly used food items, with a global market value of $3 billion. Black pepper, capsicums, cumin, cinnamon, nutmeg, ginger, turmeric, saffron, coriander, cloves, dill, mint, thyme, and curry powder are some of the most extensively used spices in the

food and culinary business as organoleptic enhancers, preservatives, and medicines in some cultures. Unfortunately, spices and herbs have been linked to human aflatoxin exposure (Kabak and Dobson, 2016). Although some researchers have found that black pepper plants have inhibitory effects on the growth of toxigenic strains of A. flavus and A. parasiticus, as well as toxin production, others have found aflatoxin in black pepper. Aflatoxin was found in 5 of 40 black pepper samples (12.5%) in values ranging from 0.88 to 1.45 g/kg in a Nigerian survey. Aflatoxin levels in chili peppers from three Nigerian states were determined. 70 samples were collected from farmers' markets and local markets. More than a quarter of the samples contained dangerous levels of aflatoxin (Ezekiel et al., 2019). Aflatoxin levels ranged from 4.22 to 28.6 g/kg in 100% of 36 red pepper samples tested in the same investigation (Barani et al., 2016). Aflatoxin was found in 78.1% of black pepper samples contaminated with total aflatoxins, with an average quantity of 320 ppb, in another study conducted in India (Jeswal and Kumar, 2015). Chilli (capsicum) is another regularly consumed hot food that can be contaminated with aflatoxin. Fungal invasion and subsequent aflatoxin contamination are a risk due to the climatic conditions of the major producers, handling and chili-processing techniques. Chilies, like other crops, can be contaminated with aflatoxin both before and after harvest (Duman, 2010). Aflatoxin levels in chilli have been found in Nigerian food to be greater than regulatory limits in reports from around the world (Ezekiel et al., 2019b). Aflatoxin contamination of various spicy goods has been documented by Kabak and Dobson (2016), including cinnamon and cassia, cloves, coriander, cumin, ginger, nutmeg, saffron, turmeric, black cumin, dill, mint, thyme, and curry powder.

Occurrence of aflatoxins in local fermented foods

The multi-mycotoxin profile of Nigerian fermented food products such as ogiri, ugba, and iru, which are used as seasonings as well as ogi and ogi-baba, which are commonly eaten as breakfast cereals, was studied. According to the European Commission ("setting maximum levels for certain contaminants in foodstuffs (Text with EEA relevance)", 2006), 56% of the 34 fermented food samples positive for AFB1 had levels over the maximum regulation limit of 2 µg/kg in foods. LC-MS/MS data revealed that ogiri samples had a higher incidence of AFB1 (48%) than other samples. In ogiri, it was discovered that AFB2 and AFG2 coexist. We also found that these significant analogues AFs (along with others, such as AFB1 and AFG1) were present in all of the samples either individually or in combination, which could be due to the presence of AF-producing fungus in similar samples of ogiri, ugba, ogi-baba, and iru (Adekoya et al., 2017) . Previously, the presence of Aspergillus spp and aflatoxin in several raw materials utilized in the production of the studied fermented foods has been demonstrated by Ezekiel et al. (2016).

Occurrence of aflatoxins in coffee and tea

Despite prior claims that caffeine inhibits the development of fungal toxins, aflatoxin has been found in both ground and whole coffee beans in Arabica and Robusta and Nigeria (Al-Ghouti et al., 2022; Kumar et al., 2021). Samples from nine different nations were tested in a study to determine human exposure to mycotoxins through coffee consumption (Bueno et al., 2015; Singh and Mehta, 2020). Aflatoxin B1 was found in certain samples, albeit it was sporadic and in lesser quantities (highest level of 1.2 µg/kg) than other mycotoxins (Bessaire et al., 2019). Aflatoxin levels in roasted coffee are frequently low, according to studies (Al-Ghouti et al., 2020). This is due to the thermal treatment given to coffee beans during the roasting process. According to a recent study roasting aflatoxin-contaminated green coffee beans reduced the initial aflatoxin concentration levels by 20% (Ganesan et al., 2022). In a prior study, Soliman (2002) found that roasting reduced aflatoxin concentration in coffee beans by 42.2% to 55.9%, depending on the variety and roasting parameters. Caffeine concentration in coffee beans also decreases potential fungus development and aflatoxin generation, according to the same study. Due to its high level of health-promoting phytochemicals like polyphenols, tea is typically connected with healthy food choices as one of the most widely drank beverages on the planet (Khan and Mukhtar, 2013). Until recently, tea research has mostly concentrated on its health advantages, with little regard for its safety. However, emerging evidence from around the world suggests that tea contamination with mycotoxins should be a cause for concern (N'dede et al., 2012). Tea has been shown to contain aflatoxin in many places of the world for example, aflatoxin B2 (14.4 to 32.2 g/L) and aflatoxin G2 were found in 14 and 18% of 44 commercial tea samples evaluated for the presence of mycotoxins respectively (N'dede et al., 2012).

Occurrences of aflatoxins in animal feeds

Unhygienic animal feedstuffs, in general, can cause nutritional losses and have a negative impact on animal output and public health. In Nigeria, there have been multiple allegations of animal feed contamination in the poultry, fishery, and livestock industries (Adeyonu et al., 2021; Ganesan et al., 2021). Fusarium spp, A. flavus, and some Aspergillus spp has been the most common fungal isolate found in maize, soybean meal, and feed in Nigeria, whereas only Aspergillus was found in feed after pelleting (Ghaemmaghami et al., 2016). A. flavus isolates were the most common among the five Aspergillus species found in corn (46.6%), soybean meal (72.7%) and chicken finished feed. Aflatoxin contamination levels, which averaged at 2.83 (ppb) with minimum and maximum levels of 0.1 and 43.8 (ppb), respectively, have been observed in samples of poultry feeds in Lagos State. If aflatoxin levels in chick feed (such as for broiler chickens) surpass 20 (ppb) and mature poultry feed exceeds 100 (ppb), the FDA's Aflatoxin Regulations Policy can support enforcement action. A. flavus was the most common Aspergillus species found in some feed ingredients and pellet feed (60.66%).

Aflatoxin contamination in milk

Food contamination with aflatoxins is not limited to plant-based foods but can also been found in a variety of animal-based meals. Aflatoxin has been found in a variety of animal-based meals, according to numerous reports. The discovery of aflatoxin in dairy products, eggs, and edible animal products prompted the creation of rules to limit their presence in animal feed, which is the primary route through which animals are exposed to aflatoxin (Fink-Gremmels and Van Der Merwe, 2019). In aflatoxin hotspots around the world, aflatoxin M1 has been found in human milk among breastfeeding mother. Aflatoxin M1 was found in 14% of 121 samples of woman breast milk in Nigeria, with values ranging from 2 to 187 mg/L (Oluwafemi, 2012). Milking cows begin excreting aflatoxin M1 in their milk 12 hours after consuming aflatoxin B1-contaminated diet (Applebaum et al., 1982). The hepatic microsomal cytochrome P450 transforms aflatoxin B1 into aflatoxin M1 in the nursing animal by hydroxylation of the fourth carbon in the aflatoxin B1 molecule (Battacone et al., 2003). Aflatoxin B1 conversion to aflatoxin M1 depends on a number of parameters, including milk output and lactation duration. (Britzi et al., 2013) have found that low-milk-yielding cows had a carryover of 1 to 2%, while high-milk-yielding cows had a carryover of up to 6%. Churchill (2017) has reported a 6.5% carry-over in high-milk-yielding dairy cows in a more recent study. Estimated amounts of 1.5 and 0.8% per kg milk have been observed in ewes and goats, respectively (Walter et al.,2016). Aflatoxin B1 carryover from feed to milk varies by animal species and rates are higher during the first phases of lactation. As a result, many countries regulate its content in meals and agricultural products (Sumon et al., 2021). Numerous investigations from various countries have found varying levels of aflatoxin M1 in various milk and dairy product categories (Zain, 2011). Aflatoxin M1 is reported to be stable under a variety of environmental and processing conditions (Iha et al., 2013). Processing has, however, been reported to

result in some amounts of decrease. For example, researchers found that pasteurizing aflatoxin M1-infected milk (at 95 °C for 5 minutes) reduced the amount of aflatoxin M1 by 18 and 16% in milk contaminated with 1.5 and 3.5 µg/kg of aflatoxin M1, respectively (Kabak and Dobson, 2016). With comparable processing settings, another study observed a 7.62% reduction in aflatoxin M1 (Kamkar et al., 2011). Pasteurization (at 72 °C for 2 minutes) reduces aflatoxin M1 by roughly 12 and 9% in milk contaminated with 1.5 g/kg and 3.5 g/L aflatoxin M1 respectively, according to (Deveci, 2007). The quantity of heat used in the processing of milk had a positive correlation with aflatoxin M1 decrease. On the other hand, Jasurent et al. (1990) have found that pasteurization (at 95 °C for 3 minutes) has no effect on aflatoxin M1 levels in milk. Aflatoxin M1 occurrence and levels in dairy products are highly reliant on animal diet (van der Fels-Klerx and Camenzuli, 2016). As a result, aflatoxin levels in animal diets must be checked and kept to a minimum for food safety reasons.

Conditions for aflatoxin production

Crops grown in tropical or semitropical climates are more susceptible to aflatoxin pollution than those grown in temperate climates. By far, the two agricultural commodities that appear to provide the greatest risk of aflatoxin contamination are groundnuts and groundnut meal (Dhanasekaran et al., 2011). These wares, on the other hand, are crucial since substrates, fungal growth, and aflatoxin pollution are all the result of interactions between the fungus, the steward, and the climate. The invasion and habitation of the substrate, as well as the type and amount of aflatoxin produced, are determined by proper blending of these components. Mould invasion and toxin production are influenced by water stress, high-temperature stress, and insect damage to the steward implant. Similarly, greater mould growth and toxin production have been associated to specific crop growth stages, inadequate fertility, high crop uniformity, and herb concurrence. The main agents that organize fungal evolution and toxin generation are the humidity content of the substrate and temperature (Guevara-González, 2011). For optimum toxin production, humidity levels of 18% for starchy cereal grains and 9-10% for oil-rich walnut and seed have been established (Dhanasekaran et al., 2011). The minimum optimum and maximum temperatures for aflatoxin production respectively are 12-27 °C and 40-42 °C. Pollution of corn and other commodities with high levels of aflatoxins has been a serious problem all over the world, causing major economic losses to farmers and posing a legitimate risk to farm animals and humans (Battilani et al., 2016).

Impact of climate change on aflatoxin production

Climate change will have a profound impact on the quality and availability of staple foods. With the growing global population, the focus has been placed on the safety of food and feed that can meet rising demands while also boosting yields by preserving crops from unfavourable climatic circumstances (Medina et al., 2017). Climate change has an impact on the complex communities of aflatoxin producing fungi by changing the quantity of aflatoxin producers and hence changing the structure of the fungal community. There are two known stages of aflatoxin contamination; this includes crop development during first stage and crop maturation during the second stage. Warm, humid, and even hot deserts, as well as drought conditions, increased pollution (Cotty and Jaime-Garcia, 2007). A. flavus has highly evolved physiological systems to adapt to harsh climatic circumstances, and it outcompetes other fungal species (Nesci et al., 2004). Climate change affects the environment's temperature and water activity (aw), which regulates gene expression to create AFs. Temperature and aw control the degree of fungal growth and the formation of AFs (Schmidt-Heydt et al., 2009). The aflatoxin producing genes are grouped on the chromosome and express both primary regulatory genes (aflR/aflS) and structural genes (aflD) that are regulated by temperature water activity circumstances. Schmidt-Heydt and coworkers (2010) have discovered that the amount of AFB1 generated is highly correlated with the expression proportion of aflR/aflS. Furthermore, the temperature and water activity conditions have a substantial impact on the expression of sugar transporter genes (Medina et al., 2015). Temperature and water activity influence the expression of the biosynthetic regulatory gene (aflR) and the synthesis of AFB1 by A. flavus in maize (Bernáldez et al., 2017). They discovered that A. flavus grows best at temperatures between 27-30 °C/0.99 aw, with no growth at 20 °C/0.90 aw. Temperature and water activity both have an effect on relative aflR gene expression and AFB1 production, but the trends for AFB1 production do not match the gene expression (Bernáldezet al., 2017). Gizachew et al. (2019) have studied the effects of temperature (20, 27, and 35 °C) and aw (0.82, 0.86, 0.90, 0.94, and 0.98) on the growth of A. flavus and A. parasiticus, as well as the generation of AFB1, on ground Nyjer seeds (Gizachew et al., 2019). For both A. flavus and A. parasiticus, the greatest AFB1 production was reported at 27 °C/0.90 aw and the maximum AFB1 was created (Lv et al., 2019). According to Battilani et al. (2016), with every 2 °C increase in temperature, the chance of AFB1 development in cereals in the European Union as a result of climate change increases across the various regions of Spain, Italy, Greece, Portugal, Bulgaria, Albania, Cyprus, and Turkey. In Europe, the risk of AFs contamination in maize is projected to rise in the next 30 years due to favourable climatic conditions for A. flavus (Moretti et al., 2019). To tackle the burning issues of AFs in food and feed, proper detection methods and control strategies are essential.

Biological effects of aflatoxins

The identification of this group of chemicals as pollutants in animal feeds, as well as the potential public health risks they pose, has sparked a significant amount of research into their effects in various biological test systems because aflatoxin consumption contributes to the body's mutagenic, carcinogenic, teratogenic, and immunosuppressive health effects. Depending on the test system, dose and period of exposure, the harmful characteristics of aflatoxins express themselves in different ways. As a result, they have been found to be deadly to animals and animal cells in culture when given acutely in big enough quantities, and to produce histological abnormalities in animals when given subacutely in smaller amounts. In some animal species, long-term chronic exposure has resulted in tumour induction (Williams et al., 2004b)but they have additional important toxic effects. In farm and laboratory animals, chronic exposure to aflatoxins compromises immunity and interferes with protein metabolism and multiple micronutrients that are critical to health. These effects have not been widely studied in humans, but the available information indicates that at least some of the effects observed in animals also occur in humans. The prevalence and level of human exposure to aflatoxins on a global scale have been reviewed, and the resulting conclusion was that ≈4.5 billion persons living in developing countries are chronically exposed to largely uncontrolled amounts of the toxin. A limited amount of information shows that, at least in those locations where it has been studied, the existing aflatoxin exposure results in changes in nutrition and immunity. The aflatoxin exposure and the toxic affects of aflatoxins on immunity and nutrition combine to negatively affect health factors (including HIV infection.

Aflatoxin and animal diseases

Aflatoxin poisoning (Aflatoxicosis) is primarily associated with animal liver injury; however, the injured animals' species, age, gender, and nutritional state differ. Aflatoxin can cause liver malfunction, decreased milk and egg production, and decreased animal immunity (Kumar et al., 2021). Harmful germs are susceptible to infection. Furthermore, long-term ingestion of food having low levels of aflatoxin in the feed might cause embryo toxicity (Ráduly et al., 2020). Aflatoxin sensitivity

is usually higher in young animals. Aflatoxin causes digestive problems, decreased fertility, impaired feed efficiency and anaemia in humans (Schrenk et al., 2020). Aflatoxins cause not only a decrease in milk supply but also the transformation of aflatoxin M1 and M2-containing milk (Kumar et al., 2021).

Aflatoxins and human health

Eating aflatoxin-contaminated food posed the greatest risk to human health. The reason for the difficulty in preventing this contamination is due to fungi in food or food components (Wanniarachchi et al., 2023). The Federal Ministry of Health and Federal Ministry of Agriculture and Rural Development in Nigeria are working towards the developing implementation strategies for applicable standards. Aflatoxin contamination at various level is a threat to food safety (Jeff-Agboola et al., 2020). Consumption of aflatoxin-contaminated food was linked to an increased risk of cancer in underdeveloped countries (Jeff-Agboola and Omosanyin, 2017). Aflatoxin in food and liver cell cancer (Liver Cell Cancer, LCC) demonstrated a favourable link in disease study conducted by Asian and African research organizations (Kensler et al., 2011). Aflatoxin B1 was designated as a human carcinogen by the International Agency for Research on Cancer (IARC) in 1988. Aflatoxin Bl 0.36 mg/kg body weight is extremely poisonous with a unique range of lethal doses (aflatoxin animal half of the lethal dose is found in the strongest carcinogens). It is 900 times more carcinogenic than dimethyl nitrosamine-induced liver cancer in the large capacity, and 75 times more carcinogenic than 3, 4-benzopyrene.

Possible strategies for the control of aflatoxins in food in Nigeria

Good Agricultural Practice

Good agricultural practice should be followed during the handling, storage, processing, and distribution of food and feed for human and animal use. Good agricultural practices (GAP) is a set of guidelines for farmers to follow during pre-production and post-production in order to produce safe and healthy agricultural and non-agricultural products (Atanda et al., 2013). It serves as a first line of defence against the contamination of food and feed with mycotoxins. It is a set of guidelines for farmers to follow during pre-production and post-production in order to produce safe and healthy agricultural and non-agricultural products (Atanda et al., 2013). Good manufacturing practice should be followed during the handling, storage, processing, and distribution of food and feed for human and animal use. Early harvesting and adequate drying have been demonstrated to contribute to efficient mycotoxin contamination control which has resulted in a reduction in aflatoxin infection. In Nigeria, good agricultural practices are the most effective strategy to reduce contamination. Nigeria has lagged behind in terms of adopting excellent agricultural practices including food safety legislation. It is critical to reach out to farmers in every state to raise GAP awareness. Contamination will be reduced. If all appropriate agricultural practices are in place by Nigerian farmers, mycotoxin contamination will be reduced

Physical separation

The first step in the physical eradication of mycotoxins is sorting and appropriate cleaning. They may be considered superior approaches because they do not produce hazardous degradable products (Chilaka et al., 2017). Several alternative treatments have been reported to be effective physical cleaning methods for various mycotoxins types, including washing, dehulling and hand picking apparently mouldy produce. Aflatoxins are not equally dispersed in grains that are stored together, according to research, and visual grain sorting has been suggested as a simple way to limit aflatoxin exposure, according to Afolabi et al., 2006. When compared to poorly sorted grain, good grade grain can be contaminated with aflatoxins to a lesser extent (Desjardins et al., 1998). Sorting would be a useful way to separate good and bad quality grains if the bad ones were discarded instead of being redirected to other uses like animal feed or mixed with good quality grains and pounded to powder.

Proper storage conditions

Infection and mycotoxins buildup occur during storage, which is a key stage (Daou et al., 2021; Kumar et al., 2020). Because storage conditions affect the total growth of fungus, they play an important role in reducing mycotoxins contamination. The growth of fungus and the accumulation of mycotoxins are reduced when stored under controlled settings, such as packaging methods, temperature control, ventilation, and proper air humidity (Uchechukwu-Agua et al. 2015). Grain that is healthy and appears to be healthy must be stored with care. Certain basic difficulties should be addressed during pre-storage treatment or handling. Because all elements contributing to contamination are linked to safe moisture content, fast drying of farm food before storage is strongly advised for managing mycotoxins problems. According to studies, aflatoxin levels rise with storage time in hot and humid regions like Nigeria, which are more vulnerable due to a combination of heat and moisture that promotes the growth of common mycotoxin producers Aspergillus and Fusarium (Villers, 2014).

Creation of aggressive awareness on prevalence and danger of mycotoxins

The high prevalence of mycotoxins in Nigeria is due to a lack of awareness of the dangers posed by fungi that create them (Atanda et al., 2013). Control, reduction, and removal of mycotoxin contamination of foods and feeds can all be achieved by using the media to raise awareness. In some parts of Nigeria, studies have found that mycotoxin contamination knowledge is inversely associated to educational attainment. The majority of farmers, food handlers and food processors are illiterate and have little understanding of the dangers of mycotoxin contamination. The government entities, private organizations, and national media networks could conduct awareness campaigns using newspapers and magazines, as well as organize seminars and workshops that serve as a conduit for knowledge exchange and dissemination between researchers and citizens (Tola and Kebede, 2016). Increasing knowledge of the impact of GAP, Good Management Practices (GMP), and Hazard Analysis Critical Control Points (HACCP) application in the control of mycotoxin contamination in the Nigerian food system will help to reduce the risk of mycotoxin exposure in both rural and urban areas.

Detoxification/degradation and food fermentation

Biological elimination has been identified as one of the most effective ways to regulate and avoid mycotoxins in food and feed. The use of Aflasafe, a bio-control product containing microbial strains (fungal strains) that control aflatogenic fungi that create aflatoxins in maize and peanuts, has been demonstrated (Ezekiel et al., 2019b). The Aflasafe product is now accessible in a few African nations, including Burkina Faso, Ghana, Kenya, Nigeria, Senegal, and The Gambia, with more African countries on the way (Adebiyi et al., 2019). Fermentation is another global biological food processing technology. Fermentation is considered one of the most technologically and appropriately relevant processes for food processing in Nigeria and other SSA nations due to its cost and suitability for the production of staple foods in rural and urban areas (Adebiyi et al., 2019). It increases the quality of food and provides

consumers with outstanding properties. It can be used as an alternative to more expensive and inconvenient methods for reducing aflatoxins (Imade et al., 2021). Food safety requires the construction of a strong and efficient food control and regulation system. As a result, food quality and safety must be ensured for both domestic and international consumption.

Conclusions

A wide range of food crops and animal products are exposed to aflatoxin contamination due to a lack of awareness of aflatoxins in Nigeria. Poor handling of foods during pre-harvesting and post-harvesting and storage has increased the rate of aflatoxin contamination in Nigerian foods and Nigerians are exposed to serious health effects of aflatoxin, as well as subjected to high economical loss. Therefore, aflatoxin related regulations should be developed and enforced by the government, awareness needs to be raised in the entire body of food chain (from farmers to consumers) and good storehouses and equipment for work need to be provided.

References

Adebiyi J.A., Kayitesi E., Adebo O.A., Changwa R., Njobeh P.B. (2019) Food fermentation and mycotoxin detoxification: An African perspective. Food Control, 106 106731

Adekoya I., Obadina A., Phoku J., Nwinyi O., Njobeh P. (2017) Contamination of fermented foods in Nigeria with fungi. LWT - Food Science and Technology, 86 76–84.

Adeyonu A.G., Otunaiya A.O., Oyawoye E.O., Okeniyi F.A. (2021) Risk perceptions and risk management strategies among poultry farmers in south-west Nigeria. Cogent Social Science, 7.

Afolabi C.G., Bandyopadhyay R., Leslie J.F., Ekpo E.J.A. (2006) Effect of sorting on incidence and occurrence of fumonisins and Fusarium verticillioides on maize from Nigeria. Journal of Food Protection, 69 2019–2023.

Agboola J., Adebanji Plotz M., Adekoya I.O., Jeff-Agboola E.O., Ogidi C.O., Anuoluwa I.A. (2020) Assessment of awareness level and attitudes of farmers inthemanagement and mitigation of health risk associated with the occurrence of mycotoxins along the cocoa value chain. IOSR Journal of Environmental Science, 14 55–62.

Agustina del Palacio, Pan D. (2020) Occurrence and toxigenic potential of Aspergillus section Flavi on wheat and sorghum silages in Uruguay. Mycology, 11 147-157

Al-Ghouti M.A., AlHusaini A., Abu-Dieyeh M.H., Abd Elkhabeer M., Alam M.M. (2022) Determination of aflatoxins in coffee by means of ultra-high performance liquid chromatography-fluorescence detector and fungi isolation. International Journal of Environmental Analytical Chemistry, 102 6999–7014.

Al-Ghouti M.A., AlHusaini A., Abu-Dieyeh M.H., Abd Elkhabeer M., Alam M.M. (2020) Determination of aflatoxins in coffee by means of ultra-high performance liquid chromatography-fluorescence detector and fungi isolation. International Journal of Environmental Analytical Chemistry, 1-16.

Aliyu R., Abubakar M., Yakubu Y., Kasarawa A., Lawal N., Bello M., Fardami A. (2016) Prevalence of potential toxigenic Aspergillus species isolated from poultry feeds in Sokoto metropolis. Sokoto Journal of Vetinary Science, 14 39.

Alvarado R., Iñiguez M., Ponce P. (2017) Foreign direct investment and economic growth in Latin America. Economics Analytical Policy, 56 176–187.

Andrade P.D., Caldas E.D. (2015) Aflatoxins in cereals: Worldwide occurrence and dietary risk assessment. World Mycotoxin Journal, 8 415–431.

Applebaum R.S., Brackett R.E., Wiseman D.W., Marth E.H. (1982) Responses of Dairy Cows to Dietary Aflatoxin: Feed Intake and Yield, Toxin Content, and Quality of Milk of Cows Treated with Pure and Impure Aflatoxin. Journal of Dairy Science, 65 1503–1508.

Atanda O., Makun H.A., Ogara I.M., Edema M., Idahor K.O., Eshiett M.E., Oluwabamiwo B.F. (2013) Fungal and Mycotoxin Contamination of Nigerian Foods and Feeds. Ed by Hussani Anthony Makun, Intech, April 10, 2013.

Awika J.M., Piironen V., Bean S. (2011) Advances in cereal science : Implications to food processing and health promotion . American Chemical Society, Washington DC, 212.

Bankole S.A., Adebanjo A. (2004) Mycotoxins in food in West Africa: current situation and possibilities of controlling it. African Journal of Biotechnology, 2 254–263.

Barani A., Nasiri Z., Jarrah N. (2016) Natural occurrence of Aflatoxins in commercial pepper in Iran. Food and Agricultural Immunology, 27 570-576.

Battacone G., Nudda A., Cannas A., Borlino A.C., Bomboi G., Pulina G. (2003) Excretion of Aflatoxin M1 in milk of dairy Ewes treated with different doses of Aflatoxin B1. Journal of Dairy Science, 86 2667–2675.

Battilani P., Toscano P., Van Der Fels-Klerx H.J., Moretti A., Camardo Leggieri M., Brera C., Rortais A., Goumperis T., Robinson T. (2016) Aflatoxin B1 contamination in maize in Europe increases due to climate change. Scientific Reports, 6 24328.

Bennett J.W., Klich M. (2003) Mycotoxins. Clinical Microbiology Review, 16 497–516.

Bernáldez V., Córdoba J.J., Magan N., Peromingo B., Rodríguez A. (2017) The influence of ecophysiological factors on growth, aflR gene expression and aflatoxin B1 production by a type strain of Aspergillus flavus. LWT - Food Science and Technology, 83 283–291.

Bessaire T., Mujahid C., Mottier P., Desmarchelier A. (2019) Multiple Mycotoxins determination in food by LC-MS/MS: An international collaborative study. Toxins (Basel), 11.

Britzi M., Friedman S., Miron J., Solomon R., Cuneah O., Shimshoni J.A., Soback S., Ashkenazi R., Armer S., Shlosberg A. (2013) Carry-over of aflatoxin B1 to Aflatoxin M1 in high yielding Israeli cows in mid- and late-aactation. Toxins, 5 173–183.

Bueno D., Istamboulie G., Muñoz R., Marty J.L. (2015) Determination of mycotoxins in food: A review of bioanalytical to analytical methods. Applied Spectroscopy Review, 50 728–774.

Bullerman L.B. (1979) Significance of mycotoxins to food safety and human health. Journal of Food Protection, 42 65–86.

Chilaka C.A., De Boevre M., Atanda O.O., De Saeger S. (2017) The status of fusarium mycotoxins in sub-Saharan Africa: A review of emerging trends and post-harvest mitigation strategies towards food control. Toxins (Basel), 9 19.

Chun H.S., Kim H.J., Ok H.E., Hwang J.B., Chung D.H. (2007) Determination of aflatoxin levels in nuts and their products consumed in South Korea. Food Chemistry, 102 385–391.

Cotty P.J., Jaime-Garcia R. (2007) Influences of climate on aflatoxin producing fungi and aflatoxin contamination. International Journal of Food

Microbiology, 119 109–115.
Daou R., Joubrane K., Maroun R.G., Khabbaz L.R., Ismail A., El Khoury A. (2021) Mycotoxins: Factors influencing production and control strategies. AIMS Agricultural Food, 6 416–447.
Darwish W.S., Ikenaka Y., Nakayama S.M.M., Ishizuka M. (2014) An overview on mycotoxin contamination of foods in Africa. Journal of Veterinary Medical Science, 76 789–797.
Desjardins A.E., Plattner R.D., Lu M., Claflin L.E. (1998) Distribution of fumonisins in maize ears infected with strains of Fusarium moniliforme that differ in fumonisin production. Plant Disease, 82 953–958.
Deveci O. (2007) Changes in the concentration of aflatoxin M1 during manufacture and storage of White Pickled cheese. Food Control, 18 1103–1107.
Dhanasekaran D., Shanmugapriya S., Thajuddin N., Panneerselvam A. (2011) Aflatoxins and Aflatoxicosis in Human and Animals. Aflatoxins - Biochemistry and Molecular Biology Ed by Ramon Gerardo Guevara-Gonzalez, Intech, 2011.
Duman A.D. (2010) Storage of red chili pepper under hermetically sealed or vacuum conditions for preservation of its quality and prevention of mycotoxin occurrence. Journal of Stored Product Research, 46 155–160.
Ezekiel C.N., Ortega-Beltran A., Oyedeji E.O., Atehnkeng J., Kössler P., Tairu F., Hoeschle-Zeledon I., Karlovsky P., Cotty P.J., Bandyopadhyay R. (2019b) Aflatoxin in Chili peppers in Nigeria: Extent of contamination and control using atoxigenic Aspergillus flavus genotypes as biocontrol agents. Toxins, 11 429.
Ezekiel C.N., Sulyok M., Somorin Y., Odutayo F.I., Nwabekee S.U., Balogun A.T., Krska R. (2016) Mould and mycotoxin exposure assessment of melon and bush mango seeds, two common soup thickeners consumed in Nigeria. International Journal of Food Microbiology, 237 83–91.
Filazi A., Sireli U.T. (2013) Occurrence of aflatoxins in food.Recent Advances and future prospects Ed by Razzaghi-Abyaneh M. Intech, 143-170.
Fink-Gremmels J., Van Der Merwe D. (2019) Mycotoxins in the food chain: contamination of foods of animal origin. ECVPH Food Safety Assurance, 7 241-261.
Ganesan A.R., Balasubramanian B., Park S., Jha R., Andretta I., Bakare A.G., Kim I.H., (2021) Ochratoxin A: Carryover from animal feed into livestock and the mitigation strategies. Animal Nutrition, 7 56–63.
Ganesan A.R., Mohan K., Karthick Rajan D., Pillay A.A., Palanisami T., Sathishkumar P., Conterno L. (2022) Distribution, toxicity, interactive effects, and detection of ochratoxin and deoxynivalenol in food: A review. Food Chemistry 378 131978.
Ghaemmaghami S.S., Modirsaneii M., Khosravi A.R., Razzaghi-Abyaneh M. (2016) Study on mycoflora of poultry feed ingredients and finished feed in Iran. Iran Journal of Microbiology, 8 47.
Gizachew D., Chang C.H., Szonyi B., De La Torre S., Ting W., Ttsyi E. (2019) Aflatoxin B1 (AFB1) production by Aspergillus flavus and Aspergillus parasiticus on ground Nyjer seeds: The effect of water activity and temperature. International Journal of Food Microbiology, 296 8–13.
Golge O., Hepsag F., Kabak B. (2013) Incidence and level of aflatoxin contamination in chilli commercialised in Turkey. Food Control, 33 514–520.
Guevara-González R.G. (2011) Aflatoxins - Biochemistry and Molecular Biology. Ed by Ramon Guevara-Gonzalez, Intech, October 5, 2011.
Habibi N., Nassiri-Toosi M., Sharafi H., Alavian S.M., Shams-Ghahfarokhi M., Razzaghi-Abyaneh M. (2019) Aflatoxin B1 exposure and the risk of hepatocellular carcinoma in Iranian carriers of viral hepatitis B and C. Toxin, 38 234–239.
Hatem N.L., Hassab H.M.A., Abd Al-Rahman E.M., El-Deeb S.A., El-Sayed Ahmed R.L., (2005) Prevalence of aflatoxins in blood and urine of Egyptian infants with protein-energy malnutrion. Food Nutrition Bulletin, 26 49–56.
Hyun S.S., Han H. (2012) A model of a patron's innovativeness formation toward a chain restaurant brand. International Journal of Contemporary Hospital Management, 24 175–199.
Iha M.H., Barbosa C.B., Okada I.A., Trucksess M.W. (2013) Aflatoxin M1 in milk and distribution and stability of aflatoxin M1 during production and storage of yoghurt and cheese. Food Control, 29 1–6.
Ikoma T., Kapoor V.K., Behari A., Mishra K., Tsuchiya Y., Asai T., Endoh K., Okano K., Nakamura K. (2016) Lack of an apparent association between mycotoxin concentrations in red chili peppers and incidence of gallbladder cancer in India : An ecological study. Asian Pacific Journal of Cancer Prevention, 17 3499–3503.
Imade F., Ankwasa E.M., Geng H., Ullah S., Ahmad T., Wang G., Zhang C., Dada O., Xing F., Zheng Y., Liu Y. (2021) Updates on food and feed mycotoxin contamination and safety in Africa with special reference to Nigeria. Mycology, 12 245–260.
Iram W., Anjum T., Iqbal M., Ghaffar A., Abbas M. (2016) Structural elucidation and toxicity assessment of degraded products of aflatoxin B1 and B2 by aqueous extracts of Trachyspermum ammi. Frontiers Microbiology, 7 346.
Jager A. V., Tonin F.G., Baptista G.Z., Souto P.C.M.C., Oliveira C.A.F. (2016) Assessment of aflatoxin exposure using serum and urinary biomarkers in São Paulo, Brazil: A pilot study. International Journal of Hygiene Environment and Health, 219 294–300.
Jeff-Agboola Y.A., Omosanyin T.R. (2017) Occurrence of toxigenic moulds isolated in maize (Zea mays) from Okitipupa metropolis, Ondo State, Nigeria. International Journal of Food Safety, Nutrition, Public Health and Technology, 9 28–37.
Jeswal P., Kumar D. (2015) Natural occurrence of to xigenic my coflora and ochratoxin A & aflatoxins in commonly used spices from Bihar state (India). IOSR Journal of Environmental Science and Toxicology, 9 2319–2399.
Kabak B., Dobson A.D.W. (2016) Mycotoxins in spices and herbs–An update. Critical Reviews in Food Science and Nutrition, 57 18-34.
Kamkar A., Khaniki G.R.J., Alavi S.A. (2011) Occurrence of aflatoxin m1 in raw milk produced in ardebil of Iran. Journal of Environment Health Science and Engineering, 8 123–128.
Keller B., Russo T., Rembold F., Chauhan Y., Battilani P., Wenndt A., Connett M. (2021) The potential for aflatoxin predictive risk modelling in sub-Saharan Africa: A review. World Mycotoxin Journal, 1–18.
Kensler T.W., Roebuck B.D., Wogan G.N., Groopman J.D. (2011) Aflatoxin: A 50-year Odyssey of mechanistic and transitional toxicology. Toxicology Science, 120 S28-S48.
Khan N., Mukhtar H. (2013) Tea and Health: Studies in Humans. Current Pharmaceutical Design, 19 6141–6147.
Kumar A., Pathak H., Bhadauria S., Sudan J. (2021) Aflatoxin contamination in food crops: causes, detection, and management: A review. Food Production, Processing and Nutrition, 3 17.
Kumar P., Mahato D.K., Kamle M., Mohanta T.K., Kang S.G. (2017) Aflatoxins: A global concern for food safety, human health and their management. Frontiers Microbiology 7.
Kumar S., Sinha A., Kumar R., Singh V., Hooda K.S., Nath K. (2020) Storage fungi and mycotoxins. In Kumar R., Gupta, A. (eds) Seed-Borne Diseases of Agricultural Crops. Detection, Diagnosis and Management. Springer, Singapore.
Liu L., Xie M., Wei D. (2022) Biological Detoxification of Mycotoxins: Current Status and Future Advances. International Journal of Molecules Science,

23.
Lv C., Jin J., Wang P., Dai X., Liu Y., Zheng M., Xing F. (2019) Interaction of water activity and temperature on the growth, gene expression and aflatoxin production by Aspergillus flavus on paddy and polished rice. Food Chemistry, 293 472–478.
Massomo S.M.S. (2020a) Aspergillus flavus and aflatoxin contamination in the maize value chain and what needs to be done in Tanzania. Science African, 10 e00606.
Massomo S.M.S. (2020b) Aspergillus flavus and aflatoxin contamination in the maize value chain and what needs to be done in Tanzania. Science African, 10 e00606.
Medina A., Akbar A., Baazeem A., Rodriguez A., Magan N. (2017) Climate change, food security and mycotoxins: Do we know enough? Fungal Biology Review, 31 143–154.
Medina Rodríguez A., Sultan Y., Magan N. (2015) Climate change factors and Aspergillus flavus: Effects on gene expression, growth and aflatoxin production. World Mycotoxin Journal, 8 171–179.
Miklós G., Angeli C., Ambrus Á., Nagy A., Kardos V., Zentai A., Kerekes K., Farkas Z., Jóźwiak Á., Bartók T. (2020) Detection of Aflatoxins in Different Matrices and Food-Chain Positions. Frontiers Microbiology, 11.
Moretti A., Pascale M., Logrieco A.F. (2019) Mycotoxin risks under a climate change scenario in Europe. Trends Food Science and Technology, 84 38–40.
Muthomi J.W., Njenga L.N., Gathumbi J.K., Chemining'wa G.N. (2009) The occurrence of aflatoxins in maize and distribution of mycotoxin-producing fungi in Eastern Kenya. Plant Pathology Journal, 8 113–119.
N'dede C.B., Jolly C.M., Vodouhe S.D., Jolly P.E. (2012) Economic Risks of Aflatoxin Contamination in Marketing of Peanut in Benin. Economics Research International, 1–12.
Nesci A., Etcheverry M., Magan N. (2004) Osmotic and matric potential effects on growth, sugar alcohol and sugar accumulation by Aspergillus section Flavi strains from Argentina. Journal of Applied Microbiology, 96 965–972.
Nicklas T.A., O'Neil C. E., Fulgoni V.L. (2020) Nutrient intake, introduction of baby cereals and other complementary foods in the diets of infants and toddlers from birth to 23 months of age. AIMS Public Health, 7 123–147.
Oluwafemi F.T. (2012) Aflatoxin M1 levels in lactating mothers in two Nigerian cities. Archives of Clinical Microbiology, 3 3.
Perrone G., Gallo A. (2017) Aspergillus species and their associated mycotoxins. Methods in Molecular Biology, 1542 33–49.
Ráduly Z., Szabó L., Madar A., Pócsi I., Csernoch L. (2020) Toxicological and Medical Aspects of Aspergillus-Derived Mycotoxins Entering the Feed and Food Chain. Frontiers in Microbiology, 10.
Azzaghi-Abyaneh M., Shams-Ghahfarokhi M., Rezaee M.B., Sakuda S. (2010) Natural aflatoxin inhibitors from medicinal plants. Mycotoxins in Food, Feed and Bioweapons, 329–352.
Rodrigues I., Handl J., Binder E.M. (2011) Mycotoxin occurrence in commodities, feeds and feed ingredients sourced in the middle East And Africa. Food Additives and Contaminants Part B Surveillance, 4 168–179.
Schmidt-Heydt M., Abdel-Hadi A., Magan N., Geisen R. (2009) Complex regulation of the aflatoxin biosynthesis gene cluster of Aspergillus flavus in relation to various combinations of water activity and temperature. International Journal of Food Microbiology, 135 231–237.
Schmidt-Heydt M., Rüfer C.E., Abdel-Hadi A., Magan N., Geisen R. (2010) The production of aflatoxin B1 or G1 by Aspergillus parasiticus at various combinations of temperature and water activity is related to the ratio of aflS to aflR expression. Mycotoxin Research, 26 241–246.
Schrenk D., Bignami M., Bodin L., Chipman J.K., del Mazo J., Grasl-Kraupp B., Hogstrand C., Hoogenboom L., Leblanc J.C., Nebbia C.S., Nielsen E., Ntzani E., Petersen A., Sand S., Schwerdtle T., Vleminckx C., Marko D., Oswald I.P., Piersma A., Routledge M., Schlatter J., Baert K., Gergelova P., Wallace H. (2020) Risk assessment of aflatoxins in food. EFSA Journal, 18. 6040.
Singh J., Mehta A. (2020) Rapid and sensitive detection of mycotoxins by advanced and emerging analytical methods: A review. Food Science and Nutrition, 8 2183–2204.
Sumon A.H., Islam F., Mohanto N.C., Kathak R.R., Molla N.H., Rana S., Degen G.H., Ali N. (2021) The Presence of Aflatoxin M1 in Milk and Milk Products in Bangladesh. Toxins (Basel), 13 440.
Tola M., Kebede B. (2016) Occurrence, importance and control of mycotoxins: A review. http://www.editorialmanager.com/cogentagri 2, 1191103. https://doi.org/10.1080/23311932.2016.1191103
Uchechukwu-Agua A.D., Caleb O.J., Opara U.L. (2015) Postharvest Handling and Storage of Fresh Cassava Root and Products: A Review. Food Bioprocessing and Technology, 8 729–748.
van der Fels-Klerx H.J., Camenzuli L. (2016) Effects of Milk Yield, Feed Composition, and Feed Contamination with Aflatoxin B1 on the Aflatoxin M1 Concentration in Dairy Cows' Milk Investigated Using Monte Carlo Simulation Modelling. Toxins (Basel), 8. 77.
Villers P. (2014) Aflatoxins and safe storage. Frontiers in Microbiology, 5.
Waliyar F., Umeh V.C., Traore A., Osiru M., Ntare B.R., Diarra B., Kodio O., Vijay Krishna Kumar K., Sudini H. (2015) Prevalence and distribution of aflatoxin contamination in groundnut (Arachis hypogaea L.) in Mali, West Africa. Crop Protection, 70 1–7.
Walter E.J., Hanna-Jumma S., Carraretto M., Forni L. (2016) The pathophysiological basis and consequences of fever. Critical Care, 20 1–10.
Wanniarachchi P.C., Uthpala T.G.G., Ranaweera K.K.D.S. (2023) Aflatoxin Occurrence, Contamination, Detection, and Decontamination with Special Emphasis on Coconut Oil: A Review. Journal of Agricultural Science - Sri Lanka, 18 101–128.
Williams J.H., Phillips T.D., Jolly P.E., Stiles J.K., Jolly C.M., Aggarwal D. (2004a) Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions. American Journal of Clinical Nutrition, 80 1106–1122.
Williams J.H., Phillips T.D., Jolly P.E., Stiles J.K., Jolly C.M., Aggarwal D. (2004b) Human aflatoxicosis in developing countries: A review of toxicology, exposure, potential health consequences, and interventions. American Journal of Clinical Nutrition, 80 1106–1122.
Zain M.E. (2011) Impact of mycotoxins on humans and animals. Journal of Saudi Chemical Society, 15 129–144.