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Prevalence of Mycotoxins in Nigerian's Staple Food

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Abstract: Mycotoxins are toxic secondary metabolites produced by certain species of mould genera that invade crops on the farmland and during post-harvest activities such as storage under suitable environmental conditions. Nigeria's climate which is primarily humid is considered ideal for the growth of toxigenic fungi, resulting in the growth and production of mycotoxins in a wide range of agricultural commodities within the country. Furthermore, the country's situation is exacerbated by inadequate storage facilities and inappropriate or lack of regulatory procedures to ensure food safety. The present review provides a comprehensive report on the prevalence of mycotoxins in the eight most produced and consumed crops in Nigeria. Due to the economic significance of these mycotoxins, proper strategies should be implemented to ensure food security and the well-being of people.

Keywords: Aflatoxins, Fumonisins, Mycotoxins, Ochratoxins, Trichothecenes, Zearelenone

1. Introduction

Nigeria has a humid tropical environment with year-round high temperatures. The tropical climate is characterized by hot and wet conditions. Nigerian agro-ecological zones are classified into two broad categories: forest and savannah zones. The humid forest zone is characterized by two growing seasons, beginning from April to November with annual rainfall between 1,500 - 2,000 mm, average annual temperature between 24.5 - 27.5°C, and mean relative humidity of 78 to 100%. Derived Savannah is the transition between the rainforest and guinea savannah zones. It receives between 200 mm to 1,700 mm of annual rainfall, with an average yearly relative humidity between 66 - 78% and typical temperature of 26 - 27 °C (Adejumo and Adejoro, 2014). This climatic condition experienced in Nigeria is favourable and conducive to the growth and development of mycotoxins in the region. Moreover, inadequate and poor agricultural practices at the post-harvest stage coupled with the humid weather scenarios witnessed in the country trigger the quick growth of mould and subsequently, in turn, bring about unbearable levels of mycotoxins in agricultural commodities (Neji et al., 2018). Based on the report it was claimed that Nigeria recorded 617-billion-naira loss due to the presence of mycotoxins beyond the safe limit in agricultural products (Imade et al., 2021). Most of the reports on mycotoxin contaminations in Nigeria were based on cereals crops with little known about other staples and popular food within the country. Therefore, this review provides a comprehensive report on the prevalence of mycotoxins in the eight most consumed and produced agricultural products in Nigeria.

Mycotoxins are secondary metabolites of molds, which are predominately produced by filamentous fungi such as *Penicillium* sp., *Fusarium* sp. and *Aspergillus* sp. (Iqbal et al., 2014). Mycotoxins are considered a natural toxin that is poisonous to both humans and animals, and their existence in agricultural commodities are considered a great threat to food security. Production of mycotoxins and the growth of fungi occur in a wide range of crops, which consequently enter the food chain, thus ingested directly by the people. When ingested, it could lead to various health consequences which include liver damage, hepatotoxicity, immunotoxicity and nephrotoxicity, as well as a reduction in milk and egg production in animals could be experienced (Muñoz-Solano and González-Peñas, 2020). Globally, mycotoxins

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contaminated approximately one-quarter of agricultural products, causing massive economic losses and affecting animal and human health and livelihood (Gbashi et al., 2018). The extent of damage caused by mycotoxins depend on the amount consumed as well as the health status of the individual. Presently, there are over 400 mycotoxins known but the most notable classes include aflatoxins (AF), ochratoxins (OTA), fumonisins (FB), deoxynivalenol (DON), and zearalenone (ZEN), which have received more attention due to their toxicity and carcinogenic properties (Iqbal et al., 2014). In order to control the amount of mycotoxins intake in food, presently, approximately 100 nations have set restrictions on the presence of mycotoxins in agricultural products (Alshannaq & Yu, 2017).

2. Occurrence of Mycotoxins in Major Foodstuffs in Nigeria

2.1 Rice

According to Food and Agriculture Organization (FAO) (2021), Nigeria's rice production was currently at 4.0 million metric tons in 2018 which increased by 0.3 million tons compared to the year before. Under inappropriate storage conditions, rice can be an ideal substrate for mycotoxin-producing fungi (Reiter et al., 2010). Approximately, 15% of harvested rice grains are destroyed beyond consumption due to fungal attacks from improper storage (Suleiman et al., 2021). Harvested rice in water-logged areas and with high moisture level is vulnerable to mould infection and consequently contamination by mycotoxin (Majeed et al., 2018). Factors such as temperature, high humidity, poor storage conditions, and transport and processing facilities play crucial role in enhancing mycotoxin production. Furthermore, organoleptic changes caused by fungi was observed during storage which include grain discoloration, viability loss, and moldiness (Ashiq, 2015).

In a study by Makun et al. (2011), multi-mycotoxins (AF, OTA, DON, ZEA, FB) occurrence was observed in rice samples analyzed. Based on the study, AF isoforms Aflatoxin B1 (AFB1), Aflatoxin B2 (AFB2), Aflatoxin G1 (AFG1) and Aflatoxin G2 (AFG2) were present in the samples with the concentration ranging from 1.3 - 309.0 μg/kg and total AF were between 27.7 - 371.9 μg/kg. Other toxins such as OTA, ZEA, DON, FB recorded 0 - 341.3 μg/kg, 0 - 41.9 μg/kg, 0 - 112.2 μg/kg, and 0.4 - 132.5 μg/kg respectively. Furthermore, the highest amount of mycotoxins contamination was observed in field samples then stored and market samples. This shows that pre-harvest conditions such as climate change are the major factor that influences mycotoxins production. In the country, a high percentage of the species belonging to the genus Aspergillus has been isolated from the cereals (Ferre, 2016).

2.2 Maize

In Nigeria, maize is grown and cultivated in the rainforest and derived from Savannah agroecological zones (Adejumo et al., 2007), which favours fungal growth. In Nigeria, the possibility of the frequent occurrence of Fusarium mycotoxins has been proven by the incidence of major mycotoxin-producing *Fusarium* species such as *F. poae*, *F. graminearum*, *F. proliferatum* and *F. verticillioides* in agricultural products (Chilaka et al., 2016). According to a survey conducted around the world, approximately, 25% of crop and oil products were contaminated with different mycotoxins at varying degrees (Sun et al., 2017). The condition in Nigeria could even be worse due to several factors such as poor management and storage conditions. One of the difficulties encountered by Nigeria's resource-poor smallholder farmers that produce the majority of the country's maize is preserving the grain quality during storage (Adejumo et al., 2007).

A multi-mycotoxins analysis study conducted by Egbuta et al. (2015) showed the incidence of AFs, OTA, FB, ZEA, DON in maize at 94.9, 92.3, 94.9, 64.1 and 69.2% respectively. Another study detected the presence of *Fusarium* toxin at 100% in stored maize with a concentration ranging from 11-479 ppb. A study was conducted on the isolation of mycotoxins from maize samples in Abuja. From this study, a wide range of mycotoxins including existing ones such as AF and FB and 19 other emerging ones such as moniliformin (MON), chanoclavine (CNV), alternariol methyl ether (AME), beauvericin (BEAU), norsolorinic acid (NA), brevianamid (BVD-F), macrosporin were observed (Adewumi and Fapohunda, 2019). The possible interaction between the already-known mycotoxins and the emerging ones in the future coupled with climate change suitable for mycotoxin growth can be considered a serious threat to food security and consumer health in Nigeria. In response to this, urgent attention is required by monitoring the mycotoxins level of maize products before being purchased by consumers. The emergence of new mycotoxins and modification of the existing ones may be exacerbated due to methods used in processing of agricultural commodities or via conjugation by animals, plants or fungi. Modified mycotoxins frequently elude normal analysis, undermining the level of mycotoxins in agricultural products and may probably get back into the parent toxins via hydrolysis during digestion (Chilaka et al., 2016).

2.3 Millet

Millet is vulnerable to fungal diseases such as ear rots and grain mold causing significant economic and production loss (Vismer et al., 2019). Moreover, the frequency of toxigenic fungal species that are highly host- and region-specific appears to also have an impact on mycotoxin contamination of millet (Choi et al., 2021). Although, pearl millet is said to be less vulnerable to AFs contamination at the pre-harvest stage, however, certain *Fusarium* species and related mycotoxins may be significant at this stage (Jurjevic et al., 2007). This doesn't imply that AFs contamination is not observed. Because previous research conducted has found that pearl millet is susceptible to mould infection with *A. flavus* and *A. parasiticus* dominating (Lasram et al., 2020). Pre-harvest contamination can be widespread during extreme climate conditions such as heavy rainfall and extreme drought events. Earlier studies have reported several *Fusarium* species associated with different millet crops. Currently, fourteen *Fusarium* species have been reported to be detected, found, and isolated in millet (Choi et al., 2021). The most important *Fusarium* species in millet include *F. pseudonygamai, F. andiyazi, F. thapsinum and F. proliferatum,* to a lesser extent, *F. verticillioides, F. nygamai and F. napiforme* (Vismer et al., 2019).

In a study conducted in Niger state, out of 49 samples of millet collected during the rainy season, 12 samples tested positive for AFB1 with the concentration ranging from 1370.28 and 3495.10 ug/kg while the prevalent fungi in millet samples collected during the dry season were *Penicillium* spp. (Makun et al., 2007). A survey was also conducted on 50 millet samples (30 millet grain, 20 millet dough (fura) collected in several locations in the Northern part of the country showed that 29% of millet grain with a concentration of 1.05-14.96 µg/Kg, and 26.3% millet dough with a concentration of 0.81-3.78 µg/Kg were positive for AF (Apeh et al., 2016). In Nigeria, a study has reported the incidence of a high amount of FB, DON, and ZEN in millet samples exceeding the European Union limit of 1000µg/kg set for total FB (Adewumi and Fapohunda, 2019).

2.4 Sorghum

Based on FAO statistics, Nigeria is ranked the highest producer of sorghum in West Africa, contributing approximately 71% of the region's sorghum production. With respect to food safety, sorghum is threatened by fungal contamination both on the field and at the post-harvest stage. Mycotoxins contamination of sorghum may be attributed to several factors including suitable climate conditions coupled with crop cultivation methods, harvesting, handling and storage which consequently results in yield and economic losses (Adewumi and Fapohunda, 2019). Mold infestation is estimated to cost Asia and Africa more than US $130 million yearly in economic loss (Ediage et al., 2015). The most common fungi that contaminate sorghum belong to *Aspergillus* and *Fusarium* genera, which are linked to the production of AF, FB, ZEA and DON, with AFs considered the most dangerous mycotoxin to this type of crop (Astoreca et al., 2019). Apart from the susceptibility of sorghum to mycotoxin contamination during pre-harvest, the development of mycotoxigenic fungi is stimulated during traditional malting and milling processes due to unhygienic environment (Nafuka et al., 2019). Sorghum contamination via this process may be prevalent in Nigeria because many environments where milling is done are unclean.

Garba et al. (2017) reviewed the level of fungal contamination and the toxigenicity of fungal strains isolated from sorghum samples studied. From this study, 701 isolates were found, with 67 fungal strains confirmed. The most prevalent species were *Aspergillus* species with 346(49.6%), then *Fusarium* species with 186(26.7%), followed by *Penicillium* species with 102(14.6%). In another study, the concentration of AFB1 in stored sorghum grain was reported to be higher compared to sorghum at farm-gate with mean of 262.8 and 9.88 µg/kg respectively. In the same study, a similar trend was observed for OTA and ZEN (Ezekiel et al., 2018).

2.5 Cassava

Nigeria is the world's largest producer of cassava with 59 million tons (approximately 20% of global production), followed by Congo DR, Thailand and Indonesia respectively (Otekunrin and Sawicka, 2019; FAO, 2021). Production is expected to rise with the development of high-yielding cultivars and improvement in production techniques (FAO, 2021). However, the expected rise may be a daunting task to achieve in the near future due to the invasion of farmlands by several biotic stress such as fungal development in regions where cassava is mostly cultivated. Contamination of cassava by mycotoxins may be more severe in Nigeria because it's cultivated in the rainforest and derived savannah zones of the country which are considered a conducive environment for fungi to thrive. At the post-harvest, significant deterioration of fresh cassava roots is observed due to high moisture content, which triggers microbial degradation and unwanted biochemical changes in the products. However, the types and concentration of microbial metabolites observed in the end products are influenced by the processing methods used, the environments and the natural micro-flora (Abass et al., 2017). During fermentation, if all conditions are conducive (pH, humidity and temperature), Aspergillus spp. may produce AFs (Obong'o et al., 2020). Some post-harvest fungi that attack cassava include *Aspergillus, Fusarium* and *Penicillium*. This can bring about offensive odours and discolouration (Gnonlonfin et al., 2008).

A study reported that 71% of of processed cassava samples (Garri and lafun) tested positive with at least one mycotoxin at a rate of 72% (Lafun) and 54% (Garri). In Garri, DON was the most commonly detected *Fusarium* mycotoxins at the rate of 38%, while FB2 was the most prevalent in Lafun with an incidence rate of 61% (30-392 mg/kg) (Chilaka et al., 2018). Another study in Nigeria reported that the concentration of AFs and FB present in the Pupuru (a locally fermented cassava flour) samples ranged from 0.00096 - 0.0081 ppm and 0.08 - 0.68 ppb respectively. In the same study, six fungal species were isolated which include *A. flavus, A., niger, P. chrysogenum, P. italicum, F. moniliforme* and *Rhizopus stolonifer* (Adeyemo and Olaribigbe, 2019).

2.6 Yam

Nigeria is the leading yam producer across the globe with 73% production, then Ghana, Coˆte d'Ivoire, and Benin with 12.1%, 10.5%, and 4.5% production respectively (Neina, 2021). Despite the increasing demand for yams locally and at the international level, the production frequency has decreased in recent years (Aighewi et al., 2021). Yam beetles especially wound the tubers by creating holes in the tuber thereby reducing the tuber's quality and then facilitating fungal infection consequently leading to tuber rots (Bassey, 2017). However, post-harvest spoilage of yam is prevalent. During post-harvest activities such as harvesting, transportation and handling, the cortical periderm which is thin get sloughed off easily, exposing the tubers to rot agents (Bankole and Mabekoje, 2004). Post-harvest physiological degradation of yam may bring about up to 60% fresh weight losses after nine months of storage; up to 70% rotted tubers after 5 months and up to 60-70% consumable dry matter losses after 10 months (Somorin et al., 2012). In Nigeria, more than 50% of the overall yam tuber produce is lost at storage. Hence, due to the perishable nature of yam, during the harvest season (July to September), it is available in abundance, inexpensive, and relatively affordable but limited in supply and costly thereafter (Bankole and Mabekoje, 2004). In order to minimize losses at the post-harvest phase, harvested yams are processed and converted into other end products such as chips and flakes to reduce the water activity (Omohimi et al., 2019).

A survey was conducted in Nigeria on seventy-six samples of dried yam chips purchased from the market, aimed to determine the presence of different types of moulds and levels of AFB1 in the samples. From the study, the nine fungal genera were isolated which include Aspergillus, Penicillium, Botryodiplodia, Cladosporium, Fusarium, Rhizopus, Mucor, Aureobasidium and Paecilomyces while 17 samples tested positive for AFB1 with the concentration ranging from 8.5 – 80.4 ppb (Bankole and Mabekoje, 2004). The latest survey conducted by Onyedum et al. (2020) showed the presence of AFs, OTA, and Fumonisin in yam flour with mean concentrations of 16.51, 2190, and 3.94 µg/kg respectively.

2.7 Groundnut

Despite Nigeria being one of the largest groundnut (also known as peanut) producers worldwide, the exportation of groundnut to other countries is still much smaller compared to other commonly consumed crops (Oyedele et al., 2017). During pre- and post-harvest phase of production, groundnut is vulnerable to contamination by aflatoxin-producing fungi notably *A. flavus* (Vabi et al., 2020). *A. flavus and A. parasiticus* are found in abundance in tropical countries where groundnut is cultivated. This makes it prone to mould infection. Moreover, the humid and hot environment of the tropical regions enhances fungi growth and development which predispose crops to AF contamination both in the field and at the post-harvest stage (Mupunga et al., 2017). Furthermore, insect herbivory and the occurrence of drought stress make the crop more vulnerable to fungal infection bringing about pre-harvest contamination while improper drying and inappropriate storage conditions result in post-harvest contamination (Mupunga et al., 2017).

The presence of AFB1 were detected in all peanut butter evaluated by Uzeh and Adebowale, (2021), with the concentration of the total AFs in the samples ranging between 373.6µg/kg – 6741.6µg/kg and the incidence rate of other AF (B2, G2, G1) present were 71.43%, 85.71%, and 57.14% of the samples respectively. Besides the occurrence of AFs in groundnut samples in Nigeria, other mycotoxins have also been reported to exist in the samples. Ifeji et al. (2014) reported that 88.9, 75.3 and 90.1% of roasted groundnut samples tested positive for AFB1, AFB2 and OTA respectively with the concentration ranging from 4.0–188 µg/kg for AFB1, 0.4 – 38.4 µg/kg for AFB2 and 0.8–45.6 µg/kg for OTA. 55% of the samples that tested positive for OTA exceeded the set limit of Nigerian and European Union standards while all samples positive for AFs exceeded the limit.

2.8 Cowpea

Nigeria is the largest in terms of cowpea consumption and production worldwide (Ogungbemile et al., 2020). The invasion of cowpea fields by pests and diseases has led to considerable yield loss in the humid forest of Nigeria. In the humid south-western part of the country, the most prevalent and economically important diseases associated with cowpea production include anthracnose, choaniphora pod rot, false smut, web blight, sclerotium stem blight, Cercospora leaf spot, and brown blotch (Nneji et al., 2020). Improper and poor post-harvest practices and processing infrastructure has resulted in significant post-cultivation losses such as seed discoloration are observed in Nigeria and other developing nations, thus providing a suitable environment for the proliferation of storage fungus (Kareem et al., 2018; Ogungbemile et al., 2020) which subsequently brings about a net grain that is only a fraction of the original worth (Sokefun et al., 2018).

Few incidences of mycotoxins occurrence in cowpea have also been reported in Nigeria. For instance, Popoola et al., (2010) evaluated the level of mould contamination in three varieties of cowpea collected from the Bulumkutu market, Maiduguri. From the study, three genera of mould including Zygomycete, Aspergillus and Penicillium were detected. The highest mould contamination was found in the Borno Brown variety while the lowest was in GV at the rate of 57.6% and 14.3% respectively. Finally, Ogungbemile et al., (2020) conducted a recent survey to the determine presence of total AFs in stored cowpea seeds in Ibadan, Nigeria. In all samples evaluated, AFB1, AFB2, AFG1, and AFG2 were detected. In Nigeria, reports on the occurrence of mycotoxins in cowpea are scanty. This signifies that little is known about mycotoxins contamination in cowpea. This is highly detrimental to human health especially since this crop is considered as one of the major foods consumed by the populace.

3. Factors Affecting Mycotoxin Production in Nigeria

3.1 Climatic Conditions

Change in climate is proposed as the most significant environmental problem and challenge facing the world, with Africa bearing the vast majority of the consequences. Changes in environmental conditions such as variations in temperature, CO_2 and rainfall patterns may enhance the risk of pathogen migration and influence mycotoxigenic fungal species colonizing crops (Gbashi et al., 2018). The two most important climatic factors that promote the development of fungal and the production of mycotoxins in agricultural commodities are temperature and moisture content. Another variable that influences the moisture level is relative humidity, which results in water available for the development of mold and then the production of mycotoxin. Generally, most molds thrive at a temperature ranging from 10 - 40.5 °C, with relative humidity above 70% and a pH range of 4 - 8 (Neme and Mohammed, 2017). These conditions approximate the ambient climatic conditions in most parts of Africa and so account for the continent's high incidence of the toxins

During water stress, an increase in AF contamination is experienced because of the reduction of moisture content in the groundnut pod, consequently allowing the entry of *A. flavus* via the fractures in the pod wall. Furthermore, water stress inhibits phytoalexin production by lowering the water activity in the kernel consequently leading to an increase in AFs level and concentration (Pandey et al., 2019). In studies conducted in South Africa as far back as 1965, the relationship between drought and high AFs contamination was established. This same association was also reported in studies conducted on agricultural products in USA and Nigeria (Sanders et al., 1993).

3.2 Farming System and Agricultural Techniques

Poor farming systems and practices during production and cultivation can transfer fungus from the field to the post-harvest processing and storage stage (Singh et al., 2019). For instance, yield cultivated from farmland that was previously used for groundnut production a year before was more infested by *A. flavus* and AFs concentration compared with produce cultivated from cropland which was previously used for rye, oats, melon, or potato farming. This indicates that the growth of mycotoxigenic mould is influenced by a farming system such as crop rotation. In contrast, it has been demonstrated that soil that was previously treated with fungicide reduces the occurrence of *A. flavus* in groundnuts to an extremely low degree (Atanda et al., 2013).

3.3 Soil Types and Conditions

The introduction of AFs into the soil occurs when contaminated agricultural crops from the storage system are worked back for the natural degradation process in the soil or when plant residues that are contaminated are left to decay in the soil. This process has the potential to increase significantly the incidence and concentration of AFs present in the soil environment and extend the duration of AFs contamination (Fouché et al., 2020). In Nigeria, AF-producing fungi were studied in the soil of maize fields to determine their distribution in different agroecological zones within the country. Based on the outcome of the study, more than 1000 isolates belonging to Aspergillus section Flavi were collected from the soil of 55 Nigerian maize fields located in three agro-ecological zones. The most prevalent member of Aspergillus section Flavi (85% of isolates) was the *A. flavus* L-strain then the unnamed taxon known as strain SBG (8%), *A. tamarii* (6%) and *A. parasiticus* (1%) (Donner et al., 2009). The level of mycotoxin contamination in crops grown in a different type of soil may differ significantly. For instance, light sandy soil support and accelerate rapid fungi growth and development, especially during dry conditions. On the other hand, Groundnuts grown on heavier soils are less contaminated because of the high-water retention ability of the soil which aids in avoiding water stress (Anthony et al., 2012).

3.4 Nutrient Availability

Irrespective of whether moulds have the genetic potential to produce a specific mycotoxin, the amount and rate of production are influenced in part by the nutrient available. Increased concentration of amino acid on the other hand generally reduces the production of AFs (Achaglinkame et al., 2017). Moreover, a deficiency of nitrogen triggers the gene expression involved in the biosynthesis of ochratoxin in *Aspergillus spp*. and fumonisin in *F. proliferatum*. While adequate nitrogen supply caused suppression of fumonisin production (Bouras et al., 2016). Based on experimental results, a low number of AFs was observed in corn produced with higher nitrogen (120 kg ha^{-1}) whereas, corn produced with a lower amount of nitrogen (80 kg ha^{-1}) recorded high AFs contamination (Abbas et al., 2009). This signifies that a proper mixture of macro-nutrients is an important part of crop management. Several literatures have reported that nitrogen sources have a significant impact on the production of mycotoxins (Bouras et al., 2016).

3.5 Time of Harvesting

Harvest of crops is considered the initial stage of the crop production chain. At this stage, the moisture content is regarded as the most significant factor with respect to crop management and protection. The moisture content marks a shift away from the problems experienced on the field by fungi such as *Fusarium* toward storage problems caused by fungi such as *P. verrucosum*. Under normal circumstances, cultivation of grain yield is supposed to be done after a period of dry weather conditions when the moisture present in the grain is at a safe level in order to avoid the need for immediate drying after harvest. In Nigeria, this is not usually done, hence harvesting during the wrong period is a risk factor in the country (Atanda et al., 2013). It was observed that when the harvest of maize was delayed for 4 weeks, an increase in the level of AFs present was observed (Atanda et al., 2013). Delay in harvest coupled with high rainfall events can affect the quality of the crop and leads to mycotoxin contamination if not properly dried. Moreover, some mycotoxins such as trichothecene may contaminate oats during post-harvest conditions due to delay harvest (Magan et al., 2011). In Maize, *Penicillium* toxins mostly occur at the storage stage and when harvesting is delayed producing penicillic acid (Neme and Mohammed, 2017).

3.6 Pest Infestation

Insect infestation is considered another factor that can predispose grain to fungal colonization and subsequent mycotoxin contamination in several ways (Abbas et al., 2013; Jouany et al., 2009). Insects burrowing via husks or down the silk channel can allow airborne or dust-borne fungal pathogens to infect the crop (Abbas et al., 2013). Insect herbivory creates wounds in the kernel, allowing fungi to access the endosperm, and insects themselves serve as a fungal spore vector (Jouany et al., 2009). Due to the detrimental implication of insect damage on crops, it is considered one of the main causes of grain and seed deterioration. Invasion of crops by insects reduces the grade, quality and market value of affected agricultural commodities, making them unfit for animal and human intake in most cases. Pest infestation is mainly caused by poor storage and post-harvest events and conditions and the extent of insect damage determines the level of mycotoxin contamination (Atanda et al., 2013). It was reported that insect damage was a good predictor of *Fusarium* mycotoxin contamination. The insect damage to maturing maize ears allows the strains of *Fusarium* to enter the ears and kernels. *Fusarium* species are always present in the ears and kernels of maize and FB has even been shown to be present in symptomless kernels of maize in Nigeria (Adejumo, and Adejoro, 2014).

3.7 Post-harvest Conditions

In tropical African countries, the presence of humid and warm weather conditions provides an ideal platform for the growth and production of mycotoxins in agricultural products (Gnonlonfin et al., 2012). Storage fungus thrive in grains and other agricultural commodities that have moisture content in equilibrium with 70-90% relative humidity, which corresponds to less than 18% moisture content in cereals (Chacha, and Mamiro, 2019). Improper storage and manufacturing practices which are frequently experienced in many parts of Nigeria favours the development of molds and subsequent mycotoxins production. After harvest, the level of AFs contamination in cereals can rise quickly during storage and manufacturing due to poor management such as high temperature and relative humidity (>65%) (Wan et al., 2020). Furthermore, if drying is delayed at the post-harvest stage, *Aspergillus* and *Penicillium* species that produce Aflatoxin B1 (AFB1$_)$ and Ochratoxin A (OTA) can contaminate foodstuff (Joubrane et al., 2020). Improper post-harvest storage management can result in a significant loss of dry matter and mycotoxins production.

4. Management of Mycotoxins

A survey conducted has revealed that lack of public orientation about crop contamination by mycotoxins is slightly correlated with the educational status of people in a certain part of Nigeria. The vast majority of food dealers, farmers especially subsistence farmers are uneducated or with low educational attainment having no knowledge regarding the consequences of crop contamination by mycotoxins (Imade et al., 2021). Therefore, increasing public understanding and enlightenment regarding the implications of human exposure to this toxin and possible control strategies may be of help in reducing its prevalence while disseminating scientific insights to the wider public for tremendous national and personal development. Local food dealers and the general public should be educated in the native language that they can understand in order to enhance the easy dissemination of information (Achaglinkame et al., 2017). Furthermore, both the local and international media outlets can be considered good platforms to propagate the needed awareness campaign.

The implementation of proper farming practices and good storage and processing facilities and conditions coupled with the use of novel processing technologies such as pulse light, heat, gamma (g) irradiation, cold plasma, electrolyzed water as well as the use of biological and chemical control strategies can help to a greater extent to limit and control the occurrence of mycotoxin in agricultural commodities (Adejumo, and Adejoro, 2014). However, it is important to maintain the nutritional value of agricultural products when decontaminating them. So therefore, prior to the detoxification of mycotoxins in agricultural products, there is a need to carry out proper screening of the products using highly selective and fast detection machines to determine and ensure the presence and quantities of mycotoxins in the products

(Ndagijimana et al., 2020). This implies that the development of fast and efficient detection machines is quite important to supplement the already existing ones.

5. Conclusion

Mycotoxins pose a major threat to both human and animal health when ingested and also cause significant economic loss to the agricultural sector worldwide. In Nigeria, high prevalence of mycotoxins has been attributed to the presence of a suitable and conducive environment in conjunction with negligence in adhering to proper farming practices, proper storage and processing practices as well as hazard analysis and critical control point during different phases of production. The present review provides a comprehensive report on the prevalence of mycotoxins in the eight most produced and consumed crops in Nigeria, especially the uneducated and poor rural residents and farmers to mycotoxins. Hence, raising awareness campaigns among the populace regarding the existence of these dangerous toxins in agricultural products is considered crucial. For consumer safety, control and management strategies including breeding for resistance and biological control, pre-harvest and post-harvest crop management strategies, prevention of exposure to mycotoxins and uses of mycotoxins binder should be employed. Educating and raising awareness among the farmers regarding the health implications of consuming mycotoxin-contaminated products should be intensified. This should be done by communicating with people using their local language for easy understanding and dissemination of information. Diversification of food consumed should be encouraged among the Nigerian population. Furthermore, government and non-governmental agencies, academia as well as the developed nations should collaborate and devote more efforts to strengthening research and development (R&D) on the control of mycotoxins in developing countries in order to enhance food safety across the globe.

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