Mycotoxins: Food Production and Exportation in Nigeria

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ABSTRACT

Mycotoxins are low-molecular weight secondary metabolites produced by fungi, mostly of the phyla Ascomycota and Basidiomycota. They are noncritical to the instantaneous survival of the organism, and mostly affect its long-term survival. Fungal growth is enhanced by the warm, humid atmosphere and organic substrate-rich soil, such as exists in Nigeria, and they massively infect Nigerian plants and livestock. One consequence is reduced agricultural yield, which leads to food shortage. Mycotoxin contamination reduces food quality, making it unfit for human and animal consumption, and lowering its commercial value. It increases cost of production, when cost of fungicides and stringent maintenance and processing practices and facilities are added to the budget. Importantly, they cause health problems, called mycotoxicoses, and reduce life expectancy in affected areas. Excess use of fungicides to deal with contaminants also gives rise to pesticide poisoning, which is common in Nigeria. Internationally, mycotoxins lead to huge fiscal losses annually due to import bans imposed on Nigerian products which do not meet quality standards, as was the case when the European Union rejected over 120 food products from Nigeria between 2013 and 2016. Suggested mycotoxin control methods include: planting resistant cultivars; adhering to excellent farming practices and aseptic techniques; and biological control, such as the use of spores from atoxigenic fungi like Aspergillus flavus and Aspergillus parasiticus.

Key Points: Mycotoxins, Secondary Metabolite, Mycotoxicoses, Pesticide Poisoning, European Union.

1. INTRODUCTION

Mycotoxins are low molecular weight (Aljicevic et al., 2008; Alshannaq and Yu, 2017) secondary metabolites (D’Mello and MacDonald, 1997; Bennett et al., 2003; Zain, 2011) produced mostly by species of the phyla Ascomycota and Basidiomycota. There are many different types, and there is no congruence among researchers on the criteria and nomenclature for their classification (Bennett et al., 2003). However, some common classes include: the aflatoxins, ochratoxins, zearalenone, fumonisins, trichothecenes, ergot toxins, citrinin and patulin (Bennett et al., 2003). Several fungi may produce the same kind of toxin, and a single fungus may produce several different toxins.

As secondary metabolites, they are noncritical to the instantaneous survival of the organism because they are by-products, rather than the drivers, of cellular metabolism; and they mostly affect the long-term survival of the organism amid competition from other species, which, perhaps grow faster and convert the substrate at a higher rate (Kennedy and Wightman, 2011). At other times, the absence of secondary metabolites has negligible to no effect on the existence of the organism, and several fungal species do not even produce them.
Whereas mycotoxins offer numerous benefits to the fungus, the same may not be said for other organisms that come in contact with them. Mycotoxins, despite having a low molecular weight (Bennett and Klích, 2003; Aljicevic et al., 2011) of less than 1,000 Daltons (Alshannaq and Yu, 2017), could still prove deleterious to much larger competition. Organisms ranging from microscopic bacteria, nematodes, and protozoa, to large mammals, are harmed or killed by these products.

In man, they often cause physical harm to major organs of the body, like the liver, kidneys and brain when ingested (Peraica et al., 1999; Pitt et al., 2000; Makun et al., 2018), or spores of toxigenic fungi are inhaled and then produce toxins within the host, in the process of metabolism and growth. People who consume food containing the Claviceps ergot toxin also experience hallucination (Peraica et al., 1999). Also, fungal mycotoxins can bring about massive economic losses due to food spoilage.

Even though they are toxic, man has found ways to harness mycotoxins for his benefit, the most essential being their use as antibiotics (Shiel, 2017). The accidental discovery that Penicillium notatum was able to inhibit bacteria led to intense research on how to use the product to combat bacteria responsible for human diseases. In the process, many other antibiotics of fungal origin were discovered, and today, there are more than 100 different antibiotics divided into 13 classes (Alshannaq and Yu, 2017; Shiel, 2017).

In spite of their benefits, their presence in food substances in certain concentrations makes the food poisonous when consumed, thereby rendering the food substance useless for consumption, processing or sale, leading to food shortage and fiscal losses. Mycotoxins contaminate foods either directly or indirectly (D’Mello and MacDonald, 1997; Tola and Kebede, 2016). When it is direct, it means that the food substance itself is contaminated with the fungus producing the mycotoxin, whereas it is indirect when part of the materials or ingredients used in the production of the food is contaminated with the toxigenic fungus, and while the fungus is destroyed, the toxins remain, as most food toxins are resistant to processing measures (Alshannaq and Yu, 2017).

The toxigenic fungi responsible for this contamination are geophilic, residing in the soil, therefore, any crop grown around where the fungi are located is at risk right from the planting stage (Holden et al.). Other factors may further increase the chances of infection, including: conditions that predispose the plant to stress during growth; warmth; humidity; acidic conditions which favour fungal growth (Peraica et al., 1999); late harvest; improper handling, processing and storage; and lack of awareness of the problem (Bankole and Adebanjo, 2003; Abt Associates, Inc., 2012). These problems are rife in developing societies like Nigeria, in which poor handling practices are very common, and this is why, despite a high crop yield, a large percentage of the food produced in the country gets destroyed by mycotoxins annually (Abt Associates, Inc., 2012). In the process, human, financial and material resources are wasted. In this review, the ways in which mycotoxins have impacted the production and exportation of food in Nigeria are discussed, and three major ways to stop the actions of mycotoxins are proffered.

2. IMPACT OF MYCOTOXINS ON FOOD PRODUCTION IN NIGERIA

Nigeria produces numerous cash and food crops every year. The soil in the sub-Saharan country is very fertile and the annual crop yield is high. The long list of the various cash and food products include: oil palm (Elaeis guineensis), rice (Oryza sativa), garlic (Allium sativum), ginger (Zingiber officinale), yam (Discorea spp.), cereals such as corn (Zea mays), cotton (Gossypium spp.), onion (Allium cepa), corn (Zea mays), cotton (Gossypium spp.), onion (Allium cepa), groundnut (Arachis hypogaea),

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cassava (Manihot esculenta), cashew (Anacardium occidentale), cowpea (Vigna unguiculata), soybean (Glycine max), rubber (Hevea brasiliensis), plantain (Musa paradisiaca), cocoa (Theobroma cacao), timber, pepper (Capsicum spp.), and sugarcane (Saccharum officinarum) (www.finlib.com, Agro News Nigeria, 2018). With an annual production rate of about 50 million metric tonnes per annum, planted over 3.7 million hectares, Nigeria occupies the pole position in cassava production across the globe (Food and Agriculture Organisation of the United Nations). In the year 2017 alone, 335 metric tonnes (MT) of palm kernel oil, 60 MT wheat, 6,550 MT sorghum, 10,500 MT maize, and 15,000,000 MT of rice was produced in the country, and in the year 2016, Nigeria, produced over 57,000 MT of cassava (www.factfish.com; Index Mundi).

Asides growing plants, animals are also reared on a commercial scale at numerous outlets in the country. Fish, chickens, ducks, geese, peafowls, turkeys, guineafowls, goats, cattle, camels, horses, donkeys, rabbits, swine, dogs, cats, sheep, deer, crocodiles, and snakes, are some of the animals reared in Nigeria in commercial quantity annually (Bourn et al., 1994; Nadi, 2015; Ugbohodaga, 2015; Hamagam, 2016).

Despite these seemingly hugefigures, vast portions of the annual harvest in Nigeria get destroyed by mycotoxins, and the net gain is eventually a fraction of the initial value. Numerous studies have been conducted and it has been repeatedly revealed that mycotoxin contamination is endemic in Nigerian crops (Bankole and Adebanjo, 2003; Makun et al., 2018). One specific example includes the contamination of Nigerian maize planted in Abuja—Nigeria, with over 23 different toxic mycotoxins (Anjorin et al., 2016), as revealed in a study. Another study revealed ochratoxin in highly nephrotoxic levels in rice samples grown in Niger State (Makun et al., 2018). Zearalenon, deoxynivalenol, fumonisin, and aflatoxins were also found in the rice samples upon analysis. In a separate study, 80% of samples from maize, one of the most planted crops in the country, planted in different locations in Southeast Nigeria, were contaminated with aflatoxin (Aja-Nwachukwu and Emejuiwe, 1994). Crops like shelled melon, groundnut, and yam chips have also been discovered to be contaminated with aflatoxins. The various cross-sectional and individual studies carried out on diverse food samples from different geopolitical zones reveal that contamination is not restricted to a particular geopolitical zone, but rather the entire country. Livestock are not spared either, as they are exposed to mycotoxins in their feed.

Some specific damages that mycotoxins cause in Nigeria are discussed as follows:

1. **Reduced Yield:** The constant attack on crops planted in Nigeria by pre-harvest toxigenic fungi—called “field fungi”—causes Nigerian farmers to record huge losses every year (Hertveldt, 2016; Udomkun et al. 2017; Pocket Diagnostics, 2018; Makun et al., 2018). Due to their destructive actions, mycotoxins significantly reduce the amount of healthy crops available for harvest due to their destruction of many of the plants during their growth stages (Aidoo, 2011). Fungal spores located in the soil or in the immediate environment of the susceptible plant can attach to the plant and begin their growth, using the plant as substrate (Bankole and Adebanjo, 2003). The light spores can also be air-borne and can land on plants that are not shielded, for example, indoors, or in a glass containment. Mechanical vectors can also carry the fungal spores on them when they take a meal from the environment or from an infected plant, and transmit it to a healthy plant. Many of these vectors are equipped with efficient motility systems, and can travel long distances to spread the fungi.

   In a typical parasitic relationship between the fungus and the plant, the fungus derives its nutrients from the plant, robbing the plant of available nutrients for growth in the process.
The activities of the mycotoxins then weaken the plant’s immune response against the fungus, and the plant cannot efficiently stop the fungus from carrying out metabolic activities at its expense, and from the metabolic processes, more mycotoxins are produced which damage the plant.

In animals, mycotoxins are mainly consumed in their feed when they eat contaminated plants, or processed feeds that are contaminated either directly before or during storage, or indirectly when one or more of the ingredients used in the formulation of the feeds is contaminated with mycotoxins (FAO; Moss, 1996; da Rocha et al., 2013; Makun et al., 2018). This affects the health and productivity of the animals. For example, consumption of feed contaminated with the T-2 toxin resulted in abortion in the final trimester of pregnancy, and also infertility in cattle (Placinta et al., 1999). In calves, ulcers develop in the abomasum, as well as sloughing of papilla in the rumen, when they consumed this toxin at 10-50 mg/kg of feed (da Rocha et al., 2014). A similar effect was observed in poultry. Ingestion of 4 or 16 mg of either diacetyoxyscirpenol or the T-2 toxin caused buccal-oral ulcers, plaque formation, reduced appetite, and slower weight gain in 7-day-old chicks (Zain, 2001). Moreover, the T-2 toxin causes a weakened immune system in cattle by lowering the amount of IgM, IgG, and IgA in the animals, as well as decreasing lymphocyte blastogenesis, activities of neutrophils, and the lymphocyte haemagglutinin response (Mann et al., 1984; Cheeke (Ed.), 1998).

Some studies have also been carried out on the effects of mycotoxins in sheep. Hepatotoxicity developed in sheep poisoned with aflatoxins at 2.5 mg/kg or 5.0 mg/kg of feed for 35 days (Harvey et al., 1995). The ability of dairy-producing animals to yield milk is also impaired by the consumption of mycotoxins (Queiroz et al., 2013). In addition, aflatoxins can damage the liver, impair gastrointestinal functions, reduce feed utilisation efficiency, hamper reproduction, give rise to birth defects, and generally reduce the quality of life of the animals (Howard et al., 2001; Hertveldt, 2016; Alshannaq and Yu, 2017). Under such conditions it will be difficult for the animals to multiply at the expected rate. This problem is heightened in a climate like Nigeria, in which the growth of fungi is highly encouraged, livestock production is practiced all over the country, and consumption of the mycotoxins even in low concentrations can cause a mycotoxicose in the vertebrate animals (Zain, 2010) and it therefore reduces the number of healthy animals for sale. In addition, aflatoxins have been proven to cause increased mortality in livestock (Zain, 2011).

Reduced yield comes with its own problems, one of which is food shortage. In a country like Nigeria with a population of about 195 million individuals as of the time of this writing, decimating the amount of food present in society will lead to food shortage. When this happens, the remaining available food will cost more in the markets, as the farmers will want to recoup investments. The effect is that the estimated 152 million people who survive on less than a dollar a day (Amaefule, 2018), will find it even more daunting to purchase a meal. The consequences of poverty combined with starvation are enormous, and discussing them in full detail will take us far beyond the scope of this review.

2. Reduced Quality: Asides reduced crop and livestock yield, another major problem that mycotoxins cause is reduced nutritional quality of food substances (Peraica et al, 1999; Makun et al., 2018; United Kingdom Food Standards Agency, 2018). The physical quality of the food substance is compromised by the action of mycotoxins, and a food product in which part, or all of its content has been effaced by mycotoxins will not pass most quality tests. Makun et al. (2018) carried out quality tests on numerous samples of rice grown in Nigeria, and subjected them to various analytical tests, such as high
performance liquid chromatography (HPLC) and thin layer chromatography (TLC) to determine whether they meet the acceptable quality standards in terms of mycotoxin concentration. They discovered, first, that there were numerous samples contaminated with different classes of mycotoxins. All (100%) of the samples contained aflatoxins, 67% contained ochratoxin, 53.4% were contaminated with zearalenone, deoxylivanenol occurred in 23.8% of the samples, and fumonisin B1 and fumonisin B2 were found in 14.3% and 4.8% of the samples, respectively.

Secondly, they found out that the aflatoxins found in all of the samples exceed the acceptable limits of 10 μg/kg, which is a binding standard among 77 countries which regulate the acceptable levels of aflatoxin in food products. Also, deoxylivanenol, which has a maximum limit of 2-50 μg/kg, was greatly exceeded, as they found samples within the range of 134-341 μg/kg, whereas zearalenone, fumonisin B’s and deoxylivanenol were found within the regulatory limits of 30-200 μg/kg, 750-2,000 and μg/kg, and <1,000 μg/kg respectively. However, their presence at all should give a cause for concern because, had the plants used not been frozen at -20°C until the time of use, the fungi in the samples stood a chance of continuous metabolism and growth, which would have resulted in an increase in the mycotoxin levels in the rice samples. Reduced quality exhibited by the presence of mycotoxin in food may be exhibited by poor aesthetic appearance, malodorous food substances, partial or total spoilage of samples, and altered taste.

3. Increased Cost: Increased cost is another problem encountered with the presence of toxigenic fungi in an environment (Cary et al., 2011). Farmers who are aware of the dangers that such fungi pose, and have perhaps, had encounters in that line, will go extra lengths to protect their crops in order to forestall wastage of labour and other resources. Such farmers will spend extra in purchasing fungicides to be used upon the crops. As majority of Nigerian farmers are subsistent farmers (Nations Encyclopaedia, accessed 26-04-2018) who sell little to nothing of their produce and have no access to loans and external funding, they make more losses in trying to keep the plants till harvest stage, without getting any financial remuneration on their expenses.

On the other hand, when the farmland is large, spanning hectares, a proportional amount of fungicides will be purchase to cover the entire expanse of land. Large farms which deliver to industrial settings may also opt for mycotoxin tests on samples of their produce. This is quite costly, especially if they intend to run automated tests, which are recommended for large farms. Veterinary costs for animals which consume contaminated feed is another factor that farmers will have to deal with (Hussein and Brasel, 2001). Costs of removing the toxins or preventing them from expression in the animal will also add to the production budget.

Storage costs will also be considerably high if all the samples may be treated with physical and chemical methods prior to storage, to increase shelf life (Hesselt time, 1979; Robens and Richard, 1992). Even while in storage, conditions in the storage facility must be consistently set to one in which the fungi and their spores cannot have access to the grains, or grow, if they are present already. Routine tests are also carried out for mycotoxins. Bearing in mind that the farmers involved will also seek to eliminate other potential pests and pathogens, this presents an added cost which cannot be exempted if the farmer wants to make any profit from his effort. Many farms and organisations such as breweries, store their produce in huge silos that are well-cleaned and monitored. Not only do these cost so much to purchase and maintain, but also, the average subsistent farmer has no financial wherewithal to purchase one.
Where the farm produce are used as ingredients in the production of other edible products such as feed, dairy products, and processed food, there will also be need for analyses of the samples collected for mycotoxins, and, in places where it is permitted by the law, the dilution of highly contaminated food items with uncontaminated ones in order to reduce the mycotoxin titre in the food material to acceptable levels where necessary. This product should then be treated immediately to prevent continuous growth. When all the individual costs encountered during production of the plant, animal, feed, or food product are added together, the producer will also seek to make his own profit, and this will give rise price inflation.

4. Health Risks: Although in highly monitored organisations, such as those under high governmental and public scrutiny, they will put in extra effort and increase budgets to reduce mycotoxin contamination to the barest minimum, the average farmer in the rural area will only concern himself with having food to eat and product to sell as soon as possible, while their physical integrity is still intact, being none the wiser over whether there are mycotoxins in the produce or not, will take the goods to the market as they are. Buyers do not often differentiate between contaminated and uncontaminated samples prior to purchase, and this predisposes them to the risk of mycotoxin poisoning. Even in cases where the presence of mycotoxin in the food substance is established, the commercial value of the food falls considerably (Bennett and Klich, 2001; Abt Associates, Inc., 2012), and majority of the buyers, mostly due to low financial, educational, and other socioeconomic factors, will prefer the cheaper goods, seeing them as cost-effective in a society where money is scarce (Bankole and Adebanjo, 2003). Foods with visible growths of mould are also actively sought out and purchased by those in the lower economic cadre in Nigeria, due to their relative cheapness. Mycotoxins also accumulate in the meat of farm animals and can be consumed when the meat of these animals are eaten (Bennett and Klich, 2003; Aidoo, 2011; Hertveldt, 2016; Aljicevic et al., 2008). Eating them in meat does not reduce their toxic effect. Humans are eucaryotes and vertebrates, just like livestock, and as such, several basic cellular constructs and processes will be highly similar. Therefore, humans are also likely to come down with the same conditions that affect animals upon consumption of mycotoxins. Zearalenone mimics oestrogen, and when in the body, it prevents further production of the hormone, which could lead to reproductive problems in humans (Pocket Diagnostics, 2018). Liver problems also commonly arise from consumption of aflatoxins (Peraica et al., 1999). Aflatoxin B1 (United Kingdom Food Standards Agency), ochratoxin (Bankole and Adebanjo, 2003) and deoxylivanenol (Ashiq, 2015) have also been observed to display genotoxic properties, with a predisposition towards oncogenesis. The vasoconstricting action of the ergot alkaloids produced by Claviceps purpurea induces gangrenous ergotism (Peraica et al. 1999). Ultimately, the life expectancy is affected in areas where mycotoxins are regularly consumed (Bankole and Adebanjo, 2003; World Development Report, 1993).

On another level, humans may not be poisoned directly from mycotoxins, but may die from fungicide poisoning. Generally, pesticide poisoning is a common problem in Nigeria (Asogwa and Dongo, 2009). Residues of various pesticides applied on the plant are usually not removed by the farmers or intermediaries, and often manage to reach the final consumers. Rural dwellers and numerous untrained urban farmers often do not know the correct concentrations to apply on the crop, and end up abusing the chemicals, leading to an overload on the plant and in the soil (; Bankole and Adebanjo, 2003; Asogwa and Dongo, 2009; Ojo, 2016). When the fungicides are abused, one worrying effect is the
resistance to these fungicides, just as antibiotic abuse will engender resistance in bacterial cells (Asogwa and Dongo, 2009; Udomkun et al., 2017).

The pesticides may be eaten in the plant, or they may be washed into water bodies with the surface runoff, and may gather in the soil. The ones that wash into water bodies may destroy aquatic life, or store in their bodies and poison the secondary and even tertiary consumers. Overuse of fungicides in a bid to protect the plant can lead to pesticide poisoning when ingested by man and other species (Sridhar and Ogbalu, 1986; Agriculture Nigeria, accessed 20-04-2018). Fungicides, including other pesticides, may also poison the worker applying them when proper personal protective equipment is not used. Ungloved hands may be contaminated, leading to skin absorption and consequent poisoning, or ingestion when the chemical is not properly washed off the hands after the exercise. Aerosols inhaled, and contact with unprotected feet may also expose one to the poison hazard. Knapsack spraying may lead to poisoning of the farm worker when the cover is faulty and the chemical leaks onto the back of the person spraying (Asogwa and Dongo, 2009). Acute pesticide poisoning may occur even after a single exposure to the poison, and chronic exposure may occur as a result of accumulation of the poison in little doses per time (Ojo, 2016).

3. IMPACT OF MYCOTOXINS ON NIGERIAN FOOD EXPORTATION

On the international scale, mycotoxins have also cost Nigeria huge losses. We already understand that mycotoxins cause reduced yield and food shortage in the country. This affects the quantity of produce available for export. Another major problem lies in the perception and policies of the buyer nations. The culminative effect of fungal infestation of the farmland and stored produce summarily gives a bad international reputation of all agricultural products emanating from the country. This leads to reduced demand of agricultural produce from the country, or a total ban on the goods. For example, purchase of different agricultural produce, especially groundnuts, grown and stored in developing countries has dropped significantly, leading to economic losses to the producing countries (Bankole and Adebanjo, 2003).

A clampdown on aflatoxin-contaminated products led to a law taking effect in 2001, limiting the maximum acceptable level of aflatoxin in a food sample to 2 μg/kg for aflatoxin B1 and 4 μg/kg for aflatoxins in nuts and cereals meant for human consumption (Bankole and Adebanjo, 2003). The policy was estimated to affect the purchase of agricultural produce from several African countries, including Nigeria, costing them USD670 million in annual trade revenue (Kellerhals, 2000).

More recently, between 2015 and 2016, the European Union rejected 67 foods including: sesame seeds, melon seeds, peanut chips, live snails, ginger, prawns, dried meat and fish, mushrooms, palm oil, bitter leaf, cowpea, crayfish, for failure to meet regulatory standards on aesthetics and bacterial contamination, appearance of mould on the samples, and failure of the food products to meet their pesticide requirements (Ogunfuwa, 2017). Physical hazards also present in the foods include glass fragments, faeces of rodents, and dead insects. Prior to that time, the EU had rejected 64 products from Nigeria for similar reasons, and in 2015, the importation of all cowpea from Nigeria was banned, due to the high pesticide concentration in the samples (Ogunfuwa, 2017).

The understanding that the climate is conducive for the growth of toxigenic fungi, and it will be difficult to market the produce, will also discourage international investors from investing in Nigeria’s agriculture. It can also directly reduce the prices of the commodities, as a means
of attracting buyers to their wares. In so doing, they may go as low as the cost and investments, thereby making a loss on the produce.

4. CONTROL OF MYCOTOXINS

Three major non-toxic methods discussed, which can be employed, not just in Nigeria, but in any affected nation, in controlling mycotoxins, and in so doing, increase the amount of food available within the country and for export, are as follows:

1. **Planting of Resistant Species:** Planting of resistant species is by far the cheapest (Warburton and Williams, 2016) and the most beneficial technique in handling the problem of mycotoxin contamination. It reduces the amount of pesticides that will be applied on the plant from planting stage to harvest. This will reduce the fungicide load in the soil, prevent water contamination from runoff, and protect aquatic biota. Decreased use of pesticides will also checkmate the incidence of fungal resistance to the chemicals. When resistant species are planted, they will display higher yield and cleaner, healthier products for consumption. Already, there are genetically-modified cereal plants that are resistant to fungal attack (D’Mello and MacDonald, 1997; Ni and Streett, 2005). Although genetically-modified plants are not accepted in all quarters (Macilwain, 2015), those who grow them should label appropriately when packaging, so that consumers who are comfortable with buying them can purchase without the fear of mycotoxin poisoning. There are also naturally-resistant plant breeds, and these should be used whenever they are available. Diversification should be combined with planting of resistant species, so that if a species is contaminated, and comes out with reduced yield, other plant produces can be sold to supplement the loss. Among livestock, sheep are thought to be the most resistant to mycotoxicoses, next to cattle and pigs, in that order (Bennett and Klich, 2003). The growth of sheep should therefore be popularised to reduce the spread of fungal infections and mycotoxins.

2. **Proper Agricultural Practices:** Asides the climate, which the farmers will find more difficult to influence, the major predisposing factor to mycotoxin contamination, especially in developing countries like Nigeria, lies in poor farming and maintenance practices (United Kingdom Food Standards Agency, 2018). Pre-treatment of the manure or organic fertiliser is a rarity, if at all existent in Nigeria. However, the excrement used for manure may transfer pathogenic microbes to the food manure (Lawal and Babalola, 2017). Birds and rodents have fungal spores in the faeces (Udomkun et al., 2017; Lawal and Babalola, 2017), and when the faeces in collected in large quantity, and poured upon the soil without prior treatment, contamination may occur, and this can even seep into the water body and cause a bigger problem (Lawal and Babalola, 2014). Early harvest is another farming practice that protects the plants from fungal attack and reduces mycotoxin concentration in food produce (Rachaputi et al., 2002). The post-harvest handling and processing should also be done in a manner that contamination will not occur. The storage facility must be dry and clean, as fungi prefer moist areas. In an experiment in Guinea, a reduction of the mean aflatoxin level in groundnut was achieved when the groundnut was thoroughly dried and properly stored (Turner et al. 2005). Radioactive rays are genocidal and can be used to destroy the pests without interfering with the integrity of the food sample (Udomkun et al., 2017). Handling of animal samples should be done in a sterile way—the animal produce should be totally shielded from any source of contamination.
3. **Biological Control:** The principle behind biological control of pests is to use organisms that are predatory to them, or which naturally inhibit them, to stop their growth around the plants. A major characteristic of living things is competition for the available resources by any means at their disposal (which accounts for the production of mycotoxins by fungi in the first place). Hence, to employ the biological method in the elimination of toxigenic fungi, other organisms with better adaptability for that environment will be used. Several studies have proven the efficacy of biological methods against mycotoxin contamination (Bankole and Adebanjo, 2003; Tola and Kebede, 2016; Udomkun et al., 2017). A study carried out in the United States on the use of the spores of the atoxigenic *Aspergillus flavus* and *Aspergillus parasiticus* to inhibit the growth of toxigenic fungi, reduced the aflatoxin contamination of peanuts in the study, by 74.3-99.9% (Dorner et al., 1998). When the atoxigenic strain of *Aspergillus flavus* was used around developing cotton plants, the result was 68-87% reduction in aflatoxin contamination (Bankole and Adebanjo, 2003; Kelman, 2016). Although results available show that postharvest use of atoxigenic fungal spores of *A. flavus* and *A. parasiticus* did not protect against the toxigenic fungi, their use prior to harvest increased the protection of the crops in storage against mycotoxins of toxigenic fungi (Bankole and Adebanjo, 2003).

As far back as 1989, researchers discovered *Saccharomyces cerevisiae* strains that produced toxins which are lethal to other fungi, such as the spheroplast of *Candida*, *Schwanniomyces*, and *Kluyveromyces* (Zhu and Bussey, 1989). Further research should be done to explore how this discovery can be applied on a commercial scale.

5. **CONCLUSION**

In a society like Nigeria, which is characterised by high poverty rate, severe paucity of funds, and serious illiteracy problem, from now till the foreseeable future, it will continue to be a great challenge to put the problem of mycotoxins under check, let alone eradicate it. However, planting resistant species, proper farming techniques, adequate training and financial facilities to subsistent farmers will also help upgrade their farming techniques. Biological control methods represent another non-toxic way recommended in handling the problem. Chemical methods are not given much prominence in this review because of the existing pesticide challenges in the country.

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