JOURNAL OF AGRICULTURAL ECONOMICS, EXTENSION & SCIENCE
ISSN (Print) 2545-5179, ISSN (Online) 2714-5018
Official Journal of the College of Agricultural Economics, Extension & Science
JAEES Vol. 6 No. 3 2020, Pages 19 - 39
www.jaees.org

A REVIEW ON IMPLICATIONS AND CONTAINMENT STRATEGIES OF MYCOTOXINS FOOD CONTAMINATIONS IN NIGERIA

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Abstract

The quality and safety of food remain pivotal issues in the livelihood and health profile of every human and animal. The United Nation's Sustainable Development Goals (SDGs) which underscore improved quality nutrition, food security and attainment of healthy living have been challenged by mycotoxin food contaminations. A plethora of biological toxins known as mycotoxins, are certain secondary metabolitesproduced by filamentous fungi with multiple toxicological effects categorized as hepatotoxins, nephrotoxins, vomitoxins, neuro-musculotoxins, carcinogenic, immunosuppressive or mutagenic as the case may be. Some molds are capable of producing more than one mycotoxin; while a particular mycotoxin can be produced by more than one fungus species. Mycotoxicosis could arise when mycotoxins contaminated food stuffs are either inhaled or ingested. In this work, we reviewed the implications of mycotoxin contaminations of agricultural commodities which are of course shortfalls in the economy of agricultural products and health challenges. Likewise, containment strategies have been reviewed and profiled into physical, chemical and biological controls. Therefore, it is pertinent for policy makers and responsible agencies to adopt preventive measures in the form of crop rotation, use of resistant varieties as well as intense drying prior to storage in order to safeguard not only the economy but also the health of the nation.

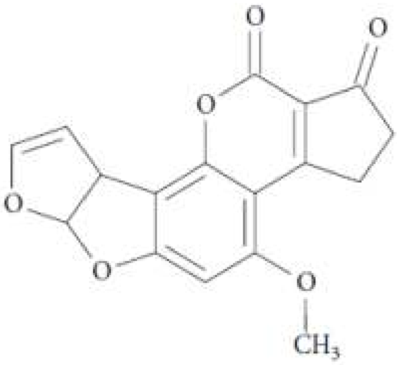
Keywords: Implications; mycotoxins; food contaminations

Introduction

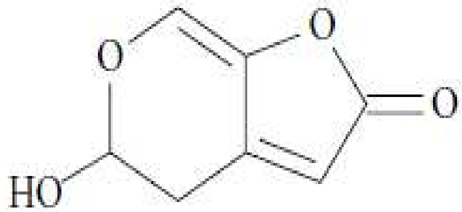
According to the Food and Agricultural Organization of the United Nations (FAO, 1999), about 25% of the world food crops including many basic foods are contaminated by mycotoxins and the estimated global losses of foodstuffs due to mycotoxin contamination is approximately 1billion tons per year.This is tied to the ability of mycotoxins to grow under wide climatic conditions.

The word mycotoxin is coined from both Greek word “mykes” meaning fungus and Latin word “toxicum” which means poisonous. Mycotoxins are therefore, toxic natural secondary metabolites produced by certain strains of some filamentous fungi (as *Fusarium,Aspergillus* and *Penicillium* genera) on agricultural commodities. They are produced by moulds growing on agricultural commodities and allied products under favourable conditions. The highest number of boarder rejections of agricultural produce have been cataloged on the potential hazards of mycotoxins detection as reported by Rapid Alert System for Food and Feed (RASFF) (http://ec.europa.eu/food/safety/rasff/index_en.htm). thus, the wide spread occurrence of mycotoxins (especially aflatoxins) undermines regional integration and establishment of continental free trade zones in agro-commodities. Huge losses in post-harvest of crops caused by mycotoxins contributes to food insecurityand a decline in economic gains.

The presence of mycotoxins in foods and feeds predisposes the health of human and animals in arrays of deleterious effects either in gastrointestinal, estrogenic, kidney disorder, carcinogenicity and mutagenicity and to a large extent, they suppress the immune system and leaving it more prone to infectious disease attack (ESFA, 2012; Marin *et al.,* 2013). The degree of toxicity on biological membranes or cytoplasm by mycotoxins varies with varying chemical structures, hence, hundreds of mycotoxins are recognized and as categorized into subscripted groups as 1, 2,...level of carcinogenicity to human by the International Agency for Research on Cancer (IARC)(IARC, 1993) and most relevant groups found in foods are aflatoxins (aflatoxin B_1 (AFB_1, aflatoxin B_2(AFB_2), aflatoxin G_1 (AFG_1), aflatoxin G_2 (AFG_2) and aflatoxin M_1 (AFM_1), metabolite of AFB_1, excreted in the milk of mammals)); ochratoxin A(OTA); trichothecene(HT-2 and T-2 toxin and deoxynivalenol (DON); zearalenone(ZEN); fumonisins B_1 and B_2(FB_1 and FB_2); citrinin(CIT); patulin (PAT) and ergot alkaloids (Marin *et al*., 2013; Caprioti *et al.,* 2012) Mycotoxins do not only implicate in economic losses when foods and feeds are contaminated but also when consumed, or breathe in or get into the body of human and animal in a way, exerts a great deal of health implication (Negedu, *et al*., 2011). About 400 types of known mycotoxins whose classification are dependent on the type of fungus, moment of production, structural characteristics or the toxicological effect (Bhat *et al.,* 2010). Below are the structural representations of some mycotoxins:



Aflatoxin



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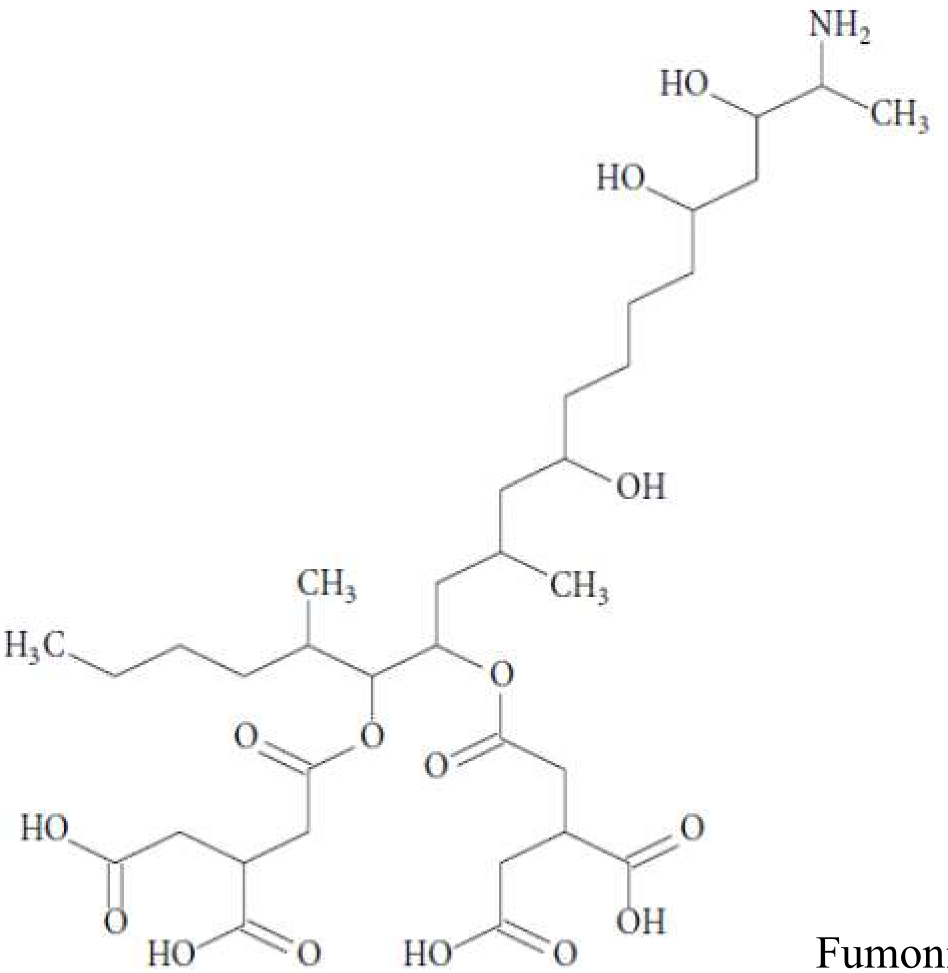
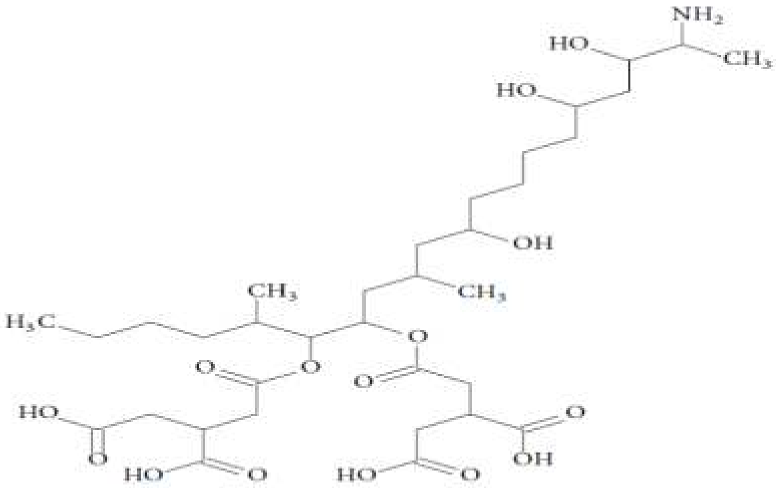
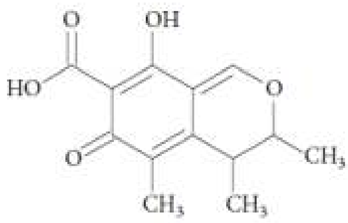


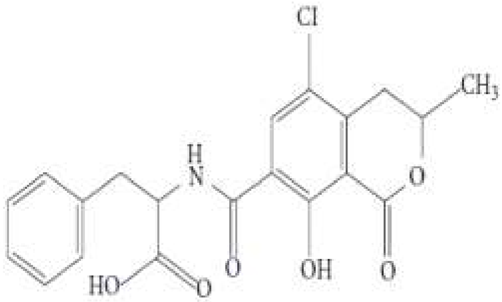
Fumonisin B_1



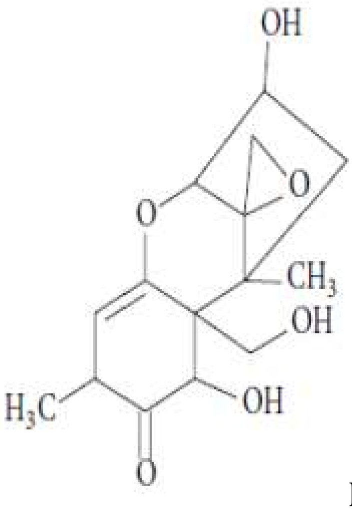
ıonisin B_1

Citrinin





Ochratoxin A

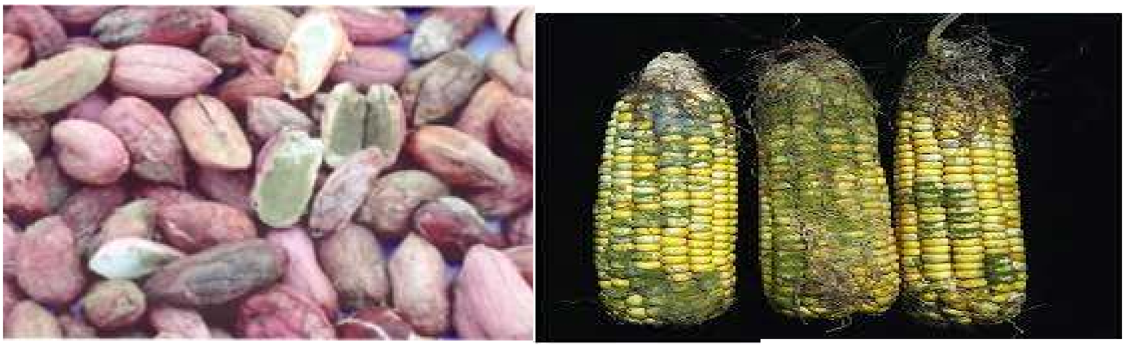


Deoxynivalenol

Figure 1.0 Chemical Structures of Some Mycotoxins of Importance

Characteristics of Mycotoxins

Mycotoxins are of course natural toxic contaminants present on surfaces of spores, mycelial fragments with multiple exposure routes. Mycotoxins are resistant to degradation thus causing short- and long-term effect as they are produced from numerous species and thus cannot be seen with the naked eyes but suspected to be either rotten, moldy, decolorized, bitter taste, foul smell when food or food products are contaminated (Ajorin *et al.,*2015).Characteristically, a wide range of agricultural and food products are commonly found contaminated with mycotoxins among which are nuts (groundnut, walnuts, cashew nuts, almonds etc.), cereals (maize, sorghum, millets, rice, wheat, (Atawodi *et al.,* 1994, .Makun et al., 2010), oil seeds such as soya beans, cotton seeds, castor oil seeds, sunflower seeds, palm fruits (Negedu, *et al.,* 2011), spices such as onions, ginger, garlic), tubers (Irish potatoes, cocoyam, cassava etc.), livestock and poultry products such as cheese, meat, egg, milk etc.; agro- allied products such as peanut butter, cornflakes, animal feeds, marijuana, fruit juice (Negedu *et al.,*2011).



Source: ICRISAT 2017

(a) (b)

Figure 1.0: Photographs of mould infected grains: (a) stored groundnut (b) maize

Mycotoxins can enter the food chain directly through plant products such as cereal grains, coffee, oil seeds, spices, fruit juices among others, and indirectly from animal diets in the form of feeds or pastures contaminated with mycotoxins, which can leave residues in milk, meat, and other products(Habib *et al*., 2015).

Conditions for Mycotoxins Production

Several conditions or factors influence the nature and quantity of mycotoxins that can be produced and these include: the types of substrate, moisture content, available nutrition, temperature, humidity in the surrounding environment, maturity of the fungal colony, co occurrence with other fungi, competition from other microorganisms, stress factors, physical damage of the substrate due to insect activity, and other associated factors (Rao 2001, Atanda *et al.,* 2013). When mycotoxins are produced, they could be present on all parts of the fungal colony, including the hyphae, mycelia, on spores, and of course in the substrate on which the colony grows. High moisture content (15-25%), high relative humidity (70-90%) and warm temperature (20-30°C) enhances mold growth and toxin production (Atanda *et al.,* 2013). Molds are generally aerobic, some species grow in deep mediums such as *stachybotrys,* some in liquid medium with low oxygen levels assuming jelly appearances or even in modified atmosphere with carbon dioxide and nitrogen dioxide (Atanda *et al.,* 2013). Fungi normally grow between 10 and 40 °C of temperature, over a pH range of 4 to 8, and at water activity (aw) levels above 0.70 (sometimes can grow on a very dry surface also) (Lacey 1991). The minimal aw requirements of some of the common toxigenic molds may also vary. For example, for *Aspergillus flavus* it is between 0.78 and 0.80 aw, *A. fumigatus* 0.85 and 0.94 aw, *A. parasiticus* 0.78 and 0.82 aw, *Eurotium* spp. 0.71 and 0.81 aw, *Fusarium spp.* 0.85 and 0.87 aw, and *Penicillium chrysogenum* 0.78 and 0.81 aw (Bhat, 2010).

Stages of Mycotoxin Infestation

Mycotoxins producing fungi can infest grains at pre-harvest stage, during post-harvest handlings or during storage (Habib, *et al.,* 2015). Based on these sites of infestation, toxinogenic fungi can be divided into three groups: (a) field fungi; (b) storage fungi; and (c) advanced deterioration fungi (Atanda *et al.,* 2013). The first category includes species of plant pathogenic fungi, namely, genus *Fusarium*, e.g. *F. moniliforme, F roseus, F. tricinctum and F. nivale.* The "storage fungi" are principally the general *Aspergillius and Penicillium*, e.g. *A. flavus and A. parasiticus*. The "advanced deterioration fungi" normally require high moisture contents and do not infest intact grains but easily attack damaged ones. The examples of the third group are *A. clavatus, A.fumigatus, Chaetomium, Scopulariopsis, Rhizopus, Mucor, and Absidia*.

Implications of Mycotoxin Food Contaminations

Economy and food security

The economic challenges attributed to mycotoxin contamination are widely impacted in agricultural sector from production to consumption in a number of ways (WHO, 2000). The farmers are affected by limited yield or limited harvest, restricted end market and inevitable price discounts, the handlers are affected by restricted storage options, cost of testing grains, grains processors incur higher cost as a result of higher losses, monitoring costs and restricted end markets. The consumers end up paying higher end products prices and the entire society pay higher cost due to increased regulations, needed research, lower export cost and higher import costs (Habib, *et al.,* 2015).

The contamination of food and feeds with mycotoxins remains a significant global problem. The three major crops and their product (Rice, Wheat and Maize) which are acknowledged as the staple foods that accounts for 60% of global energy intake are vulnerable to the risk of mycotoxins (Adedeye, 2016). Regulations on mycotoxins have been set and are strictly enforced by most importing countries there by affecting international trade. The economic importance of mycotoxins is considerable in countries where agricultural commodities account for about 50% of national export(UNEP 2016).
Annual food loss of 16% is attributed to microbial diseases out of which fungi alone has contributed about 80% (David *et al.,* 2013). Fungi being cosmopolitan and flourish under the same environmental conditions where most of the staple foods can effectively grow has affected the quality of products and causing massive production loss (CAST,2003).Changes in climatic patterns also have serious implications for food safety and security in Africa (UNEP 2016). Unseasonable rain, drought and high temperatures increase the risk of aflatoxin and fumonisins contamination in many tropical countries (Medina *et al.* 2014). *Aspergillus, Penicillium, Fusarium, Trichoderma*, *Trichothecium* are some of the significant fungi groups producing mycotoxins like Aflatoxins, Fumonisins, Ochratoxins among others (Richard, 2007). FAO estimates that mycotoxins, produced by different groups of fungi, has affected one-third of global food crops (Krska *et al*., 2012). The United States, the largest producer of corn, reported that 98% of samples were affected by at least one mycotoxin and 74% of corn contained more than two mycotoxins (Mycotoxin Survey in US corn, 2019). These alarming figures implicate the amount of food lost due to contamination by mycotoxins, ultimately leading to a threat to global food security.Researchers at the World Bank have opined that aflatoxin contamination prevents the redevelopment of a groundnut export market in Europe and Africa(Diaz Rios and Jaffee 2008, Atawodi and Lamorde, 1994). Europe has been able to meet its import needs for groundnuts by switching to China and the USA (Boonsaeng *et al*. 2008). Africa has the potential to revive its share in the global market as the major net exporter of groundnuts in the decades to come. Europe is the largest peanut importing region and Africa could be competitive if a compliant supply chain will be established (Atanda, 2013). Recently, the African Union Commission (AUC)-Partnership for

Aflatoxin Control in Africa (PACA) estimated the losses from aflatoxin related cancer cases in Africa to exceed $100 million USD (PACA 2018).

Health implications of mycotoxins

Through ingestion alongside food, skin contact or inhalation, mycotoxins contaminated foods or food products, feeds, fodders and silages successfully get into the body system (Gallo *et al.* 2015). On health perspectives, mycotoxins of importance in foods and feeds are: aflatoxins, ochratoxin, trichothecenes, fumonisins, ZEN, and patulin. Aflatoxins, fumonisins, and ergot alkaloids are associated with acute mycotoxicoses in both humans and livestock. However, on the positive side, mycotoxin associated diseases are not contagious (Rajeev *et al.,* 2009).

Humans and animals (especially monogastrics) are exposed to unknown poisoning that could prolong over a period of time which remain unchecked in many countries that lack the appropriate means to regulate and monitor mycotoxins contamination especially aflatoxins (Habib *et al*., 2015).Ruminants generally have been reported to be more resistant to the adverse effects of mycotoxins because, the rumen microbiota is capable of degrading mycotoxins (Muhammed, 2010).

Though, a public health problem, mycotoxins are neglected and their control is not prioritized by many African governments due to limitations in coordinated monitoring and medical surveillance; hence, exposure impact on health is grossly underreported.

Mycotoxins can cause several serious health issues ranging from acute poisoning to long-lasting and incurable problems like cancer, in humans and animals (WHO, 2018; Surai *et al.* 2008). The impact of consuming low doses of mycotoxins over prolong period can be far reaching resulting health issues such as cancer and other generally irreversible effects in humans and animals (James, 2005). Acute toxicity generally has a rapid unset and an obvious toxic response. (WHO, 2018).The World Health Organization estimated that over 500 million among the poor populace are exposed to unsafe mycotoxin levels, most of whom live in sub-Saharan Africa.

Several human outbreaks of mycotoxicoses have been caused by *Fusarium* species, *F. sporitrichoides* and *F. poae* contaminate cereal grains which were implicated in alimentary toxic aleukia in Russia from 1932 to 1947 (Lewis *et al*., 2005). Fusarium species that are responsible for the production of different mycotoxins like deoxynivalenol (DON), nivalenol (NIV), T-2 and HT-2 toxins, zearalenone (ZEN), fumonisins, etc. has led to severe health issues among which are rapid irritation of skin and irritation, intestinal mucosa and lead to diarrhea. Moreover, long-term exposure to mycotoxins found to be related to neuropsychiatric symptoms like inability to stand on one's toes, inability to walk in a straight line with eyes closed, short-term memory loss, altered blink-reflex latency, verbal recall impairments, etc. (Ratnaseelan *etal*. 2018).

Aflatoxin which is considered to be the most poisonous toxin is produced by molds *Aspergillus flavus* and *Aspergillus parasiticus*. Aflatoxin B1 produced by various strains of *Aspergillus flavus*, *A. parasiticus*, among others are the most potent carcinogenic aflatoxin for animals (Peterson *et al.* 2007). Having a wide variety of host range, i.e. maize, wheat, rice- the three global leading staple food, pulses, spices, milk and milk products, etc., aflatoxin has affected a considerable sum of population all-round the globe. Aflatoxin exposure results in acute toxicities mainly in children, a substantial cancer burden and is associated with child stunting (WHO 2018). Poor awareness about aflatoxins, appropriate control measures to control contamination in the field and in storage and the negative health effects of aflatoxin consumption are reported in most African countries including Nigeria (Antonio *et al.,* 2018). Aflatoxin is potently immunosuppressive (IARC 2015; JECFA 2017; 2018) with certain health implications such as liver cirrhosis, chronic gastritis, Reyes syndrome respiratory associated diseases in many Africa and Asian countries (Adedeye, 2016). To put this into perspective, globally, acute aflatoxin exposure may cause hundreds of deaths while chronic exposure causes nearly a third of all of the liver cancer cases in Africa (Gibbs *et al*. 2015).

Fumonisins (B1 and B2) are cancer-promoting metabolites produced by *Fusarium proliferatum* and *Fusarium verticillioides* which have led to severe health issues in the form of rapid irritation of skin, intestinal mucosa resulting to diarrhea associated with esophageal cancer in humans in various parts of the world (WHO, 2018). Fumonisin is a potent cancer promoter, associated with child stunting, neural tube defect in babies among other birth defects (Maracas *et al*., 2004; Zain, 2010).

Ochratoxin A (OTA), produced by various species of *Aspergillus* and *Penicillium,* are nephrogenic and nephrocarcinogenic compounds that are found to be occurring in kidney, liver, and blood of animals (Adedeye, 2016). OTA found to contaminate field grapes at times but generally it is produced on storage fresh produce in cereal, coffee, dried fruits and spices. Zearalenone (ZEA) produced by *Fusarium* species is found to be affecting the reproductive health of animals (Zain, 2011). The feeding of highly contaminated crops affects animal health and productivity, thus lowering the supply of protein (JECFA 2018). Trichothecene, produced by *Fusarium sp*., *Myrothecium sp.,Phomopsis sp*., *Trichoderma sp*. etc. inhibit eukaryotic protein synthesis, interfering in the initiation, elongation and termination steps of protein synthesis in the animal body. Deoxynivalenol (DON), one of the essential trichothecene and most commonly found in grains, if ingested by animals in higher doses cause nausea, vomiting, and diarrhea (Edite *et al.,* 2014).

Mycotoxins that affect poultry species are the aflatoxins B1, B2, G1 and G2, ochratoxin A (OTA), fumonisins (FUM) and trichothecene. Ducks are most sensitive followed by turkey, broiler and layer rations. Contamination by aflatoxins can reduce bird's ability to withstand stress by inhibiting the immune system (Cegielska-Radziejewska *et al*., 2013). Generally, growing poultry should not receive more than 20ppb aflatoxin, laying birds tolerate higher levels than young birds but should still be less than 50bbp (Bhat, 2010). A higher dose cause reduction in egg size and also lowers the production of eggs. Aflatoxins metabolites have been found in egg yolk, so preventive measures should be taken (Baht, 2010). Ochratoxin A (OTA) is primarily nephrotoxic in terms of L_D50 whose symptoms of toxicity in poultry manifest in reduced growth rate and egg production, anemia, weakness, decrease feed consumption and poor feathering (Skaug *et al.,* 2001).Signs in chicks, ducks and turkey include liver pathology, reduced body weight, reduced feed conversion and weight gain was observed with 300ppm of fumonisinB1(Bhat, 2010).

The most extensively studied mycotoxins on poultry is the T-2 toxin of trichothecene which signaling effects includes oral lesion, decrease egg production and shell quality, abnormal feathering, peroxidative changes in liver and growth retardation(Cegielska-Radziejewska *etal*., 2013).Pulmonary mycosis, abortion, or mastitis has been reported in animals feeding on contaminated silage and hay (Dos-Santos et al., 2003). Contaminated hay has been shown to result in impaired semen quality in bulls (Alm et al., 2002).

Table 1. Preventive Measures of Mycotoxins Food Contamination

GAPs	Activities	References
Choice of variety	-Use varieties recommended for a certain region -Use of resistant cultivars to certain diseases	(Habib*et al.,* 2015).
Crop rotation	- Alteration of crops which are hosts for fungi with crops which are no hosts for fungi -The planting of consecutive small grain crops should be avoided, unless risk assessments indicate only low infection pressure	(Richard, 2007; Peng *et al.,* 2018
Crop planning	- Avoid high temperatures and drought stress during seed development and maturation - Avoid wet periods during early flowering - Maintain recommended plant spacing to avoid overcrowding (increased humidity)	Temesgen and Geremew 2018
Soil and crop management	-Removal, destruction or burial of infected crop residues -Ploughing should especially be considered between two Fusarium susceptible crops -Optimized plant nutrition and irrigation - Avoid insect damage and weeds (grasses) -Timely application of fungicides.	Habib *et al.,* 2015
Harvesting	-Delaying harvest of infected crops may increase mycotoxin content - Planning to harvest the crop at low moisture content and full maturity	Marta*et al.,* 2016
Drying	-The grain should be dried as soon as possible after harvest. - Harvest should be planned according to the capacity of the dryers. - Keep grains at moisture below ± 15 %	Marin*et al* ., 2013; Makun *et al.,* 2010
Storage	-Maintain good quality control at intake for storage -Avoid contamination of stored products by the environment and cross-contamination between stored products -Avoid storage at high moisture content - Good storage conditions: cool, dry and ventilated -Pest control using approved pesticides -Adequate cleaning and maintenance of premises	Lyagin*etal.,* 2005; Mohamed, 2010.
Distribution or transportation	-Ensure that transport containers are dried and free of molds or insect. Protect shipments from moisture entry due to rain; also avoid dust as possible i n case of mold containing dust infestation.	Habib *et al.,* 2015

Prevention of mycotoxin contaminations

Preventing contamination of crops by mycotoxins is the primary measure beyond controlling it. This involves the adoption of good agricultural practices that prevent fungal infection. Among these practices are the use of resistant varieties, optimum maturity harvest, crop rotation to prevent mycotoxigenic fungal biota, crop planning, rapid and intense drying as well as good storage conditions (Tumescent and Geremew, 2018).

Containment Strategies of Mycotoxin Contaminations

Decontamination and detoxification of mycotoxins from various agricultural products are a global problem. Mycotoxins can be eliminated by variousmeans such as thermal insulation, radiation treatment, and low-temperature plasma, chemical methods, such as oxidation, reduction, hydrolysis, alcoholysis, and absorption, and biological methods with the use of biological (Lyagin and Efremenko, 2019). Chemical and physical detoxification methods have many limitations; they cause nutrient loss, time-consuming and ineffective, and need expensive equipment when compared with biological methods that have proven to be more effective and environmentally friendly (Wang *et al*., 2019). Mycotoxin control strategies can be physical, chemical or biological.

Physical control

Hand sorting, washing and crushing combined with de-hulling are some of the physical approaches of reducing mycotoxins (Marta and Bedaso, 2016). A significant number of mycotoxins can be removed by electronic sorting and hand-picking (Dickens and Whitaker, 1975; Kirksey, Cole and Dorner, 1989).Thermal inactivation for a particular toxin should be evaluated for the temperatures of a specific process. Irradiation may also be an option for mycotoxin control. Researches have evident that gamma irradiation at doses from 15- 30kGrays resulted in mycotoxin reduction in groundnut kernels. Also, cooking and steaming for a long time under pressure reduces mycotoxin load (Ephraim, 2015).

Chemical control

Chemical methods of reducing the effectsmycotoxin include alkalization, oxidation, reduction, hydrolysis, hydration and conjugation (He *et al.,* 2010). Ammoniation is the chemical method that has received the most research attention, it is an effective and safe way of decontaminating aflatoxin-contaminated feeds. Nixtamalization is a traditional alkaline treatment of maize that partially degrades aflatoxins and fumonisins, but the residual molecules can either be regenerated by digestive processes or become more toxic (Price and Jorgensen, 1985). The addition of oxidizing agents, such as hydrogen peroxide, has been shown to be an effective aid in nixtamalizatio (Lopez-Garcia, 1998). Some recent studies have shown that hydrogen peroxide and sodium bicarbonate are effective for simultaneous degradation/detoxification of aflatoxins and fumonisin. Other chemical processes that have shown promise in controlling aflatoxins are the use of sodium chloride during thermal processing, sodium bisulphite at various temperatures and ozonation (Burgos-Hernandez, 1998).

Biological control

An emergent alternative to efficiently manage mycotoxins production is the use of biological control agents hence reducing the use of chemical compounds. Using pure microbial strains greatly contributed to the disinfection of mycotoxins in vitro. Moreover, the effectiveness of fermentation in reducing and eliminating mycotoxins was also demonstrated. As it have been reported by Guan *et al.* (2011), it is possible to control aflatoxin B1 by AFB1 binding with probiotics/dairy strains of lactic acid bacteria such as Lactobacillus, Lactococcus, Bifzdobacterium species, Propionibacterium and yeaststrains (Saccharomyces cerevisiae) The use of biocontrol agents for toxigenic fungi control has focused on the efficacy in terms of control of germination/growth/colonization by the fungi to raw or processed food commodities and reduction in the production of the associated mycotoxin by often targeting the biosynthetic genes involved in toxin bio-synthesis (Medina *et al*., 2017). The use of non-toxic strains of A. flavus and A. parasiticus on maize, cotton, pistachio, and peanuts yielded remarkable success in reducing aflatoxin contamination. Fungi such as Aspergillus, Rhizopus, Trichoderma, Clonostachys, and Penicillium spp. show efficient abilities in the detoxification of mycotoxins (Albert *et al.,* 2017)and are able to degrade and possibly convert and use degradation products as a source of energy under starvation conditions (Kagot *et al*., 2019).

Feed additive binding

European Commission defines' feed additives' as materials that suppress or reduce the absorption of mycotoxins, promote the excretion of mycotoxins or modify their mode of action and thereby mitigate possible adverse effects of mycotoxins on animal health (EC, 2009). An ideal mycotoxin binding agent is expected to be harmless to the animal health and productive performance, it should rapidly produce stable detoxified mycotoxin-absorbent complex before mycotoxins enter the blood, it should be effective to different mycotoxin concentrates under various environments of the entire GI tract, and finally, it must be environment-friendly after excreted out of animal bodies (Jard *et al*., 2011).

Food fermentation

Fermentation is a fairly inexpensive mycotoxin disinfection approach that can be used both to improve the ingredients in foods and to reduce and even eliminate mycotoxins. Fermentation can be an alternative and desirable technique to reduce mycotoxins compared to costly and impractical techniques. The nature of metabolites and the toxicity of products formed after fermentation should be carefully documented in order to produce safe foods (Sarrocco and Vannacci,2018).Yeasts, for example, can develop rapidly on many substrates in bioreactors, unlike many filamentous fungi or bacterial antagonists, yeasts do not produce allergens or other secondary metabolites (Tilocca *etal* 2019; Farbo *et al.,* 2018).

Moreover, low concentrations of mycotoxins AFB1 and OTA in chicken diets can be reduced with the addition of S. *cerevisiae* yeast cell walls (Mendieta *et al.,* 2018). Microbial transformation such as bacterial biotransformation for instance bacterial strain *Nocardia corynebacterioides* (formerly *Flavobacterium aurantiacum*); fungal biotransformation by non-aflatoxinproducing filamentous fungi, edible fungal strains and biotransformation by its producing fungi which is dependent on mycelial lysis and high-aeration and microbial enzyme transformation such as peroxidase enzyme such as laccase enzymes from various sources play an important role in controlling AFB1 contamination (Guan *et al*., 2011) Many bacterial strains belonging to *Streptococcus, Bifidobacterium, Lactobacillus, Butyribrio, Phenylobacterium, Pleurotus, Saccharomyces, Bacillus and Acinetobacter* genera and certain fungi belonging to the genera Aspergillus have more than 95% OTA degradation tendencies and some have shown detoxifying properties (Reddy, *et al.,*2010). Similar to aflatoxins and fumonisins, Saccharomyces yeasts can be used for the decontamination of OTA (Reddy *et al.,* 2010).

Biotechnology for mycotoxin elimination

Biotechnological strategies have come into play in many life endeavors and in the case of mycotoxins elimination, biotechnology is considered with the following three basic requirements: knowledge about the fungus; environmental factors (drought stress); and hostplant resistance (Gabriel and Puleng, 2013). Genetic studies have been done to monitor the molecular characteristics of the toxin in the fungus. (Van Egmond, 2007). As drought increases aflatoxin contamination, drought tolerance trait does not seem to be sufficient by itself to reduce aflatoxin production (Pooja, 2015). Therefore, identification of useful variations among genotypes provides molecular tools for selection of resistant lines of which genetics, genomics and proteomics provided additional information (Nakayashiki, 2005). Advances in genomics, marker development and genetic engineering technology have the potential to improve food safety from aflatoxin contamination (Van Egmond, 2007). Research advances in microarrays, fungal expressed sequence tags (EST), and whole genome sequencing have led to discovery of many genes responsible for host plant interactions and aflatoxin contamination (Bhatnagar-Mathur *et al.,* 2015). Induced gene silencing is a promising technology in which the pathogenic fungi are directed by the host plant to down-regulate the expression of their own genes, without requiring the host plant to express a foreign protein (Nakayashiki, 2005). Gene manipulation studies are extensively in progress to mitigate the molecular regulation of aflatoxins. success has been achieved in identification of genes involved in aflatoxin biosynthesis and their subsequent cloning for use as "molecular tools" for identifying agents and compounds which act as inhibitor in the aflatoxin biosynthesis pathway (Nakayashiki, 2005). This knowledge has opened the possibility of identifying resistance mechanisms which inhibit aflatoxin biosynthesis and, of course, other fungal growth, besides providing a robust and economical way of indirect measurements of fungal toxin control (Ehrlich, 2014).

Conclusion and Recommendations

Evidences abound from multitudes of research have implicated mycotoxin food contaminations to have retrogressively affected economic growth and resulted to many health challenges of both humans and animals. Nevertheless, containment strategies in the form of physical, chemical and biological controls have proven to minimize the level of mycotoxin contaminations in foods as well as in feeds.

From these studies, it is recommended that, in order to minimize both the associated health risks and the economic losses arising from mycotoxins food contaminations, increase in awareness among farmers, grain handlers, food producers on adoption of guidelines such as good agricultural practices (GAPs) or Hazard Analysis Critical Control Points(HACCP)which offers suitable approach to control mycotoxins by preventing its formation should be encouraged. Similarly, conferences, symposiums, trainings and workshops on current trends of mycotoxins should be promoted. Finally, low-cost technologies for assessment, prevention and control of mycotoxins contaminations could be shipped from advanced countries to third world countries in order to curtail the economics and health implications of food mycotoxin contaminations.

References

Adedeye, S.A.O (2016). Fungal Mycotoxins in Foods: A Review. Cogent Food Agric. 2, 1–11.

Anjorin, S.T., Fapohunda, M., Sulyokc, A., Negedu, I. and Ogara, K. (2015). Natural Co occurrenceof Microbial Metabolites of Pearls Millet and Maize Grains in Abuja, Nigeria.

Mycotoxicology, 2: 1-15

Alberts, J.F., Lilly,M., Rheeder, J.P., Burger, H.M. and Shephard, G.S. (2017).Technological

and Community-based Methods to Reduce Mycotoxin Exposure. Food Control Vol. Pp. 73, 101–109

Alm, K., Dahlbom. M., Saynajarvi, M., Anderson, M.A., Salkinoja Salonen, M.S. and Andersson,

M.C. (2002).Impaired semen quality of AI bulls fed with moldy hay: a case report. *Theriogenology* **58**: 1497– 502.

Antonio, F.L, David, M., Mari, E, Rudolf, K., Amare, A., Ranajit, B. and Paola B. (2018). The Mycotoxin Charter: Increasing Awareness of, and Concerted Action for, Minimizing Mycotoxin Exposure Worldwide. Toxins 10:149-166.

Atanda, S.A., Pessu, P.O., Aina, J.A., Agoda, S., Adekalu, O.A., and Ihionu, G.C (2013). Mycotoxin Management in Agriculture, Greener Journal of Agricultural Sciences. 3(2): 176-186

Atawodi, S.E., Atiku, A., and Lamorde, A.G. (1994). Aflatoxin Contamination of Nigerian

Foods and Feeds. Food Chemical Toxicology, Vol.32: 61-63

Bhat, R.V. and Vasanthi, S. (2003). Mycotoxin Food Safety Risk in Developing Countries. In: LJ Univar,

Editor. 2020 Focus 10: Food Safety in Food Security and Food Trade.Washington,D.C.: Intl.

Food Policy Research Inst.

Boonsaeng, T., Fletcher, S. M. and Carpio, C. E. (2008). European Union Import Demand for in Shell Peanuts. Journal of Agricultural and Applied Economics, 40:941–951.

Burgos-Hernandez, A. (1998).Evaluation of Chemical Treatments and Intrinsic Factors that Affect the Mutagenic Potential of Aflatoxin B1-Contaminated Corn. Louisiana State University, Baton Rouge, Louisiana, United States. (Ph.D. dissertation).

Capriotti, A.L., Caruso, G., Cavaliere, C., Foglia, P., Samperi, R. andLagana, A. (2012). Multiclass Mycotoxin analysis in Foods, Environmental and Biological Matrices with Chromatography/Mass Spectrometry. Mass Spectrometry Reviews, Vol. 31, No. 4, pp. 466-503.

CAST (2003). Council of Agricultural Sciences and Technology, Ames, IOWA, USA Mycotoxins.

Risk in Animal, Plant and Human Systems. Task Force Report, 139.

Diaz Rios, L. and Jaffee, S. (2008). Barrier, Catalyst, or Distraction? Standards, Competitiveness, and Africa's Groundnut Exports to Europe. Agriculture and Rural Development Discussion Paper 39, World Bank.

Dickens, J.W. and Whitaker, T.B. (1975). Efficacy of Electronic Color Sorting and Hand Picking to Remove Aflatoxin Contaminated Kernels from Commercial lots of Shelled Peanuts.

Peanut Science., 2:45.

David, Moore, G.D.R. and Anthony, P.J.T. (2013) 21St Century Guidebook to Fungi. Choice Reviews Online, 49(07), 493854-49–3854. DOI: 10.5860/choice.49-3854

Dos Santos, V.M., Dorner, J.W. and Carreira,F. (2003). Isolation and Toxigenicity of Aspergillus fumigatus from Moldy Silage. *Mycopathologia* **156**: 133– 8.

Edite, B., Rocha, M., Freire, F., Guedes, M., Rondina, D. (2014). Mycotoxins and Their Effects on Human and Animal Health. Food Control, 36(1), 159–165. DOI: 10.1016/j.foodcont.2013.08.021

Ephrem, G. (2015). Aflatoxin Contamination in Groundnut (*Arachis hypogaea* L.) Caused by Aspergillus Species in Ethiopia. Journal of Applied & Environmental Microbiology 3(1):11-19.

European Food Safety Authority (2012). http://www.efsa.europa.eu/en/topics/topic/mycotoxins.htm.

Gabriel, O.A. and Puleng, L. (2013). Strategies for the Prevention and Reduction of Mycotoxins in Developing Countries. Mycotoxin and Food Safety in Developing Countries. Available at http://dx.doi.org/10.5772/52542.

Gallo, A., Giuberti, G., Frisvad, J.C., Bertuzzi, T. and Nielsen, K.F. (2015) Review on Mycotoxin Issues in Ruminants: Occurrence in Forages, Effects of Mycotoxin Ingestion on Health Status and Animal Performance and Practical Strategies to Counteract Their Negative Effects. Toxins, 7(8), 3057–3111. DOI: 10.3390/toxins7083057

Gibb, H., Devleesschauwer, B., Bolger, P. M., Wu, F. andAdegoke, G. (2015). World Health Organization Estimates of the Global and Regional Disease Burden of Four Foodborne Chemical Toxins: A data synthesis. F1000Research, 4.

Farbo, M.G., Urgeghe, P.P., Fiori, S., Hassan, Z.U. and Migheli, Q (2018). Effect of Yeast Volatile Organic Compounds on Ochratoxin A-producing Aspergillus carbonarius and A. ochraceus. International Journal of Food Microbiology 2018, 284, 1–10

Guan, S., Zhou, T., Xie, M., Ruan, Z. and Young, C.J. (2011). Microbial Strategies to Control Aflatoxins in Food and Feed. World Mycotoxin Journal 4(4):413-424.

Habib, M.A. Negedu A., Kwanashie, C.N.,and Kabir, J.(2015). Detection of Total Aflatoxin in Chicken Eggs from Four Local Government Areas of Kaduna State, Nigeria.

He, J.W., Zhou,T., Young,J.C., Boland,G.J. and Soott,P.A. (2010). Chemical and Biochemical Transformation for Detoxification of Trichothecene Mycotoxins in Human and Animal Food Chain; A Review. Trends Food Science and Technology 21, 67-76.

International Agency for Research on Cancer (2015). IARC Working Group Report No. 9, Lyon, France.

IARC (1993). Monographs on the Evaluation of Carcinogenic Risks to Humans. Vol.56, IARC, Lyon, France.

Jard, G., Liboz, T., Mathieu, F., Guyonvarch, A. and Lebrihi, A. (2011). Review of Mycotoxin Reduction in Food and Feed: From Prevention in the field to Detoxification by Adsorption or Transformation. Food Additives and

Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment, 28(11), 1590–1609. DOI: 10.1080/19440049.2011.595377

JECFA (2017). Evaluation of certain contaminants in food. Eighty-third Report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series 1002: WHO and FAO 2017.

Joint Expert Committee on Food Additives (2018). Co-Exposure of Fumonisins with Aflatoxins; Food Safety Digest; WHO/FAO: Geneva, Switzerland; pp. 1–4.

Lyagin, I. and Efremenko, E. (2019). Enzymes for Detoxification of Various Mycotoxins: Origins andMechanisms of Catalytic Action. Journal of Enzymes. Vol. 29; pp. 220-239.

Kagot, V., Okoth, S., De Boevre, M., and De Saeger, S.(2019) Biocontrol of Aspergillus and Fusarium Mycotoxins in Africa: Benefits and Limitations. Toxins, 11, 109.

Kirksey, J.W., Cole, R.J. and Dorner, J.W. (1989). Relationship between Aflatoxin Content and Buoyancy in Florunner peanuts. Peanut Science, 16: 48.

Lacey J. (1991). Natural occurrence of mycotoxins in growing and conserved forage crops. In: JE Smith, RE Henderson, editors. *Mycotoxins and animal foods*. Boca Raton.: CRC Press. Pp. 363– 97.

Makun, H.A., Anjorin, B., Moronfoye, F.O. and Balogun, B.O. (2010). Fungal and Aflatoxin Contamination of Some Human Food Commodities in Nigeria. African Journal of Food Science 4(4): 127-135

Maracas, W. (2001). Discovery and Occurrence of the Fumonisins; A Historical Perspective Programme on Mycotoxins and Experimental Carcinogenesis, Medical Research Council, Tygerberg, South Africa. Environmental Health Perspectives 109(2):39-243.

Marin, S., Ramos, A.J., Cano-Sancho, G. and Sanchis, V. (2013). "Mycotoxins: Occurrence, Toxicology and Exposure Assessment" Journal of Food and Chemical Toxicology, Vol. 60.Pp. 218-237.

Marta, T., Bedaso, K. (2016). Occurrence, Importance and Control of Mycotoxins: A review. Cogent Food & Agriculture 2:1191-1203.

Medina, A., Rodriguez, A., and Magan, N. (2014). Effect of Climate Change on Aspergillus flavus and Aflatoxin B1 Production. Frontiers in Microbiology, 5:1–7.

Medina, A., Sejakhosi, M., Nik I, Putra, S., Alicia R-S, Alicia R, Naresh, M. (2017). Biocontrol of Mycotoxins: Dynamics and Mechanisms of Action. Current Opinion in Food Science 17:41-48.

Mendieta, C.R., Gomez, G.V., Del Río, J.C.G., Cuevas, A.C. and Ávila, E.G.(2018) Effect of the Addition of Saccharomyces Cerevisiae Yeast Cell Walls to Diets with Mycotoxins on the Performance and Immune Responses of Broilers. Journal of Poultry Science, 55,38–46.

Negedu, A., Ameh, J.B., Umoh, V.J., Atawodi, S.E., and Tanko, H.Y. (2011). Economics andHealth Perspectives of Mycotoxins: A Review. Continental Journal of Biomedical Sciences, 5(1): 5-26

Mohamed, E. Zain. (2011). Impact of Mycotoxins on Human and Animal, Journal of Saudi Chemical Society, 15, 129-144.

Price, R.L. and Jorgensen, K.V. (1985). Effects of Processing on Aflatoxin Levels and on Mutagenic Potential of Tortillas made from Naturally Contaminated Corn. Journal of Food Science, 50: 347.

Rao, C.Y. (2001). Toxigenic Fungi in the Indoor Environment. In: JD Spengler, J.M Samset, J.S McCarthy, Editors. *Indoor air quality handbook*. Washington,D.C.: McGraw Hill. Pp 1– 17.

Ratnaseelan, A.M., Tsilioni, I., and Theoharides, T.C. (2018). Effects of Mycotoxins on Neuropsychiatric Symptoms and Immune Processes. Clinical Therapeutics, 40(6), 903 917. DOI: 10.1016/j.clinthera.2018.05.004

Richard, J.L. (2007). Some Major Mycotoxins and Their Mycotoxicoses- An overview. International Journal of Food Microbiology 199, 3-10

Pooja, B., Sowmini S., Madhurima, B., Farid, W. and Kiran, K. S. (2015) Biotechnological

Advances Combating Aspergillus Flavus and Aflatoxin Contamination in Crops, Plant Science234;119-132.

Skaug, M.A., Helland, I., Solvoll, K. and Saugstad, O.D. (2001). Presence of Ochratoxin A in Human Milk in Relation to dietary intake. *Food Additive Contamination* Vol. **18**: 321– 7.

Sarrocco, S. and Vannacci, G. (2018). Preharvest Application of Beneficial Fungi as a Strategy to Prevent Postharvest Mycotoxin Contamination: A review. Crop Protection 2018, 110, 160–170.

Surai, P.F., Mezes, M., Melnichuk, S.D. and Fotina, T.I. (2008) Mycotoxins and Animal Health: fromOxidative Stress to Gene Expression.

Temesgen, A. and Teshome, G. (2018) Major Mycotoxins Occurrence, Prevention and Control Approaches Biotechnology and Molecular Biology Reviews 12(1), 1-11

UNEP (2016). Frontier Report: Emerging Issues of Environmental Concern. United Nations Environment Programme, New York.

Nakayashiki, H. (2005). RNA Silencing in Fungi: Mechanisms and Applications. FEBS Letter Vol.579:5950-5957.

Rajeev, B., Ravishankar, V., Rai, A.A. and Karim (2009): Mycotoxins in Foods and Feeds: Present Status and Future Concerns. Journal of Food Science and Food Safety. https://doi.org/10.1111/j.1541-4337.2009.00094.x

Reddy, K., Salleh,B., Saad,B., Abbas, H.K., Abel, C.A. and Shier, W.T., (2010). An Overview of Mycotoxin Contamination in Foods and its Implication for Human Health. Journal Toxin Review 29, 3-36.

Tilocca, B., Balmas, V., Hassan, Z.U., Jaoua, S. andMigheli, Q.A. (2019). Proteomic Investigationof Aspergillus Carbonarius Exposed to Yeast Volatilome or to its Major Component 2 Phenyl ethanol Reveals Major Shifts in Fungal Metabolism. International Journal of Food Microbiology, 306, 108265.

Van Egmond, H.P., Schothorst, R.C. and Jonker,M.A. (2007). Regulations Relating to Mycotoxins in Food. Perspectives in a Global and European Context. *Anal Bio anal Chem* **389**: 147– 57.

Wang, L., Wu, J., Liu, Z., Shi, Y., Liu, J., Xu, X., Hao, S., Mu, P., Deng, F. and Deng, Y. (2019).Aflatoxin B1 Degradation and Detoxification by *Escherichia coli* CG1061 Isolated from Chicken Cecum. Front. Pharmacology, 9, 1–9.

WHO (2018) Mycotoxins News, https://www.who.int/news-room/factsheets/detail/mycotoxins.