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Fungal mycotoxins in foods: A review

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Abstract: This study aimed to review fungal mycotoxins in foods, their roles and significance in human nutrition and health. This paper provided comprehensive information on the mycological quality and mycotoxin safety of foods. The review showed that moulds are multicellular fungi that form thin thread like structures called hyphae. They are widely distributed and found wherever moisture is present with adequate nutrients that can sustain their growth. Fungi are major spoilage of foods and feedstuffs. The proliferation of various fungi in agricultural products leads to reduction in yield and quality with significant economic losses. Fungi produce secondary metabolites which are referred to as mycotoxins which have been found to be present in most food substances. The mycotoxins are low weight metabolites which cause harm known as mycotoxicoses, in livestock, domestic animals and humans and therefore of public health significance. The production of mycotoxins is stimulated by certain environmental factors: Therefore the extent of contamination will differ with geographic location, agricultural methods and the susceptibility of commodities to the penetration of fungi during storage and processing periods. Fungi that produce toxins in food are therefore classified into field fungi and storage fungi based on their ecological requirements for growth. Mycotoxins have been reported in several food products such as cereals, legumes, processed flour, and smoked-dried fish and in dried meats.

Subjects: Bioscience; Environment & Agriculture; Food Science & Technology

Keywords: fungi; mycotoxins; safety; foods; review

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PUBLIC INTEREST STATEMENT

Food safety has become a public health issue all over the world. Food contamination, as a result of fungal infestation and their metabolites, has become a source of concern to the researchers and public. In 2004 in Kenya, 125 people died and nearly 200 others were treated after eating aflatoxin-contaminated maize. The 2004 outbreak resulted from widespread aflatoxin contamination of locally grown maize, which occurred during storage of the maize under damp conditions. Similar cases of food poisoning as a result of toxicity of mycotoxins had occurred in several countries in Africa. This review focuses on various aspects of mycotoxins. The present work collects information that may be of interest both to industry and researchers as regards the opportunity for healthier and safer food for all.

1. Introduction

Moulds are microscopic, plant-like organisms, composed of long filaments called *hyphae.* Mould hyphae grow over the surface and inside nearly all substances of plant or animal origin (Moore et al., 2011). Because of their filamentous construction and consistent lack of chlorophyll they are considered by most biologists to be separate from the plant kingdom and members of the kingdom of fungi. They are related to the familiar mushrooms and toadstools,differing only in not having their filaments united into large fruiting structures (Moore et al., 2011; Richard, 2007).

Moulds are multicellular fungi that form thin thread like structures called hyphae. They are widely distributed and found wherever moisture is present (Adejumo & Adejoro, 2014; Richard, 2007). Fungi are major spoilage of foods and feedstuffs. The proliferation of various fungi in agricultural products leads to reduction in yield and quality with significant economic losses (Adejumo & Adejoro, 2014; Bankole, 1994; Bayman & Baker, 2006; Richard, 2007). They produce secondary metabolites which are referred to as mycotoxins which have been found to be present in most food substances.

The mycotoxins are low weight metabolites which cause harm known as mycotoxicoses, in livestock, domestic animals and humans and therefore of public health significance (Ashiq, 2015; Bayman & Baker, 2006; Bhat & Vasanthi, 2003; Jeswal & Kumar, 2015; Richard, 2007). The production of mycotoxins is stimulated by certain environmental factors: therefore the extent of contamination will differ with geographic location, agricultural methods and the susceptibility of commodities to the penetration of fungi during storage and processing periods (Jonathan & Esho, 2010). Fungi that produce toxins in food are therefore classified into field fungi and storage fungi based on their ecological requirements for growth (Bayman & Baker, 2006; Pelczar, Chan, & Krieg, 1993).

Mycotoxins are a group of secondary metabolites produced by filamentous fungi which may contaminate foods, feeds or the raw materials used to produce them (Ashiq, 2015; Jeswal & Kumar, 2015; Richard, 2007). They also produce mycotoxicoses in humans and animals. The genera of mycotoxigenic fungi are mainly represented by *Aspergillus*, *Penicillium* and *Fusarium*, but *Trichoderma*, T*richothecium* and *Alternaria* are also important as food contaminants or pathogens for plants, among others (Ashiq, 2015; Moss, 1994; Richard, 2007). Mycotoxins, particularly aflatoxins (AFTs) and ochratoxin A (OTA) pose a significant threat to human health. Aflatoxins are potent carcinogens and, in association with hepatitis B virus, are responsible for many thousands of human deaths per annum, mostly in non-industrialized tropical countries (Richard, 2007; Shephard, 2008). AFTs are secondary metabolites, difuranocoumarins, produced by *Aspergillus flavus* and *A. parasiticus,* commonly found in food and feeds and have been associated with various diseases such as aflatoxicosis, in livestock, domestic animals and humans throughout the world (Ashiq, 2015).

Ochratoxin A is a probable human carcinogen and it was reported to cause urinary tract cancer and kidney damage in people from Eastern Europe. Exposure to OTA seems to be the biggest hazard correlated to microscopic fungi for the European consumers of cereals (Ashiq, 2015; Richard, 2007). Fumonisins are a group of *Fusarium* mycotoxins occurring worldwide in maize and maize-based products destined for human and animal consumption. Fumonisins are known to be the cause of equine leuko-encephalomalacia (a brain disease that is often fatal) and porcine pulmonary oedema syndrome (swelling of lungs and thorax), both associated with the consumption of corn-based feeds (Ashiq, 2015; Richard, 2007).

Aspergillus is a group of moulds that is found worldwide. Their potential for contamination of food stuffs and animal feeds is widespread under favourable environmental conditions. The genus Aspergillus is a large proportion of all the moulds found in industrial food (Adejumo & Adejoro, 2014; Onions, Allsopp, & Eggins, 1981; Richard, 2007). They have particular importance as spoilage organisms of food. Changes due to spoilage by *Aspergillus* species can be sensorial, nutritional and qualitative nature like pigmentation, discoloration, rotting development of off odours and off flavours. Many species grow at very low water activity and are found attacking various foods and producing mycotoxins (Adejumo & Adejoro, 2014; Lee, Wang, Allan, & Kennedy, 2004). *Aspergillus niger* are worldwide distributed occurring on a great variety of substrates, is also the most common species of *Aspergillus* and responsible for post-harvest decay (Ashiq, 2015; Pitt, Basílico, Abarca, & López, 2000).

Penicillium is another group of mould with high occurrence. Occurrence of Penicillium in some samples during this investigation is in agreement with the report Barbosa et al. (2013). He reported high occurrence of Penicillium species from fish feed obtained from farm with *Penicillium citrinum* having the highest occurrence. Many of *Penicillium* species can also produce a wide range of toxic compounds such as citrin and citreoviridin (Barbosa et al., 2013; Richard, 2007).

Fusarium is another group of field mould with high occurrence in food and feeds. They produce mycotoxins such as deoxynivalenol and zearalenone (Barbosa et al., 2013; Richard, 2007). The detection of aflatoxigenic mould in the smoked-dried frog samples is in agreement with the work of Gautam, Gupta, and Soni (2012) who reported that aflatoxigenic fungi were screened in rice, also with Sekar, Yumnam, and Ponmurugan (2008) in which aflatoxigenic fungi were screened in dried fruits and grains. Kana et al. (2013) also detected aflatoxigenic fungi in food (grains and maize) and poultry feeds. All the *A. flavus* isolates in this study were all toxigenic.

The occurrence of aflatoxin in the smoked-dried frog samples may be due to contamination of the frog samples by the toxigenic strains of *A. flavus*. Aflatoxin contamination occurs when aflatoxigenic species of *A. flavus* group successfully colonize the sample, grow in it and produce aflatoxins as secondary metabolite. Incidence of aflatoxins in other food products such as smoked-dried fish, dried meats, dried yam chips, has been reported as well (Adebayo-Tayo, Onilude, & Patrick, 2008; Akinyemi, Adejola, Obasa, & Ezeri, 2011; Hassan, Hassan, El-Shafei, El- Ahl, & Abd El-Dayem, 2011; Makun et al., 2010; Oladejo & Adebayo-Tayo, 2011).

The aflatoxin content obtained from the smoked-dried frog samples was higher which is not in agreement with the report of Akinyemi et al. (2011) and Adebayo-Tayo et al. (2008) who reported a lower level which was between 0.0301–1.150 ppb and 1.5–8.1 ppb. The aflatoxins found to be associated with the smoked-dried frog samples sold in different market in Ibadan, were found to be in non-significant levels that may be toxic to human health. According to the regulatory levels issued by the Food Drug Administration (FDA) of United States the levels for aflatoxin intake for humans is maximum of 20 ppb (Food & Drug Administration, 2000).

The occurrence of deoxynivalenol (DON) in the smoked-dried frog samples may be due to contamination of the frog samples by the toxigenic strains of *Fusarium* species. Deoxynivalenol contamination occurs when mycotoxigenic species of *Fusarium* group successfully colonize the sample, grow in it and produce toxins such as deoxynivalenol, zearalenone as secondary metabolite. The occurrences of deoxynivalenol in other food products such as in rice, wheat and maize have also been reported by (Duverger et al., 2011). The deoxynivalenol produced were between (0.00–0.96 ppm). This was also within the stipulated tolerance limits by the FDA of a maximum of 1.0 ppm. Some of the samples were shown not to have Deoxynivalenol (Adejumo & Adejoro, 2014). Bewaji and Bababunmi (2001), also reported that zearalenone which is another mycotoxin produced by *Fusarium* species was not detected in Nigerian food stuffs.

This study aims to review fungal and mycotoxins in foods, their roles and significance in human nutrition and health.

2. Major groups of mycotoxins in foods

Aflatoxins are a type of mycotoxin produced by *Aspergillus* species of fungi, such as *A. flavus* and *A. parasiticus* (Adejumo & Adejoro, 2014; Ashiq, 2015; Martins, Martins, & Bernardo, 2001). The umbrella term aflatoxin refers to four different types of mycotoxins produced, which are B_1, B_2, G_1, and G_2 (Yin, Yan, Jiang, & Ma, 2008). Aflatoxin B_1, the most toxic, is a potent carcinogen and has been directly correlated to adverse health effects, such as liver cancer, in many animal species

(Ashiq, 2015; Martins et al., 2001). Aflatoxins are largely associated with commodities produced in the tropics and subtropics, such as cotton, peanuts, spices, pistachios, and maize (Ashiq, 2015; Martins et al., 2001; Yin et al., 2008).

Ochratoxin is a mycotoxin that comes in three secondary metabolite forms, A, B, and C. All are produced by *Penicillium* and *Aspergillus* species. The three forms differ in that Ochratoxin B (OTB) is a nonchlorinated form of Ochratoxin A (OTA) and that Ochratoxin C (OTC) is an ethyl ester form Ochratoxin A (Ashiq, 2015; Bayman & Baker, 2006; Jeswal & Kumar, 2015). *Aspergillus ochraceus* is found as a contaminant of a wide range of commodities including beverages such as beer and wine. *Aspergillus carbonarius* is the main species found on vine fruit, which releases its toxin during the juice making process. OTA has been labeled as a carcinogen and a nephrotoxin, and has been linked to tumors in the human urinary tract, although research in humans is limited by confounding factors (Ashiq, 2015; Bayman & Baker, 2006; Jeswal & Kumar, 2015).

Citrinin is a toxin that was first isolated from *P. citrinum*, but has been identified in over a dozen species of *Penicillium* and several species of *Aspergillus*. Some of these species are used to produce human foodstuffs such as cheese (*Penicillium camemberti*), sake, miso, and soy sauce (*Aspergillus oryzae*). Citrinin is associated with yellowed rice disease in Japan and acts as a nephrotoxin in all animal species tested (Bennett & Klich, 2003). Although it is associated with many human foods (wheat, rice, corn, barley, oats, rye, and food colored with Monascus pigment) its full significance for human health is unknown. Citrinin can also act synergistically with Ochratoxin A to depress RNA synthesis in murine kidneys (Ashiq, 2015; Bennett & Klich, 2003; Jeswal & Kumar, 2015).

Ergot is a compound produced as a toxic mixture of alkaloids in the sclerotia of species of *Claviceps*, which are common pathogens of various grass species. The ingestion of ergot sclerotia from infected cereals, commonly in the form of bread produced from contaminated flour, cause ergotism the human disease historically known as St. Anthony's Fire. There are two forms of ergotism: Gangrenous, affecting blood supply to extremities, and convulsive, affecting the central nervous system. Modern methods of grain cleaning have significantly reduced ergotism as a human disease, however it is still an important veterinary problem. Ergot alkaloids have been used pharmaceutically (Ashiq, 2015; Bennett & Klich, 2003; Jeswal & Kumar, 2015).

Patulin is a toxin produced by the *P. expansum*, *Aspergillus*, *Penicillium*, and *Paecilomyces* fungal species. *P. expansum* is especially associated with a range of moldy fruits and vegetables, in particular rotting apples and Figs. (Moss, 2008; Trucksess & Scott, 2008). It is destroyed by the fermentation process and so is not found in apple beverages, such as cider. Although patulin has not been shown to be carcinogenic, it has been reported to damage the immune system in animals (Moss, 2008). In 2004, the European Community set limits to the concentrations of patulin in food products. They currently stand at 50 μg/kg in all fruit juice concentrations, at 25 μg/kg in solid apple products used for direct consumption, and at 10 μg/kg for children's apple products, including apple juice (Moss, 2008; Trucksess & Scott, 2008).

Fusarium toxins are produced by over 50 species of *Fusarium* and have a history of infecting the grain of developing cereals such as wheat and maize (Schaafsma & Hooker, 2007). They include a range of mycotoxins, such as: the fumonisins, which affect the nervous systems of horses and may cause cancer in rodents; the trichothecenes, which are most strongly associated with chronic and fatal toxic effects in animals and humans; and zearalenone, which is not correlated to any fatal toxic effects in animals or humans. Some of the other major types of *Fusarium* toxins include: beauvercin and enniatins, butenolide, equisetin, and fusarins (Desjardins & Proctor, 2007).

3. Occurrence of mycotoxins in foods

Although there are many species of toxigenic moulds, only a few mycotoxins, particularly those affecting cereals (maize, wheat, barley, oats and rice) and groundnuts, are considered to be significant for humans (Bhat, Ramakrishna, Beedu, & Munshi, 1989; Desjardins & Proctor, 2007; Jeswal &

Kumar, 2015; Lewis et al., 2005). The most well-known mycotoxin, the potent human hepatocarcinogen aflatoxin, is produced by *A. flavus* and *A. parasiticus.* These moulds occur in warm climates and produce aflatoxin in drought-stressed maize and groundnuts in the field. They also affect these crops and many other commodities (copra, cottonseed, pepper) which are stored under improper conditions of temperature and humidity (Desjardins & Proctor, 2007; Jeswal & Kumar, 2015).

There are 24 toxigenic species of *Fusarium* which are increasingly viewed as having an important effect on human and animal health. *Fusarium graminearum,* which causes head blight and ear rot, produces a variety of potent mycotoxins including deoxynivalenol, zearalenone and fusarin C. *F. sporotrichioides* produces T-2 toxin and related compounds which were responsible for the large-scale human toxicosis in Eastern Europe noted above (Bayman & Baker, 2006; Desjardins & Proctor, 2007; Jeswal & Kumar, 2015

Epidemics of *Fusarium* head blight and maize ear rot are chronic in cereal-growing areas of Asia as well as parts of Africa and South America. Public health authorities in these areas report acute human toxicosis from deoxynivalenol The effect of chronic exposure to trichothecenes (which are immunosuppressors) is not known. Of great concern at the moment are the toxins of *F. moniliforme,* namely fusarins and fumonisins. The presence of these toxins in maize in southern Africa and parts of China may explain the high rates of oesophageal cancer in these regions. There are a number of other species of moulds, particularly *Aspergillus* and *Penicillium,* that produce mycotoxins under poor storage conditions. Ochratoxin is thought to be (Bhat et al., 1989; Desjardins & Proctor, 2007; Jeswal & Kumar, 2015), the most important mycotoxin in this category (Desjardins & Proctor, 2007).

There is no information available on the precise extent of mycotoxins contamination and co-occurrence of various mycotoxins in different commodities on a worldwide basis. Data from the Joint UNEP/FAO/WHO Food Contamination Monitoring Programme indicated that "much of the grain monitored in the United States and the Soviet Union, and to a lesser extent in Guatemala and Kenya, contained 90th percentile levels above 5–20 mg/kg, the regulatory levels for foods in most countries". Data from 185,000 samples of peanuts from Brazil, Guatemala, Ireland, Mexico, Switzerland, the United Kingdom, the United States and the USSR indicated that, for all but 1% of the samples, the 90th percentile levels of aflatoxins were less than 20 mg/kg (Desjardins & Proctor, 2007; Jelinek, Pohland, & Wood, 1989).

Although there is little firm evidence, the results of these surveys suggest that in certain situations as much as 50% of the grain may be contaminated with mycotoxins. In certain years, the deoxynivalenol content in wheat was found to be more than 500 mg/kg in some countries (Jelinek et al., 1989).

The poorest quality grain (where it can be spared) is used for animal feed. Animal feeds with ingredients such as oilseed cakes, peanut, cottonseed and coconut cake or corn grits often contain mycotoxins (Jelinek et al., 1989). Feed conversion to animal protein is always reduced by the presence of mycotoxins. In addition, mycotoxins have a negative effect on animal health and fertility is decreased. When animals ingest the contaminated feeds, some toxins can be metabolized and remain in milk, meat and eggs. The presence of mycotoxins in animal products such as aflatoxins and ochratoxins in milk, meat and eggs has been of concern in some countries (Jelinek et al., 1989; Rodricks & Stoloff, 1977). The levels of toxins such as aflatoxin and ochratoxins present in these secondary sources are much lower than those in agricultural commodities. However, their levels in these products, in particular milk, is strictly regulated in most developed countries. The effects of this source of toxins on human health may be modest in developed countries because of feed safety regulations and pooling of milk at dairies. However, in developing countries where animals are likely to consume mycotoxin-contaminated animal feeds and are milked individually at the household level, the levels of toxins can be higher. Despite this, mycotoxin occurrence in animal products in some high-risk areas is being paid little attention (Jelinek et al., 1989) (Table 1).

Table 1. Mycotoxins in staple grains and seeds

Mycotoxin	Commodity	Fungal source(s)	Effects of ingestion
Deoxynivalenol/nivalenol	Wheat, maize, barley reported from	*Fusarium graminearum* *Fusarium crookwellense* *Fusarium culmorum*	Human toxicoses India, China, Japan, and Korea. Toxic to animals, especially pigs
Zearalenone	Maize, wheat	*F. graminearum* *F. culmorum* *F. crookwellense*	Identified by the International Agency for Research on Cancer (IARC) as a possible human carcinogen. Affects reproductive system in female pigs
Ochratoxin A	Barley, wheat, and many other commodities	*Aspergillus ochraceus* *Penicillium verrucosum*	Suspected by IARC as human carcinogen. Carcinogenic in laboratory animals and pigs
Fumonisin B1	Maize	*Fusarium moniliforme plus several less common species*	Suspected by IARC as human carcinogen. Toxic to pigs and poultry. Cause of equine eucoencephalomalacia (ELEM), a fatal disease of horses
Aflatoxin B_1, B_2	Maize, peanuts, and many other commodities	*Aspergillus flavus*	Aflatoxin B1, and naturally occurring mixtures of aflatoxins, identified as potent human carcinogens by IARC. Adverse effects in various animals, especially chickens
Aflatoxin B_1, B_2, G_1, G2	Maize, peanuts	*Aspergillus parasiticus*	

Source: Food and Agriculture Organization ([FAO], 2004).

4. Health implications of eaten foods contaminated by mycotoxins

The consumption of mycotoxin-contaminated commodities is related to several acute and chronic diseases in humans as well as in animals. While the exact cause and effect relationship has been established for only a few of the diseases, speculation about the role of mycotoxins in the aetiology of various illnesses has been based on circumstantial evidence in other cases. The acute diseases for which there is some evidence of an association with mycotoxins include: Aflatoxic hepatitis in India and Kenya; enteric ergotism in India; vascular ergotism in Ethiopia; and deoxynivalenol mycotoxicosis in India and China. A common feature in all these outbreaks has been the involvement of staple foods such as corn, wheat or pearl millet, following unseasonable rains or drought during either the growing season or harvest (Jelinek et al., 1989).

Among the mycotoxins, aflatoxins have been implicated in human diseases including liver cancer, Reye's syndrome, Indian childhood cirrhosis, chronic gastritis, kwashiorkor and certain occupational respiratory diseases in various parts of the world, particularly in African and Asian countries. In China, the Philippines, Thailand, Kenya, Swaziland and Mozambique, higher levels of aflatoxins in the food supply have been correlated with aflatoxins and their derivatives in human fluids which may be associated with liver cancer (Jelinek et al., 1989; Palmgren & Hayes, 1987). *Fusarium* toxins have been suspected to have a role in diseases such as Kashin Beck syndrome in the USSR, China and Viet Nam; Mseleni joint disease in southern Africa; endemic familial arthritis in India; alimentary toxic aleukia in the USSR; and oesophageal cancer in southern Africa. Ochratoxins have been associated with Balkan endemic nephropathy and urinary tract tumours (Berry, 1988). However, in most of these instances, conclusive evidence for the role of mycotoxins in disease causation has been lacking.

5. Economic implications of mycotoxins in foods

International trade in agricultural commodities such as wheat, rice, barley, corn, sorghum, soybeans, groundnuts and oilseeds amounts to hundreds of millions of tonnes each year (FAO, 1988). Many of these commodities run a high risk of mycotoxin contamination. Regulations on mycotoxins have been set and are strictly enforced by most importing countries, thus affecting international trade. For some developing countries, where agricultural commodities account for as much as 50% of the total national exports, the economic importance of mycotoxins is considerable.

There is a notable length of time between the purchase of the agricultural commodity at the village market of the exporting country and its arrival at the distribution centre of the importing country. The transport chain for agricultural commodities from village to port, from the port of the exporting country to that of the importing country as well as from the port to the distribution centre can be long. Furthermore, storage conditions at the farm level as well as during transport under adverse weather conditions may not always be satisfactory. For these reasons, there is considerable opportunity for mould and mycotoxin contamination of agricultural commodities to take place throughout the food system - from production to distribution and transport - and this may lead to economic losses (Bhat, 1988).

The exact figures for world economic losses resulting from mycotoxin-contamination may never be available. Apart from the obvious losses of food and feed, there are losses caused by lower productivity; losses of valuable foreign exchange earnings; costs incurred by inspection, sampling and analysis before and after shipments; losses attributable to compensation paid in case of claims; farmer subsidies to cover production losses; research, training and extension programme costs; costs of detoxification; etc. When combined, these costs may be staggering (Coulibaly, 1989).

6. Prevention and control of mycotoxins in foods

Several preventive measures to minimize mycotoxin contamination in agricultural commodities have been attempted. These can be divided into three broad categories:

- plant breeding;
- good agronomic practices;
- detoxification.

The problem of ergot contamination of cereals and millets has been successfully minimized in the past by cultivating varieties of rye, wheat and pearl millet that are resistant to the disease. The periodic re-emergence of the problem can be attributed to the release of varieties which are not resistant to ergot. However, there has been little success in providing resistant varieties of corn and peanut to minimize the problem of aflatoxins (Fox & Howlett, 2008; Jelinek et al., 1989). Other agronomic approaches such as avoiding water stress, minimizing insect infestation and reducing inoculum potential have been suggested and are effective when the farmers can implement such practices. Following good agricultural practices during both pre-harvest and post-harvest conditions would, minimize the problem of contamination by mycotoxins such as aflatoxins, ochratoxin and trichothecene mycotoxins (Fox & Howlett, 2008). These include appropriate drying techniques, maintaining proper storage facilities and taking care not to expose the grains or oilseeds to moisture during transport and marketing. The method of segregating contaminated, mouldy, shrivelled or insect-infested seeds from sound kernels has been particularly useful in minimizing aflatoxin contamination in peanuts (Fox & Howlett, 2008; Jelinek et al., 1989).

Detoxification of aflatoxins in foods and animal feeds has been attempted in the past. For instance, Senegal has been operating commercial facilities to detoxify peanut cake contaminated with aflatoxins by the ammonia process. Any detoxification procedure must be tested for safety and efficacy and invariably results in increased handling and costs. In addition, the detoxified product has been considered suitable only for animal feed purposes and not for human consumption (Fox & Howlett, 2008; Jelinek et al., 1989).

Several countries have introduced legislation concerning mycotoxins. Most of this legislation pertains to aflatoxins, ergot alkaloids, deoxynivalenol and ochratoxins. Although various legislative measures have yet to be harmonized among countries, the Codex Alimentarius Commission is making efforts to establish international guideline levels for mycotoxins, and aflatoxins in particular (Fox & Howlett, 2008; Jelinek et al., 1989).

Mycotoxin control measures have been implemented for agricultural commodities entering international trade or located in countries with centralized or large-scale buying and distribution systems. However, in developing countries, where local food consumption or subsistence agriculture is practised by as much as 70% of the population, such measures would be difficult to implement (Fox & Howlett, 2008; Jelinek et al., 1989). Because of the stringent mycotoxin control measures being maintained by those countries importing food grains and oilseeds, and because of the need for exporting countries to earn foreign exchange, the best of the commodities are often sold abroad while the substandard or contaminated commodities are retained for domestic use. Such a situation exacerbates the risk to human and animal health (Fox & Howlett, 2008; Jelinek et al., 1989).

Continuous surveillance of high-risk agricultural commodities for contamination by selected mycotoxins and the monitoring of human population groups for diseases attributable to mycotoxins have to be carried out throughout the world to ensure a supply of safe food which is free from naturally occurring contaminants. The financial and human investments in this endeavour would be returned in terms of better human and animal health as well as reduced economic losses.

7. Removal of mycotoxins in foods

In the feed and food industry it has become common practice to add mycotoxin binding agents such as montmorillonite or bentonite clay in order to affectively adsorb the mycotoxins (Ashiq, 2015; Jeswal & Kumar, 2015; Kabak, Dobson, & Var, 2006). To reverse the adverse effects of mycotoxins, the following criteria are used to evaluate the functionality of any binding additive:

- Efficacy of active component verified by scientific data.
- A low effective inclusion rate.
- Stability over a wide pH range.
- High capacity to absorb high concentrations of mycotoxins.
- High affinity to absorb low concentrations of mycotoxins.
- Affirmation of chemical interaction between mycotoxin and adsorbent.
- Proven *in vivo* data with all major mycotoxins.
- Non-toxic, environmentally friendly component.

Since not all mycotoxins can be bound to such agents, the latest approach to mycotoxin control is mycotoxin deactivation. By means of enzymes (esterase, de-epoxidase), yeast (*Trichosporon mycotoxinvorans*), or bacterial strains (Eubacterium BBSH 797), mycotoxins can be reduced during preharvesting contamination. Other removal methods include physical separation, washing, milling, nixtamalization, heat-treatment, radiation, extraction with solvents, and the use of chemical or biological agents. Irradiation methods have proven to be effective treatment against mold growth and toxin production (Ashiq, 2015; Jeswal & Kumar, 2015; Kabak et al., 2006).

8. Regulations on mycotoxins in foods

Many international agencies are trying to achieve universal standardization of regulatory limits for mycotoxins. Currently, over 100 countries have regulations regarding mycotoxins in the feed industry, in which 13 mycotoxins or groups of mycotoxins are of concern (van Egmond, Schothorst, & Jonker, 2007). The process of assessing a need for mycotoxin regulation includes a wide array of in-laboratory testing that includes extracting, clean-up and separation techniques (Shephard, 2008). Most official regulations and control methods are based on high-performance liquid techniques (e.g. HPLC) through international bodies (Ashiq, 2015; Jeswal & Kumar, 2015; Shephard, 2008). It is implied that any regulations regarding these toxins will be in co-ordinance with any other countries with which a trade agreement exists. Many of the standards for the method performance analysis for mycotoxins is set by the European Committee for Standardization (Shephard, 2008). However, one must take note that scientific risk assessment is commonly influenced by culture and politics, which, in turn, will affect trade regulations of mycotoxins (Ashiq, 2015; Jeswal & Kumar, 2015; Kendra & Dyer, 2007).

Food-based mycotoxins were studied extensively worldwide throughout the 20th century. In Europe, statutory levels of a range of mycotoxins permitted in food and animal feed are set by a range of European directives and EC regulations. The US Food and Drug Administration has regulated and enforced limits on concentrations of mycotoxins in foods and feed industries since 1985. It is through various compliance programs that the FDA monitors these industries to guarantee that mycotoxins are kept at a practical level. These compliance programs sample food products including peanuts and peanut products, tree nuts, corn and corn products, cottonseed, and milk. There is still a lack of sufficient surveillance data on some mycotoxins that occur in the US (Ashiq, 2015; Jeswal & Kumar, 2015; Wood, 1992).

9. Conclusion

Mycotoxins have been widely studied and their implications in foods are enormous. Regulatory control and fast and effective analyses and detection will go a long way in reducing the danger of mycotoxins in foods especially in Africa where there is shortage of food.

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