ZIBELINE INTERNATIONAL PUBLISHING
ISSN: 2637-0778 (Online)
CODEN: ECRNAE

Environmental Contaminants Reviews (ECR)

DOI: http://doi.org/10.26480/ecr.02.2020.53.61

CrossMark

RESEARCH ARTICLE

THE IMPLICATIONS AND MANAGEMENT STRATEGIES OF ANIMAL FEED MYCOTOXINS

Emanuel Joel Lao*

Department of Sustainable Agriculture, Biodiversity and Ecosystem Management, The Nelson Mandela African Institution of Science and Technology (NM-AIST). P. O. Box 447, Tengeru, Arusha – Tanzania.
****Corresponding Author's email: laoemanueljoel@gmail.com***

ARTICLE DETAILS

Article History:

Received 02 January 2020
Accepted 06 February 2020
Available online 28 February 2020

ABSTRACT

Mycotoxins are toxic metabolites of economic importance on yield and quality of crops, whereby under favourable humidity and temperature can invade feed and food chains. The United Nations Food and Agriculture Organization (FAO) estimates at least 25% of all crops in the world being annually affected by mycotoxins contamination. The mycotoxins groups of great concern include aflatoxin, zearalenone, fumonisins, ochratoxin, deoxynivalenol, ergot alkaloids, and moniliformin. With their toxicity, there are intense health threats to farm animals that can range from acute symptoms to life-threatening consequences including overall impairment of health and performance. The severity of the toxicity is influenced by one or a combination of factors like levels of mycotoxins ingested, exposure duration, type of animals, their breed, age, health status, diseases, and temperature. The detoxification against mycotoxicity has been implemented by pre-harvest cultural practices but also post-harvest by employing several biological, physical and chemical strategies with varying levels of effectiveness. The control of fungal growth and hence mycotoxins production is essential for achieving maximum animal performance but also important for a livestock keeper's welfare and markets for livestock products.

KEYWORDS

Mycotoxicity, Animal performance, Cereals, Animal Feed, Detoxification.

1. INTRODUCTION

Mycotoxins are poisonous secondary metabolites of low molecular weight that are produced mainly from certain fungal strains of *Aspergillus*, *Fusarium* and *Penicillium* (Kosicki et al., 2016; Misihairabgwi et al., 2017; Pinotti et al., 2016). Under favorable conditions of moist and elevated temperatures, they can colonize the field crops, during the harvesting period, storage, when feeding of animals until products are consumed by humans (Misihairabgwi et al., 2017; Wild et al., 2015). Generally, mycotoxin production will vary with crop type, geographical location, seasonal variations, humidity, temperature, hygienic status, storage conditions and overall farming practices employed (Marroquín-Cardona et al., 2014). The contaminated feed and food products such as eggs, meat, milk, cereals, and beverages carry high health risks to animal and human metabolic conditions which can range from acute symptoms of severe illness to long-term effects (Anukul et al., 2013; Pinotti et al., 2016). Such long-term consequences include carcinogenic, teratogenic and mutagenic effects, immunity suppression, cytotoxicity, cardiotoxicity, and respiratory complications, among others (Anukul et al., 2013; Lawlor and Lynch, 2005; Yiannikouris and Jouany, 2002). Apart from irreversible health concerns to life forms, the economy and international trades are being in peril due to poor quality of crops, impaired animal productivity, and increased contaminated products in the market (Iheshiulor et al., 2011).

Whilst hundreds of groups of mycotoxins have been identified, only about a dozen which are common in cereal crops are known to have economic impacts and health implications, specifically the aflatoxins, ochratoxin A, fumonisins, moniliformis, trichothecenes, zearalenone, deoxynivalenol and ergot alkaloids. Even though mycotoxins are considered one of the major dangerous feed and food contaminants globally, certain groups of mycotoxins seem to be more ubiquitous in some geographic regions than others (Lawlor and Lynch, 2005). For instance, while zearalenone, ochratoxin, and vomitoxin appear to be a problem in temperate regions like Europe and Northern America, the aflatoxins and fumonisins are on the other hand, are huge threats in humid and high-temperature regions of Asia, Africa and Latin America (Zahra et al., 2019).

Although the mycotoxicity affects all types of farm animals, certain species and groups tend to be less sensitive than others. Compared to poultry and pigs, the ruminants are less susceptible to the toxicity, even though the excessive exposure to contaminated feed can interfere with the quality and productivity levels of milk, beef or wool (Hussein and Brasel, 2001). Also, with their weak immune system, young-aged animals are less resistant to mycotoxicity compared to old ones and hence their growth and development are likely to be prejudiced (Zhu et al., 2016).

The animals exposed have a propensity to some clinical signs such as the dramatic decrease in milk yield, feed refusal, reduced body live weight, liver damage as well as suppression of immunity level (Cortyl, 2008; Yiannikouris and Jouany, 2002; Zhu et al., 2016). This article aims to explicate the potential groups of mycotoxins in cereals and their products with the reason that they carry a high risk for feed contamination and hence being of economic importance on animal health and overall

Quick Response Code	Access this article online	
	Website: www.contaminantsreviews.com	**DOI:** 10.26480/ecr.02.2020.53.61

Cite the Article: Emanuel Joel Lao (2020). The Implications And Management Strategies Of Animal Feed Mycotoxins. *Environmental Contaminants Reviews*, 3(2): *53-61.*

productivity. Besides, the effectiveness and limitations of the current biological, physical and chemical methods applied to control mycotoxins are well described.

2. MATERIALS AND METHODS

The systematic search of publications was done using the online internet-based search engines from December 2019 to January 2020. The data and information fundamental in preparing this review article was based on scrupulous analysis, evaluation and extraction from numerous sources from peer-reviewed journal articles but also from books, online documents and reports using the four search engines namely Google Scholar, Science Direct, and African Journal Online (AJOL). The keywords or search words used were "animal feed contaminations", "mycotoxins in animal feed", "effects on mycotoxins on farm animals", "management of mycotoxins", "regulation of mycotoxins" and "limitations and success of mycotoxin control".

3. MYCOTOXINS FROM CEREALS AND ITS PRODUCTS AND THEIR IMPLICATIONS ON FARM ANIMALS

3.1 Aflatoxin (AF)

These are the most studied group of mycotoxins which are produced by different species of *Aspergillus* genera (i.e. *Aspergillus flavus, A. nomius,* and *A. parasiticus*) (Gizachew et al., 2016; Khanafari et al., 2007). The fungi are plentiful in warm and humid tropical and subtropical regions that are responsible for the production of different types of aflatoxins including AFB_1, AFB_2, AFG_1, and AFG_2 when the optimum environmental conditions of 33^0 C and 0.99 aw (water activity) are available (Zahra et al., 2019). There are also M_1 and M_2 types which are mammalian bioconversion products of AFB_1 and AFB_2 and are common in bovine milk.

The aflatoxins are fluorescent compounds with their biosynthesis from the *Aspergillus* being through the polyketide pathway (Akande et al., 2006). They are considered the most poisonous mycotoxins and predominantly grow in grains, hay, decaying vegetation as well as in the soil (Johansson et al., 2006; Khanafari et al., 2007). Among the most affected crops include cereals (i.e. barley, wheat, rice, sorghum, and maize), tree nuts (almond, coconut, and pistachio), oilseeds (groundnuts, sunflower, cotton, and soybean) as well as spices (turmeric, ginger, and chili peppers) (Van Egmond, 2002; Valdez, 2012). The contaminated products of animal origin especially milk, meat, liver, and other tissues are also known to cause mycotoxicity to humans when consumed (Milićević et al., 2010).

Generally, these metabolites are of great apprehension on animals and human and health due to their influence on several conditions such as immunosuppressive disorders, cytotoxic, teratogenic (malformations in a fetus), carcinogenic, and mutagenic effects (Hussein and Brasel 2001; Khanafari et al., 2007; Zhu et al., 2016). When animals consume a substantial amount of aflatoxins can develop aflatoxicosis, a condition characterized by reduced feed intake, poor feed conversion efficiency, pulmonary and cerebral edema, severe damage of liver and kidney and even (Bucher, 2013). Even though animals of all ages are affected by mycotoxicity, young animals are relatively more susceptible (Iheshiulor et al., 2011). The presence of 0.02 ppm in feed rations for pigs (finishers) can significantly reduce growth rates while with 0.05 ppm, there is a high risk for milk contamination in lactating sows that can be hazardous to the health and growth of piglets (Devegowda et al., 1998).

For poultry, ducks are reported to be more susceptible as compared to turkey, broilers, and layers, and the high exposure to these metabolites are associated with reduced performance levels such as eggshell quality, hatching, resistance to diseases, coccidiosis, kidney problems and failure in vaccines (Cortyl, 2008). In ruminants, aflatoxins tend to reduce the feed utilization efficiency since these metabolites compromises with optimum rumen function, reducing the digestion rates, the production rate of short-chain fatty acids (SCFA), impeding with rumen motility as well as suppression of lymphocytes' functions (Cook et al., 1986; Paul et al., 1977). Serious health conditions including calving of poor and unhealthy calves, diarrhea, respiratory complications and mastitis when the dairy cows were exposed at maize diet containing 120 ppb of aflatoxin have been reported (Charoenpornsook and Kavisarasai, 2006).

The International Agency for Research on Cancer (IARC) under WHO evaluated and classified the carcinogenicity of mycotoxins and has categorized AFB_1 as carcinogenic to human beings while others including OTA and fumonisins were regarded as possibly carcinogenic too (Yiannikouris and Jouany, 2002). Besides, Aflatoxin B_1 is associated with coagulopathy in animals due to the reduced synthesis of vitamin K, and this condition impairs the normal ability of the blood to coagulate following injuries (Babatunmi et al., 1980).

3.2 Ochratoxin A (OTA)

These metabolites are mostly produced by species from *Aspergillus* and *Fusarium* genera while recently been discovered also to be produced by some *Penicillium* species in a temperate climate (Hussein and Brasel, 2001; Zhu et al, 2016). The *Aspergillus ochraceous* is responsible for OTA production in a warm climate while *Penicillium verrucosum,* on the other hand, produces OTA in temperate regions (Iheshiulor et al, 2011). The overall optimum conditions for OTA growth are 25 - 30^0 C and 0.98 aw (water activity) as reported by Zahra et al.,(2019). Ochratoxin A (OTA or OA), also known as food-contamination mycotoxin is common in cereals and its products, fruits, spices, and coffee beans and as reported by Khanafari et al.,(2007), they are toxicologic and related to several immunosuppressive disorders particularly to humans. The nephrotoxic conditions (renal damage) in poultry, as well as hepatotoxic and neurotoxic effects in mice and rats due to OTA, has been reported (El Khoury and Atoui, 2010). The common symptoms of OTA in poultry include high mortality, poor feed conversion rates, reduced growth, and an overall feed refusal while for laying birds both the production and quality of eggs are significantly impaired (Cortyl, 2008). Besides, pigs provided with rations with high levels of OTA can result in a medical condition called porcine nephropathy or kidney damage which often causes pork rejection at the slaughterhouses (Cortyl, 2008; Iheshiulor et al, 2011).

3.3 Deoxynivalenol (DON) or Vomitoxins

Other mycotoxins of great importance to livestock are deoxynivalenol (DON) or also known as vomitoxin which is produced by *Fusarium* especially *F. culmorum* and *F. graminearum* (Voss et al, 2007). Vomitoxins affect several crops such as maize, barley, and rice both in the field and during storage (Hussein and Brasel, 2001). When livestock consume feed sources contain vomitoxins they experience gastrointestinal nuisance, experience feed refusal but also becoming immunosuppressant (Yiannikouris and Jouany, 2002; Zhu et al, 2016). A human being can contact these metabolites directly by consuming cereals or indirectly through animal products such as eggs, liver, and milk (Sobrova et al, 2010). The susceptibility of animals to the exposure of these mycotoxins is affected by genetic, physiological and environmental factors (Schwake-Anduschus et al, 2015; Sobrova et al, 2010).

3.4 Fumonisins (FBs)

Fumonisins (B_1, B_2, and B_3) which are both cytotoxic and cancer-promoting secondary metabolites are produced by *Fusarium* (commonly *F. verticillioides*, *F. oxysporum*, *F. globosum,* and *F. proliferatum)* and occur mostly in maize but also in other crops like sorghum, barley, and rice (Keller et al, 2012; Voss et al, 2007). Specifically, fumonisins B_1 is the most toxic as it has been reported to stimulate tumor growth in rodents whilst even the low levels of these metabolites can result in liver and pancreases damage as well as porcine pulmonary edema in pigs (Keller et al, 2012). Moreover, fumonisins are responsible for the neurologic disease called leukoencephalomalacia in horses which is characterized by softening of the white matter part of their brain (Harrison et al. 1990; Ramljak et al, 2000). Poultry are relatively resistant to FBs, for instance, Broomhead et al.,(2002) reported that even when the chicks were provided with 20 or 50 ppm in feed, neither did their body weight gain, feed conversion rate nor feed intake altered.

3.5 Zearalenone (ZEN)

This group of metabolites is reported to primarily be produced by several *Fusarium* species including *F. culmorum*, *F. graminearum*, and *F. sporotrichioides* (Hussein and Brasel, 2001). Even though zearalenone is common in maize, it has on a global scale related to other cereals, for example, rye, wheat, sorghum and barley (Withanage et al, 2001). The favorable condition for *Fusarium* growth which is the same conditions for attacking the crops is a moist cool environment. Zearalenone is mostly linked with estrogenic effects that related to the sexual and reproductive development of farm animals (Hussein and Brasel, 2001; Withanage et al, 2001). When present at 1 - 30 ppm in feed, ZEN is likely to interfere several reproductive processes including the ovulation, conception, implantation as well as development of the fetus while also cases like stillbirth, abortion, reduction of litter size in pigs have been reported (Jones et al, 1994). Physiologically, the zearalenone binds the estrogen receptors that in return inhibit the binding of estrogenic hormones in mammary glands (Withanage et al, 2001). While pigs are sensitive to ZEN exposure, poultry, as reported by studies, can tolerate certain levels of these compounds with no metabolic consequences (Cortyl, 2008).

3.6 Moniliformin

Numerous *Fusarium* species are responsible for moniliformin production and these include *F. moniliforme*, *F. avenaceum,* and *F. proliferatum* (Thiel, 1978). The produced metabolites can be transferred between successive growing seasons as they can survive for years in the soil (Thiel, 1978). Although ruminants such as cattle, goats, deer, and sheep are known to be resistant to the negative effects of moniliformin, their products such as milk, beef, and wool can be affected when animals consume contaminated feed for an extended period (Hussein and Brasel, 2001). On the other hand, these contaminants can be deadly to poultry and duck especially at a young age where they are associated with complications with the respiratory system and heart dysfunction condition called cardiotoxicity (Hussein and Brasel, 2001; Thiel, 1978).

3.7 Trichothecenes

Trichothecenes are produced by numerous types of *Fusarium* species but also from other genera including *Myrothecium*, *Trichoderma,* and *Stachybotrys* (Zhu et al, 2016). The cytotoxic effects of these secondary metabolites are associated with prohibiting the synthesis of molecules such as protein, DNA and RNA (Hussein and Brasel, 2001). Moreover, impairment of cell membrane normal functions and transportation capacity of amino acids, nucleotides, and glucose, as well as suppression of the immune system and blood functions, are some of the reported negative effects of trichothecenes in animals (Zhu et al, 2016).

3.8 Ergot alkaloids

Ergot alkaloids, identified as mycotoxins of significant agro-economical importance are produced by ergot fungi of *Claviceps* genera, with specifically *Claviceps purpurea* which is common in grass and cereals (Hussein and Brasel, 2001). Researchers have indicated cool and damp weather (such as springtime for temperate regions) as favorable conditions for these fungi to massively grow. Ergot alkaloids are associated with several health conditions including fescue foot, fat necrosis, and hyperthermia (Rhodes et al, 1991). The hyperthermia which is the elevated body temperatures above the normal levels is characterized by animals deprived with a normal appetite, weight loss, and heat stress. In addition to hyperthermia, these mycotoxins are associated with fat necrosis whereby the body areas covered by fat are hardened which results in constriction of internal organs, among others (Rhodes et al, 1991).

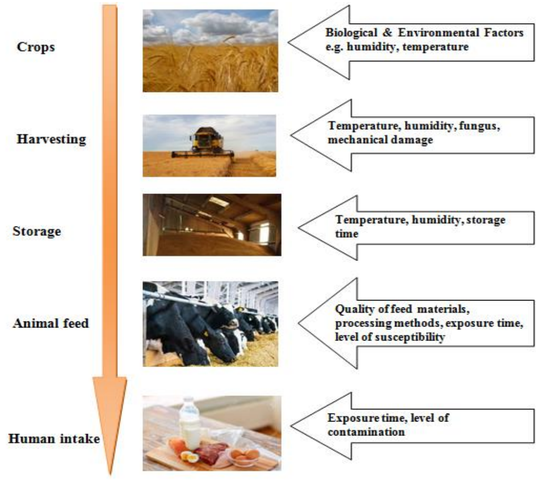

Figure 1: Factors influencing the production of mycotoxins along the livestock production chain

Table 1: The major groups of mycotoxins in cereals and their products with their associated impacts on animal health and productivity

Groups of mycotoxins	Responsible fungi species	Main affected crops/products	Impacts on animals	References
Aflatoxins B_1, B_2, G_1, G_2 & M_1 and M_2	*Aspergillus flavus*, *A. nomius*, and *A. parasiticus*	Peanuts, barley, rice, spices, vegetable, wheat, and milk	Coagulopathy, Immunosuppressive disorders, teratogenic, carcinogenic and mutagenic effects	(Bababunmi et al, 1980; Hussein and Brasel, 2001; Zhu et al, 2016)
Ochratoxin A (OTA or OA)	*Aspergillus clavatus, A. carbonarius,* and *Penicillium Verrucosum*	Grains, legumes, peanuts, cashews, cocoa, wine, grape juice, and meat products	Renal tumors and nephrotoxic in rodents, also carcinogenic to animals and likely to humans too	(El Khoury and Atoui, 2010)
Deoxynivalenol (DON) and its acetylated derivatives	*Fusarium graminearum* and *F. culmorum*	Wheat, maize, barley, oats, sorghum, rye, and rice	Gastrointestinal nuisance, diarrhea, immunosuppressant, vomiting, and feed refusal. Also, higher doses affect liver, heart, spleen, and thymus	(Yiannikouris and Jouany, 2002; Zhu et al, 2016)
Fumonisins (FBs) - B_1, B_2, and B_3	Some species *Fusarium* genera (*F. verticillioides* and *F. proliferatum*) and *Aspergillus niger*	Maize and grapes	Tumor growth in rodents and pulmonary edema in pigs. Also responsible for a multifocal neurologic disease called leukoencephalomalacia in horses	(Keller et al, 2012)
Trichothecenes	Various species of *Fusarium*, *Myrothecium*, *Trichoderma* and *Stachybotrys*	All cereals	Cytotoxicity and impairment of cell membrane normal functions	(Hussein and Brasel, 2001; Zhu et al, 2016)
Zearalenone	*Fusarium graminearum*, *F. culmorum,* and *F. crookwellense*	All grains but most common in maize and wheat	Estrogenic effects on sexual and reproductive impairment of farm animals	(Withanage et al, 2001)
Moniliformin	*Fusarium moniliforme*, *F. avenaceum,* and *F. proliferatum*	Most of the cereals	Complications of the respiratory system and cardiotoxicity in young aged fowls	(Thiel, 1978)
Ergot alkaloids	*Claviceps purpurea*	True grasses, rye, millet, oats, barley, wheat, and triticale	Fescue foot, fat necrosis, and hyperthermia in cattle	(Hussein and Brasel, 2001; Rhodes et al, 1991)

4. Cost-Effective Methods to Minimize and/or Eliminate Mycotoxins in Cereals And is Byproducts

There have been ever-increasing concerns regarding the effect of mycotoxins in feed and food chains around the world over the last decades. The various strategies, both preharvest and postharvest have been developed and implemented with the main purpose of removing, inactivating or detoxifying these toxic substances. While preharvest control often relies on the appropriate cultural practices (e.g. development of resistant varieties, pest control, soil management, crop rotation, cropping pattern, irrigation, timely planting, and harvesting), the postharvest strategies are done using numerous physical, chemical and biological strategies to minimize the production and spread of mycotoxins.

The physical strategies such as sorting, washing, sieving, dehulling and heating aim at reducing the contaminated fractions without hugely affecting the total weight of cereals or feed materials. To be effective, other methods such as the use of mycotoxin binders e.g. activated charcoal, montmorillonite or bentonite need to have certain properties including being stable over a wide range of pH levels, must be a good adsorbent, non-toxic, environmental-friendly plus having high affinity even to very low concentrations (Kabak et al, 2006). Also, the treatment using chemicals such as sodium bicarbonate, sodium bisulfite, acetic acid, hydrogen peroxide and ozone are presumed to be most effective for mycotoxins decontamination. The role of chemical treatment is to convert toxins into non-toxic derivatives without having deteriorating outcomes on the feed material or an animal when consumed. Besides, since not all of these metabolites can be absorbed, the mycotoxins deactivation also can be done using a certain groups of enzymes, yeast, and bacterial strains. Tables 2, 3 and 4 present in brief, the efficacies and some inadequacies for the most applied strategies that aim at lessening the levels of contamination in cereals, their products as well as animal feed in general.

Table 2: The effectiveness and limitations of the most commonly applied physical methods in reducing mycotoxin contamination in cereals and their products

Practices	The efficacy of the Practices	Limitations
Sorting	Effective in reducing substantial dust, debris, admixtures as well as damaged and broken kernels that possess most of the contaminations which on average share abou 6% of total weight (Johansson et al, 2006; Whitaker et al, 2003). This method is useful for aflatoxins and ergot alkaloids due to their nature of heterogeneous contaminations (Kabak et al, 2006).	Not efficient for fumonisins as they don't often show symptoms. The grain sorting technique for reducing aflatoxin using UV light illumination doesn't work for dried commodities (Karlovsky et al, 2016). Also, grain sorters at the industrial scale may be expensive.
Sieving	The dust, debris and broken kernels with extensive mold growth can be greatly reduced by sieve cleaning. Sieving can enhance intact kernels to have 10 times less contamination as compared to smaller particles. Up to 80 % reduction of ZEN and DON can be achieved (Murphy et al, 1993; Trenholm et al, 1991).	Poor quality kernels can result in a substantial quantity of kernels being rejected. For instance, Trenholm et al, (1991) reported nearly 70%, 34% and 55% of maize, barley, and wheat respectively were rejected using sieving.
Washing	Effective for surface decontamination of water-soluble mycotoxins in barley by 65 - 69 %. For slightly water-soluble metabolites such as ZEN addition of alkaline solution like Na_2CO_3 improves the toxicity reduction of up to 87% in maize and barley (Karlovsky et al, 2016; Trenholm et al, 1992).	Insufficient drying of grain just after washing can surpass the potential of this technique (Karlovsky et al, 2016).
Floatation	This strategy is based on differences in physical properties between damaged and intact kernels which are done by fractionation or density separation. Floating of kernels in solutions such as sodium chloride, water, sucrose, and saturated brine can reduce ZEN, aflatoxins, and DON by more than 50% whilst the reduced total weight of kernels being less than 20% (HUFF and HAGLER JR, 1985; Karlovsky et al, 2016; Shetty and Bhat, 1999).	Some studies involve the FBs in maize observed high carryover of mycotoxin after removal of the floating fraction. The study suggested significant concentrations remained in grains was due to the presence of mycotoxins in inner parts of the pericarp and endosperm (Van der Westhuizen et al, 2011).
Dehulling	It involves the removal of outer layers of grains that contain considerable levels of mycotoxins. Up to 93% of aflatoxins can be removed from maize through dehulling (Mutungi et al, 2008; Vučković et al, 2013).	Not effective for cereals with fine grain particles.
Steeping	Usually done before wet milling, soaking of cereals such as maize for 48 hours at 50^0 C in a water solution contains 0.1 - 0.2% of sulphur dioxide can reduce about 50% of aflatoxin. This technique works also for sorghum and the reduction can be even higher (Aly, 2002; Karlovsky et al, 2016; Pujol et al, 1999).	The presence of some mycotoxins in inner parts of the pericarp and endosperm can reduce the efficacy.
Heating	At the industrial scale, temperature above 100^0 C is used in processes like frying, toasting and roasting to reduce the contamination. Studies have reported the reduction of aflatoxin (50-80%) in grain, aflatoxins in peanuts (22-87%), OTA in coffee beans (97%) and ZEN in maize (65-83%) with the application of heating (Bullerman and Bianchini, 2007; Cheftel, 1989; Conway et al, 1978).	The conventional food preparation with a temperature level of up to 100^0 C has little impact on mycotoxicity reduction (Karlovsky et al, 2016).
Irradiation	The industrial application of solar, UV, microwave and gamma radiations not only eliminates the pathogens but can to some extent the degrade mycotoxins. Direct sunlight of 3 to 30 hours is effective in reducing aflatoxin levels by 40 to 75%, respectively, in cereals. A significant reduction has been observed in peanuts, rice, maize, and pistachios when microwave and gamma radiations were applied (Bretz et al, 2006; Ghanem et al, 2008; Herzallah et al, 2008).	Some studies have documented the little reduction of below 25% toxicity for aflatoxin and OTA (Visconti et al, 2004; Webb et al, 2014).

Mycotoxin binders	The activated charcoal is an effective adsorbent for plant-produced toxins, pollutants and mycotoxins in animal feed (Huwig et al, 2001; Pinotti et al, 2016). When added at 1-2 % (on feed DM basis) in the dairy rations can have a noteworthy reduction of 41-74 % of aflatoxin B_1 while also its levels in milk being reduced up to 45 % (Galvano et al. 1996: Galvano et al, 2001). Montmorillonite and bentonite are also commonly used binders in the feed and food industry (Kabak et al, 2006).	The high levels of activated carbon in feed can bind not only mycotoxins but some desirable nutrients too (Hatch et al, 1982).

Table 3: The effectiveness and limitations of the commonly applied chemical methods for reducing mycotoxins

Practices	The efficacy of the Practices	Limitations
Acid treatment	Most mycotoxins are known to be resistant against weak acids and therefore strong acids have widely been used against mycotoxicity (Doyle et al, 1982). Hydrochloric, citric, sulphuric and acetic acids are effective in destroying the biological activity of aflatoxins to form traces that are non-toxic (Aiko et al, 2016).	The effectiveness of some of these acid treatment methods has not been studied at the industrial scale.
Alkaline treatment	The degradation of aflatoxin in animal feed contains groundnuts and cottonseed meal and maize is usually done using alkaline reagents such as sodium hydroxide, $Ca(OH)_2$, Na_2CO_3, Na_3PO_4 and ethanolamine (Muller, 1983). Also, the ammoniation of aflatoxin has extensively been done in both laboratory and field trials with up to 75% success in maize while completely decomposing the OTA in barley, wheat, and maize has been researched (Chelkowski et al, 1981; Park et al, 1988).	The efficacy of the alkaline treatment is highly affected by factors such as temperature, moisture, pressure, duration and the type of substrate (Park et al, 1988).
The use of reducing agents	Treatment of aflatoxin-contaminated maize with sodium bisulfite ($NaHSO_3$) can decontaminate completely the toxicity. Several combinations can also be employed, for example, the use of hydrogen peroxide followed by $NaHSO_3$ or heating the bisulfite samples at 65^0 C for 1 hour which can reduce aflatoxin by 65% and 68%, respectively (Doyle et al, 1982; HAGLER JR et al, 1982). Also, $NaHSO_3$ solution can decontaminate DON in maize by up to 85% (Schwartz et al, 2013).	The effectiveness of most of these reducing agents has not deeply studied in the industrial scale
Oxidizing agents	Several oxidizing agents such as ozone, sodium hypochlorite, sodium hydroxide, and ammonium hydrochloride have shown varying efficacy in mycotoxin detoxification. Aflatoxin B_1 and G_1 are quite sensitive to ozone, and the addition of 1.1 mg/litre of ozone completely degrades the toxicity as compared to B_2 and G_2 which require higher levels of ozone of 34.3 mg/litre. These agents are also responsible for detoxifying ZEN and OTA in maize and groundnuts (Samarajeewa et al, 1990).	The aflatoxin B_2 and G_2 require relatively long exposure to oxidizing agents like ozone for them to be degraded (Samarajeewa et al, 1990). Some oxidizing agents such as sodium hypochlorite may result in the formation of aflatoxin B_1-2,3-dichloride, which is carcinogenic and the addition of acetone is often done to avoid the consequences (Castegnaro et al, 1981).
Food ingredients	Certain food ingredients such as spices and herbs from some Asian countries have been demonstrating detoxification potential against mycotoxins. When extracts from holy basil (*Ocimum tenuiflorum*) and leaves from vasaka herbs (*Adhatoda vasica*) are incubated for 24 - 48 hours at 37 - 65^0 C can completely degrade aflatoxin but also blocking fumonisins toxicity on cell tissue cultures on rats and pigs (Fernandez-Surumay et al, 2005; Vijayanandraj et al, 2014).	Due to the availability and little research, this method is constrained to certain geographical regions

Table 4: The effectiveness and limitations of the biological methods for reducing mycotoxicity

Practices	The efficacy of the Practices	Limitations
Enzymatic detoxification	Some studies (Alberts et al, 2009; Wang et al, 2011) have come up with detoxification potential of laccases and peroxidases, which are among the few enzymes that have no distinguishing property of the enzyme's specificity.	By lacking specificity, these enzymes (e.g. laccases and peroxidases) can also degrade the valuable food constituents. The lack of concise findings has made this strategy not being widely used.

Probiotics	Probiotic organisms such as *Saccharomyces cerevisiae* and *Lactobacillus delbrueckii* are among the most known for detoxifying the aflatoxin contamination as reported by Zahra et al, (2019). The dried cell mass of yeast and the wall substances of *Lactobacillus* are capable of reducing toxicity by binding with mycotoxins. Also, the ability of fungal conidia to bind to some mycotoxins especially ZEA and OTA has been observed (Jard et al, 2009).	The efficacy on survival and colonization of probiotics is a function of many factors including pH, temperature, oxygen toxicity, bile and digestive enzymes, processing, and storage conditions.
Fungi	Metabolites like ZEA are known to interfere with the reproductive functioning of animals. Certain fungi species especially *Thamnidium elegans* and *Mucor bainieri* could transform ZEA into non-estrogenic substances that are not harmful. Also, the fungus *Aspergillus tubingensis* isolated from the soil have demonstrated the ability to degrade DON by hydrolysis as reported by He et al, (2008).	Under certain conditions, the degradation may not always result in detoxification as reported by Venkatesh and Keller, (2019).
The role of Bacteria	The degradation of mycotoxins by be achieved by microorganisms from various sources. Certain species of *Actinomycetales* such as *Nocardia corynebacterioides*, *Nocardia asteroids*, *Corynebacterium rubrum*, *Rhodococcus erythropolis*, *Mycobacterium fluoranthenivorans*, and *Mycobacterium smegmatis* can degrade up to 99% of aflatoxin in liquid culture (Kong et al, 2012). The biotransformation of ZEA by bacteria strains like *Rhodococcus erythropolis*, *R. ruber* and *R. pyridinivorans* can degrade over 50% of the toxicity. Also, rumen fluid in cattle and chicken intestines contain microbes capable of transforming DON, AF and other metabolites into non-toxic forms (Ji et al, 2016).	Some of the products from degradation as well as biochemical and genetic mechanisms underlying these processes remain unclear

5. Regulations of Mycotoxins in Animal Feed

The strict maximum limits on the concentrations of feed and food-based mycotoxins have been implemented since the 1980s by the European Union (EU) through directives and regulations as well as the United States Food and Drug Administration (FDA) to protect consumers from ingesting contaminated foodstuffs (Wood, 1992). The decisions for setting limits for mycotoxins control among countries are based on numerous factors including; availability of toxicological and exposure data, knowledge on the distribution of mycotoxin concentration among products, legislations in other countries where contamination exists but also the need to have sufficient food supply (van Egmond et al, 2007). Unlike some developed regions like Europe and America where there are clear-cut standards on feed quality and safety, currently, there are no regionally established regulations in Africa that make individual countries to have their standards (Matumba et al, 2015).

By 2003, a worldwide survey that was done by FAO found only 15 African countries had documented mycotoxins regulations (FAO, 2004). In a subsequent study by Matumba et al, (2015), it was proclaimed significantly little or no improvement had been done, with even the existing regulations being poorly enforced with indicators of mycotoxin exposures being a threat to human health. In 2015, the International Agency for Research on Cancer (IARC) in a survey for low and medium-income countries identified some of the countries with no existing regulations and guidelines on mycotoxin control which include Swaziland, Lesotho, Zambia, Botswana, and Namibia (Wild et al, 2015). The suggested reasons behind weak and nonexistence regulations and standards in most of the developing countries are lack of prevalence data of certain mycotoxins, human capacity and necessary resources to obtain toxicological and exposure data (Matumba et al, 2015; Mboya and Kolanisi, 2014; Wild et al, 2015). In addition to that, research on mycotoxins doesn't appear as a top priority in most of the developing countries with most of the attention being given on issues related to malaria, HIV/AIDS and infant mortality (Wild et al, 2015).

Besides having the regulations, it is important to augment the level of awareness among food producers, livestock keepers, and feed manufacturers. To ensure that there are positive outcomes that start from farm levels, efforts should be made to develop and implement several low-cost technologies for assessment, prevention, and control of mycotoxins. The United Nations organizations particularly UNEP, FAO, and FAO are continuously involved in disseminating the essential information and strategies regarding the control of mycotoxins around the world. These include the guidelines and methodology on sampling and analysis, inspection and surveillance systems on feed and food, essential protocols in detoxification as well as quality control of products. The knowledge bridging through the use of conferences, numerous trainings symposiums, and workshops on feed and food chains should promote the current knowledge and minimize the contamination.

6. Conclusion and Recommendations

The extensive research on biosynthesis and contamination of mycotoxins has been done, and the current literature signifies how its contamination a serious threat to crop production, animal and human health, national economies and international trade. A wide range of mycotoxins, with varying chemical characteristics and toxicity levels in animal feed sources, are associated with the reduced production, impairment of the immune system, having carcinogenic, teratogenic and mutagenic effects, cytotoxicity, cardiotoxicity and the complications of the respiratory system. With their complexity, it is difficult to have a simple and singular preventive or reduction strategy that will solve the problem. To minimize the exposure, the interventions starting from cultural practices when crops are still in the field to post-harvest methods need to be widely developed and implemented. More efforts should be emphasized on monitoring, managing and controlling their levels starting from the field until their products reach the market. Understanding the physiological and environmental factors for mycotoxin biosynthesis, biology, and ecology of fungi and overall interaction of the host plant is crucial for effective control of mycotoxin contamination. More research and investment need to be directed into developing and implementing surveillance programs, testing methods and rapid detection from the farm to industrial scale.

Disclosure Statement

The author declares no conflict of interest.

Acknowledgment

The author received no specific financial support for the reviewing, authorship, and/or publication of this article.

References

Aiko, Visenuo, Prasad Edamana, Mehta, A., 2016. Decomposition and Detoxification of Aflatoxin B1 by Lactic Acid. Journal of the Science of Food and Agriculture, 96(6), 1959–66.

Akande, K.E., Abubakar, M.M., Adegbola, T.A., Bogoro, S.E., 2006. Nutritional and Health Implications of Mycotoxins in Animal Feeds: A Review. Pakistan Journal of Nutrition, 5 (5), 398–403.

Alberts, J.F., Gelderblom, W.C.A., Botha, A., Van Zyl, W.H., 2009. Degradation of Aflatoxin B1 by Fungal Laccase Enzymes. International Journal of Food Microbiology, 135 (1), 47–52.

Aly, Soher, E., 2002. Distribution of Aflatoxins in Product and By-products during Glucose Production from Contaminated Corn. Food/Nahrung, 46 (5), 341–44.

Anukul, Nampeung, Vangnai, K., Mahakarnchanakul, W., 2013. Significance of Regulation Limits in Mycotoxin Contamination in Asia and Risk Management Programs at the National Level. Journal of Food and Drug Analysis, 21 (3), 227–41.

Bababunmi, E.A., Thabrew, I., Bassir, O., 1980. Aflatoxin-Induced Coagulopathy in Different Nutritionally Classified Animal Species. World Review of Nutrition and Dietetics, Pp. 161–81.

Bretz, Michael, Beyer, M., Cramer, B., Knecht, A., Humpf, H.U., 2006. Thermal Degradation of the Fusarium Mycotoxin Deoxynivalenol. Journal of Agricultural and Food Chemistry, 54 (17), 6445–51.

Broomhead, J.N., Ledoux, D.R., Bermudez, A.J., Rottinghaus, G.E., 2002. Chronic Effects of Fumonisin B1 in Broilers and Turkeys Fed Dietary Treatments to Market Age. Poultry Science, 81 (1), 56–61.

Bucher, John, R., 2013. Regulatory Forum Opinion Piece* Tox21 and Toxicologic Pathology. Toxicologic Pathology, 41 (1), 125–27.

Bullerman, Lloyd, B., Bianchini, A., 2007. Stability of Mycotoxins during Food Processing. International Journal of Food Microbiology, 119 (1–2), 140–46.

Castegnaro, Marcel, Friesen, M., Michelon, J., Walker, E.A., 1981. Problems Related to the Use of Sodium Hypochlorite in the Detoxification of Aflatoxin B1. American Industrial Hygiene Association Journal, 42 (5), 398–401.

Charoenpornsook, K., Kavisarasai, P., 2006. Mycotoxins in Animal Feedstuffs of Thailand. KMITL Science and Technology Journal, 6 (1), 25–28.

Cheftel, Claude, J., 1989. Extrusion Cooking and Food Safety. Extrusion Cooking, 435–61.

Chelkowski, J., Goliński, P., Godlewska, B., Radomyska, W., Szebiotko, K., Wiewiorowska, M., 1981. Mycotoxins in Cereal Grain. Part IV. Inactivation of Ochratoxin A and Other Mycotoxins during Ammoniation. Food/Nahrung, 25 (7), 631–37.

Conway, H.F., Anderson, R.A., Bagley, E.B., 1978. Detoxification Of Aflatoxin-Contaminated Corn By Roasting.

Cook, W.O., Richard, J.L., Osweiler, G.D., Trampel, D.W., 1986. Clinical and Pathologic Changes in Acute Bovine Aflatoxicosi: Rumen Motility and Tissue and Fluid. Am. J. Vet Res., 47 (8).

Cortyl, Mathieu. 2008. Mycotoxins in Animal Nutrition Problems and Solutions.

Devegowda, G., Raju, M.V.L.N., Afzali, N., Swamy, H.V.L.N., 1998. Mycotoxin Picture Worldwide: Novel Solutions for Their Counteraction. Feed Compounder (United Kingdom).

Doyle, M.P., Applebaum, R.S., Brackett, R.E., Marth, E.H., 1982. Physical, Chemical and Biological Degradation of Mycotoxins in Foods and Agricultural Commodities. Journal of Food Protection, 45 (10), 964–71.

El Khoury, André, Atoui, A., 2010. Ochratoxin A: General Overview and Actual Molecular Status. Toxins, 2 (4), 461–93.

FAO. 2004. Worldwide Regulations for Mycotoxins in Food and Feed in 2003.

Galvano, Fabio, Pietri, A., Fallico, B., Bertuzzi, T., Scire, S., Galvano, M., Maggiore, R., 1996. Activated Carbons: In Vitro Affinity for Aflatoxin B1 and Relation of Adsorption Ability to Physicochemical Parameters. Journal of Food Protection, 59 (5), 545–50.

Galvano, Fabio, Piva, A., Ritieni, A., Galvano, G., 2001. Dietary Strategies to Counteract the Effects of Mycotoxins: A Review. Journal of Food Protection, 64 (1), 120–31.

Ghanem, I., Orfi, M., Shamma, M., 2008. Effect of Gamma Radiation on the Inactivation of Aflatoxin B1 in Food and Feed Crops. Brazilian Journal of Microbiology, 39 (4), 787–91.

Gizachew, Dawit, Szonyi, B., Tegegne, A., Hanson, J., Grace, D., 2016. Aflatoxin Contamination of Milk and Dairy Feeds in the Greater Addis Ababa Milk Shed, Ethiopia. Food Control, 59, 773–79.

Hagler, J.R., Winston, M., Hutchins, J.E., Hamilton, P.A.T.B., 1982. Destruction of Aflatoxin in Corn with Sodium Bisulfite. Journal of Food Protection, 45 (14), 1287–91.

Harrison, Lenn, R., Colvin, B.M., Greene, J.T., Newman, L.E., Cole, J.R., 1990. Pulmonary Edema and Hydrothorax in Swine Produced by Fumonisin B1, a Toxic Metabolite of Fusarium Moniliforme. Journal of Veterinary Diagnostic Investigation, 2 (3), 217–21.

Hatch, R.C., Clark, J.D., Jain, A.V., Weiss, R., 1982. Induced Acute Aflatoxicosis in Goats: Treatment with Activated Charcoal or Dual Combinations of Oxytetracycline, Stanozol, and Activated Charcoal [Aflatoxins, Aspergillus Flavus]. American Journal of Veterinary Research (USA).

He, Chenghua, Fan, Y., Liu, G., Zhang, H., 2008. Isolation and Identification of a Strain of Aspergillus Tubingensis with Deoxynivalenol Biotransformation Capability. International Journal of Molecular Sciences, 9 (12), 2366–75.

Herzallah, S., Alshawabkeh, K., Fataftah, A.A.L., 2008. Aflatoxin Decontamination of Artificially Contaminated Feeds by Sunlight, γ-Radiation, and Microwave Heating. Journal of Applied Poultry Research, 17 (4), 515–21.

Huff, William, E., Winston, M., Hagler, J.R., 1985. Density Segregation of Corn and Wheat Naturally Contaminated with Aflatoxin, Deoxynivalenol and Zearalenone. Journal of Food Protection, 48 (5), 416–20.

Hussein, Hussein, S., Brasel, J.M., 2001. Toxicity, Metabolism, and Impact of Mycotoxins on Humans and Animals. Toxicology, 167 (2), 101–34.

Huwig, Alexander, Freimund, S., Käppeli, O., Dutler, H., 2001. Mycotoxin Detoxication of Animal Feed by Different Adsorbents. Toxicology Letters, 122 (2), 179–88.

Iheshiulor, O.O.M., Esonu, B.O., Chuwuka, O.K., Omede, A.A., Okoli, I.C., Ogbuewu, I.P., 2011. Effects of Mycotoxins in Animal Nutrition: A Review. Asian J. Anim. Sci., 5, 19–33.

Jard, G., Liboz, T., Mathieu, F., Guyonvarc'h, A., Lebrihi, A., 2009. Adsorption of Zearalenone by Aspergillus Japonicus Conidia: New Trends for Biological Decontamination in Animal Feed. World Mycotoxin Journal, 2 (4), 391–97.

Ji, Cheng, Fan, Y., Zhao, L., 2016. Review on Biological Degradation of Mycotoxins. Animal Nutrition, 2 (3), 127–33.

Johansson, Anders, S., Whitaker, T.B., Hagler, W.M., Bowman, D.T., Slate, A.B., Payne, G., 2006. Predicting Aflatoxin and Fumonisin in Shelled

Corn Lots Using Poor-Quality Grade Components. Journal of AOAC International, 89 (2), 433–40.

Jones, F.T., Genter, M.B., Hagler, W.M., Hansen, J.A., Mowrey, B.A., Poore, M.H., Whitlow, L.W., 1994. Understanding and Coping with Effects of Mycotoxins in Livestock Feed and Forage. AG (North Carolina Agricultural Extension Service)(USA), 523.

Kabak, Bulent, Dobson, A.D.W., 2006. Strategies to Prevent Mycotoxin Contamination of Food and Animal Feed: A Review. Critical Reviews in Food Science and Nutrition, 46 (8), 593–619.

Karlovsky, Petr, Suman, M., Berthiller, F., Meester, J.D., Eisenbrand, G., Perrin, I., Oswald, I.P., Speijers, G., Chiodini, A., Recker, T., 2016. Impact of Food Processing and Detoxification Treatments on Mycotoxin Contamination. Mycotoxin Research, 32 (4), 179–205.

Keller, L.A.M., Pereyra, C.M., Cavaglieri, L.R., Dalcero, A.M., Rosa, C.A.R., 2012. Fungi and Mycotoxins from Pre-and Poststorage Brewer's Grain Intended for Bovine Intensive Rearing. ISRN Veterinary Science.

Khanafari, A., Soudi, H., Miraboulfathi, M., 2007. Biocontrol of Aspergillus Flavus and Aflatoxin B1 Production in Corn. Iranian Journal of Environmental Health, Science and Engineering, 4 (3), 163–68.

Kong, Qing, Zhai, C., Guan, B., Li, C., Shan, S., Yu, J., 2012. Mathematic Modeling for Optimum Conditions on Aflatoxin B1 Degradation by the Aerobic Bacterium Rhodococcus Erythropoli. Toxins, 4 (11), 1181–95.

Kosicki, R., Błajet-Kosicka, A., Grajewski, J., Twarużek, M., 2016. Multiannual Mycotoxin Survey in Feed Materials and Feedingstuffs. Animal Feed Science and Technology, 215, 165–80.

Lawlor, P.G., Lynch, P.B., 2005. Mycotoxin Management. African Farming and Food Processing, 46, 12–13.

Locksley, T.H., Charmley, L.L., Prelusky, D.B., Warner, R.M., 1991. Two Physical Methods for the Decontamination of Four Cereals Contaminated with Deoxynivalenol and Zearalenone. Journal of Agricultural and Food Chemistry, 39 (2), 356–60.

Locksley, T.H., Charmley, L.L., Prelusky, D.B., Warner, R.M., 1992. Washing Procedures Using Water or Sodium Carbonate Solutions for the Decontamination of Three Cereals Contaminated with Deoxynivalenol and Zearalenone. Journal of Agricultural and Food Chemistry, 40 (11), 2147–51.

Marroquín-Cardona, A.G., Johnson, N.M., Phillips, T.D., Hayes, A.W., 2014. Mycotoxins in a Changing Global Environment–a Review. Food and Chemical Toxicology, 69, 220–30.

Matumba, Limbikani, Poucke, C.V., Ediage, E.N., Jacobs, B., Saeger, S.D., 2015. Effectiveness of Hand Sorting, Flotation/Washing, Dehulling and Combinations Thereof on the Decontamination of Mycotoxin-Contaminated White Maize. Food Additives & Contaminants: Part A., 32 (6), 960–69.

Mboya, Mujila, R., Kolanisi, U., 2014. Subsistence Farmers' Mycotoxin Contamination Awareness in the SADC Region: Implications on Millennium Development Goal 1, 4 and 6. Journal of Human Ecology, 46 (1), 21–31.

Milićević, Dragan, R., Škrinjar, M., Baltić, T., 2010. Real and Perceived Risks for Mycotoxin Contamination in Foods and Feeds: Challenges for Food Safety Control. Toxins, 2 (4), 572–92.

Misihairabgwi, J.M., Ezekiel, C.N., Sulyok, M., Shephard, G.S., Krska, R., 2017. Mycotoxin Contamination of Foods in Southern Africa: A 10-Year Review (2007–2016). Critical Reviews in Food Science and Nutrition, 1–16.

Muller, H.M., 1983. Entgiftung von Mykotoxinen. II. Chemische Verfahren Und Reaktion Mit Inhaltsstoffen von Futtermitteln. Ubersichten Zur Tierernahrung.

Murphy, Patricia, A., Rice, L.G., Ross, P.F., 1993. Fumonisin B1, B2, and B3 Content of Iowa, Wisconsin, and Illinois Corn and Corn Screenings. Journal of Agricultural and Food Chemistry, 41 (2), 263–66.

Mutungi, Christopher, Lamuka, P., Arimi, S., Gathumbi, J., Onyango, C., 2008. The Fate of Aflatoxins during Processing of Maize into Muthokoi–A Traditional Kenyan Food. Food Control, 19 (7), 714–21.

Park, D.L., Lee, L.S., Price, R.L., Pohland, A.E., 1988. Review of the Decontamination of Aflatoxins by Ammoniation: Current Status and Regulation. Journal-Association of Official Analytical Chemists, 71 (4), 685–703.

Paul, P.S., Johnson, D.W., Mirocha, C.J., Soper, F.F., Thoen, C.O., Muscoplat, C.C., Weber, A.F., 1977. In Vitro Stimulation of Bovine Peripheral Blood Lymphocytes: Suppression of Phytomitogen and Specific Antigen Lymphocyte Responses by Aflatoxin. American Journal of Veterinary Research, 38 (12), 2033–35.

Pinotti, Luciano, Ottoboni, M., Giromini, C., Dell'Orto, V., Cheli, F., 2016. Mycotoxin Contamination in the EU Feed Supply Chain: A Focus on Cereal Byproducts. Toxins, 8 (2), 45.

Pujol, Rosa, Torres, M., Sanchis, V., Canela, R., 1999. Fate of Fumonisin B1 in Corn Kernel Steeping Water Containing SO2. Journal of Agricultural and Food Chemistry, 47 (1), 276–78.

Ramljak, Danica, Calvert, R.J., Wiesenfeld, P.W., Diwan, B.A., Catipovic, B., Marasas, W.F.O., Victor, T.C., Anderson, L.M., Gelderblom, W.C.A., 2000. A Potential Mechanism for Fumonisin B1-Mediated Hepatocarcinogenesis: Cyclin D1 Stabilization Associated with Activation of Akt and Inhibition of GSK-3β Activity. Carcinogenesis, 21 (8), 1537–46.

Rhodes, M.T., Paterson, J.A., Kerley, M.S., Garner, H.E., Laughlin, M.H., 1991. Reduced Blood Flow to Peripheral and Core Body Tissues in Sheep and Cattle Induced by Endophyte-Infected Tall Fescue. Journal of Animal Science, 69 (5), 2033–43.

Samarajeewa, U., Sen, A.C., Cohen, M.D., Wei, C.I., 1990. Detoxification of Aflatoxins in Foods and Feeds by Physical and Chemical Methods. Journal of Food Protection, 53 (6), 489–501.

Schwake-Anduschus, C., Proske, M., Sciurba, E., Muenzing, K., Koch, M., Maul, R., 2015. Distribution of Deoxynivalenol, Zearalenone, and Their Respective Modified Analogues in Milling Fractions of Naturally Contaminated Wheat Grains. World Mycotoxin Journal, 8 (4), 433–43.

Schwartz, Elisabeth, H., Hametner, C., Slavik, V., Greitbauer, O., Bichl, G., Kunz-Vekiru, E., Schatzmayr, D., Berthiller, F., 2013. Characterization of Three Deoxynivalenol Sulfonates Formed by Reaction of Deoxynivalenol with Sulfur Reagents. Journal of Agricultural and Food Chemistry, 61 (37), 8941–48.

Shetty, Prathapkumar, H., Bhat, R.V., 1999. A Physical Method for Segregation of Fumonisin-Contaminated Maize. Food Chemistry, 66 (3), 371–74.

Sobrova, Pavlina, Adam, V., Vasatkova, A., Beklova, M., Zeman, L., Kizek, R., 2010. Deoxynivalenol and Its Toxicity. Interdisciplinary Toxicology, 3 (3), 94–99.

Surumay, F., Guillermo, Osweiler, G.D., Yaeger, M.J., Rottinghaus, G.E., Hendrich, S., Buckley, L.K., Murphy, P.A., 2005. Fumonisin B– Glucose Reaction Products Are Less Toxic When Fed to Swine. Journal of Agricultural and Food Chemistry, 53 (10), 4264–71.

Thiel, Pieter, G., 1978. A Molecular Mechanism for the Toxic Action of Moniliformin, a Mycotoxin Produced by Fusarium Moniliforme. Biochemical Pharmacology, 27 (4), 483–86.

Valdez, Benjamin., 2012. Food Industrial Processes: Methods and Equipment. BoD–Books on Demand.

Van der Westhuizen, L., Shephard, G.S., Rheeder, J.P., Burger, H.M., Gong, Y.Y., Gelderblom, W.C.A., Wild, C.P., 2011. Optimising Sorting and Washing of Home-Grown Maize to Reduce Fumonisin Contamination under Laboratory-Controlled Conditions. Food Control, 22, 396–400.

Van Egmond, Hans, P., 2002. Worldwide Regulations for Mycotoxins. Pp. 257–69 in Mycotoxins and food safety. Springer.

van Egmond, Hans, P., Schothorst, R.C., Jonker, M.A., 2007. Regulations Relating to Mycotoxins in Food. Analytical and Bioanalytical Chemistry, 389 (1), 147–57.

Venkatesh, Nandhitha, Keller, N.P., 2019. Mycotoxins in Conversation with Bacteria and Fungi. Frontiers in Microbiology, 10.

Vijayanandraj, S., Brinda, R., Kannan, K., Adhithya, R., Vinothini, S., Senthil, K., Chinta, R.R., Paranidharan, V., Velazhahan, R., 2014. Detoxification of Aflatoxin B1 by an Aqueous Extract from Leaves of Adhatoda Vasica Nees. Microbiological Research, 169 (4), 294–300.

Visconti, Angelo, Haidukowski, E.M., Pascale, M., Silvestri, M., 2004. Reduction of Deoxynivalenol during Durum Wheat Processing and Spaghetti Cooking. Toxicology Letters, 153 (1), 181–89.

Voss, K.A., Smith, G.W., Haschek, W.M., 2007. Fumonisins: Toxicokinetics, Mechanism of Action and Toxicity. Animal Feed Science and Technology, 137 (3–4), 299–325.

Vučković, Jovana, Bodroža-Solarov, M., Vujić, D., Bočarov-Stančić, A., Bagi, F., 2013. The Protective Effect of Hulls on the Occurrence of Alternaria Mycotoxins in Spelt Wheat. Journal of the Science of Food and Agriculture, 93 (8), 1996–2001.

Wang, Jianqiao, Ogata, M., Hirai, H., Kawagishi, H., 2011. Detoxification of Aflatoxin B1 by Manganese Peroxidase from the White-Rot Fungus Phanerochaete Sordida YK-624. FEMS Microbiology Letters, 314 (2), 164–69.

Webb, J., Broomfield, M., Jones, S., Donovan, B., 2014. Ammonia and Odour Emissions from UK Pig Farms and Nitrogen Leaching from Outdoor Pig Production. A Review. Science of the Total Environment, 470, 865–75.

Whitaker, Thomas, B., Richard, J.L., Giesbrecht, F.G., Slate, A.B., Ruiz, N., 2003. Estimating Deoxynivalenol in Shelled Corn Barge Lots by Measuring Deoxynivalenol in Corn Screenings. Journal of AOAC International, 86 (6), 1187–92.

Wild, Christopher, P., Miller, J.D., Groopman, J.D., 2015. Mycotoxin Control in Low-and Middle-Income Countries. International Agency for Research on Cancer Lyon, France.

Withanage, G.S., Murata, H., Koyama, T., Ishiwata, I., 2001. Agonistic and Antagonistic Effects of Zearalenone, an Etrogenic Mycotoxin, on SKN, HHUA, and HepG2 Human Cancer Cell Lines. Veterinary and Human Toxicology, 43 (1), 6–10.

Wood, G.E., 1992. Mycotoxins in Foods and Feeds in the United States. Journal of Animal Science, 70 (12), 3941–49.

Yiannikouris, Alexandros, Jouany, J.P., 2002. Mycotoxins in Feeds and Their Fate in Animals: A Review. Animal Research, 51 (2), 81–99.

Zahra, Naseem, Saeed, M.K., Sheikh, A., Kalim, I., Ahmad, S.R., Jamil, N., 2019. A Review of Mycotoxin Types, Occurrence, Toxicity, Detection Methods and Control. Biological Sciences-PJSIR, 62 (3), 206–18.

Zhu, Yan, Hassan, Y.I., Watts, C., Zhou, T., 2016. Innovative Technologies for the Mitigation of Mycotoxins in Animal Feed and Ingredients—A Review of Recent Patents. Animal Feed Science and Technology, 216, 19–29.