33

Mycotoxins Incidence in Animal Feeds, Their Prevention and Control Measures

AUTHORS DETAIL

Muhammad Mobashar

Assistant Professor Department of Animal Nutrition, UAP
*Corresponding author: mobashar@aup.edu.pk

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INTRODUCTION

The demand for livestock production and their products is the main prospect of livestock feeds globally. This increase in demand of animal feed is the result of increasing growth of world population. Food and Agriculture Organization evaluates that need for foodstuff will rise up to 60% by 2050, and protein production from animal origin will increase by 1.7% /year from 2010-50, with beef production likely to increase by nearly 70%, aquaculture by 90%, and diary by 55% (IFIF 2021). Mycotoxins are toxic secondary metabolites produced by molds naturally. Some mycotoxins like aflatoxins (AFs), fumonisins (Fms), ochratoxins (OT), trichothecene, and. zearalenone are predominant in animal feedstuffs. More than 500 either regulated or tested mycotoxins have been identified (Awuchi et al. 2021) causing diseases to living organisms. Three fungal genera: Aspergillus, Penicillium and Fusarium produce mcotoxins (Bennett and Klich 2003).
Mycotoxin formation generally occurs in the field, during processing and storage of feeds under unfavorable conditions. Fungal colonization, water activity and ambient temperature are major factors for mycotoxin production (D'mello 2002). Some drawbacks with intake of contaminated feed in livestock are low feed consumption, poor feed conversion, reduced body weight, greater syndrome prevalence and reduced reproductive capacities (Gashaw 2016), causing large costs on economy (CAST 2003).
Nevertheless, it is very important to understand some potential sources of mycotoxins that contaminate livestock feeds.

Classification of Fungi and Mycotoxins

Mycotoxin formation can occur at pre and post-harvest stages. Based on these two stages and climatic conditions, classification of toxigenic fungi is summarized in Table 1. It is noteworthy that only following four classes of toxigenic fungi cause mycotoxins formation. A summary of various mycotoxins caused by different fungi in several feed and foodstuffs along with their toxigenic effects at different biological activities are depicted in Table 2.

Dynamics of Fungal Growth and Mycotoxins Formation

Fungal colonization and subsequently mycotoxin production are generally affected by variable determinants. Some stress factors such as drought, poor fertilization, high crop densities, weed competition and mechanical damage can weaken the plant's natural defense system and promote mycotoxin formation. Optimal temperature and water activity for mycotoxin production range between 20 to 30°C and 0.9 to 0.99aw, respectively (Table 3). Water activity, oxygen content, and surface area are the physical characteristics of substrate, while chemical features including availability of different nutrients such as starches, oil and fats, vitamins, and amino acid composition cause mycotoxin production (Zaki et al 2012).
Storage fungi can grow at a minimum water activity of 0.70 aw; however, water activity for toxin formation under field conditions should be more than 0.85 aw (Golob 2007). Relative humidity between 70 to 75% and moisture content between 14 to 15% may initiate growth of fungal species like *Aspergillus glaucus* on cereal grains, pulses, pelleted feeds and meals from oil seed (Williams 1991). Interactions may occur between environmental factors like temperature and water activity for fungal growth. It means that optimum temperature and water activity are interlinked and are not the same for some mycotoxins formation as for fungal growth. Optimum growth of fungal species like *F. verticillioides* was obtained at water activity of 0.995 aw and 20 and 25° C temperature range, but when value of water activity shifted to 0.98 aw, the optimum temperature changed between 30 to 35°C (Medina et al. 2017).

Implications of Mycotoxins in Different Livestock Animals

Food originated from animals and their products are consumed by the humans and may contain mycotoxin residues. However, in society, where consumers are main users, shifting of mycotoxin residues into milk and animal tissues from the feed should not be overlooked. The financial impact of mycotoxicosis in animals is many folds higher than mortality caused due to mycotoxicosis (Zain 2011).

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Table 1: Classification of toxigenic fungi (D'mello 2002; Santin 2005)

1.Field Fungi	2.Storage Fungi
1. Invade seeds of crop in the field.	Invade grain or seeds at storage.
2. High moisture content (20–21%).	low moisture content (13–18%).
3.These are mainly *Fusarium*, *Alternaria*, *Cladosporium* and *Diplodia*,	These are *Aspergillus* and *Penicillium*
3.Tropical and sub-tropical fungi	4.Temperate Fungi
1. Include *Asperigillus flaivus*, *A. parasiticuis* and *A. ochraceus*	Include *Penicillium expansum* and *P. verrucosum*.
2. Predominant under warm and humid conditions	More prevalent under cold conditions.

Table 2: Mycotoxin's prevalence in food and feedstuffs and their toxigenic effects (Jarvis 1971; Moss 1991; Grenier and Oswald 2011; Zaki et al. 2012; Milani 2018).

Fungal species	Mycotoxins produced	Food/feed substrate	Toxigenic effects	Biological activities
Aspergillus flavus, *A. parasiticus*	Aflatoxins	Wheat, maize, rice, peanuts, oilseeds, and cottonseed, milk and dairy products	Carcinogenic and immunosuppressive	Temp. 25-37°C Water activity. 0.94-0.99aw pH. Less than 6.0
Fusarium. Culomorum, *F. graminearum*, *F. sporoitrichioides*, *A. ochraceus*, *A. Alliaceus*, *A. melleus*, *A. ostianus*, *A. sulphureus*, *Penicillium*	Deoxynivalenol	Corn, wheat and their by-products	Acute temporary nausea, vomiting, diarrhea, abdominal pain, headache.	Temp. 23.75° C Water activity. 0.98aw pH. 4.91
virudicatum, *P. palitians*, *P. communne*, *P. variabile*,	Ochratoxin A	Wheat, barley, oats, cocoa beans, coffee beans, dried fruits, and wine	Carcinogenic and immunosuppressive and nephrotoxic	Temp. 30° C Water activity. 0.98aw pH. 4.0
F.acuiminatum, *F. equisetti*, *F. poae*, *F. semitictum*,	T-2 toxin	Rye, wheat, corn, barley and oat	Immunosuppressive	Temp. 10-37° C Water activity. 0.995-0.90aw pH. 7.3
F. culmoruim, *F. graminearuim*, *F. sambucinuim*,	Zearalenone	Maize, wheat, barley, rye and animal feed	Oestrogenic	Temp. 22-28° C Water activity. 0.98aw pH. 5.6-74
F. proliferatum, *F. verticillioides*	Fumonisins	Cereal grains	Carcinogenic and neurotoxic	Temp. 20-30° C Water activity. 0.94-0.99aw pH. 3-4
Fusarium *spp*. Myrothecium *spp*. Trichoderma *spp*. Trichothecium *spp*.	Trichothecene (type B)	Cereal grains and animal feed	Dermonecrotic	Temp. 30° C Water activity. 0.98aw pH. 4.0-5.0

Table 3: Production of mycotoxins in grains at optimum temperatures and water activity (Milani 2018)

Mycotoxin	Temperature (°C)	Water activity (aw)
Aflatoxin	30	0.99
Ochratoxin	25–30	0.98
Fumonisin	15–30	0.9–0.995
Zearalenone	25	0.96
Deoxynivalenol	26–30	0.995

Effects on Monogastric Animals

Monogastrics are more sensitive to toxic effects. Feed manufacturers should be aware that if feed analysis shows presence of even a single mycotoxin, it is most probable that other mycotoxins may also be present. Different fungal strains such as *A. flavus* and *A. parasiticus* cause aflatoxins (AFs) formation. AFs occur naturally in tropical and sub-tropical regions which include aflatoxin B1 (AFB1), aflatoxin B2, (AFB2), aflatoxin G1, (AFG1) and aflatoxin G2 (AFG2). AFB1 is the most predominant in feeds and very effective hepatocarcinogens. Reduced feed intake, reduced feed efficiency, growth retardation, decreased appetite, anorexia, depression, low milk production and immunosuppression are some effects of AFs. Under acute conditions (at higher level) mortality of animal cannot be ignored. AFM1 which is metabolized form of AFB1 can be transmitted to suckling piglets through milk (Prodanov-Radulovic et al. 2017).

Ochratoxin is produced by fungi of Aspergillus *species* in tropical and subtropical climates and in temperate region by Penicillium *species*. It exerts toxigenic effects on livestock and humans (Sherazi et al. 2015). Partially, in all animal species and particularly in monogastric animals, its principal target organs are kidneys. Ochratoxin A (OTA), which is a primary ochratoxin, has greater protein affinity due to which it accumulates in animal tissues (Mobashar et al. 2010).

Deoxynivaleinol (DON) is one of the most frequently mycotoxins detected in grains (Mishra et al. 2013). In fact, DON is also called vomitoxin because of its association with swine vomiting. DON is normally produced by *F. graminearum*. Animal gender, age and dose of DON are factors which determine sensitivity to DON toxicity (Hughes et al. 1999; Awuchi et al. 2021). Presence of relatively low microbial biomass and subsequently poor metabolism of DON in stomach of monogastric animals is the major explanation for their higher susceptibility towards DON (Maresca 2013).

T-2 is very toxic and is produced by *F. tricinctum*. Its primary targets in swine are immune system and GIT because of rapid cell division in these sites (Marin et al. 2013).

Zearalenone is one of the important mycotoxins of Fusurium *species* which is stable at storage and shows tolerance at high temperature during processing of food (Gajęcki 2002). In various studies, it has been shown that during feed processing, zearalenone was not further degraded and it was found in all animal feed products (Chang et al. 2017). Therefore, concentration of zearalenone in diet should not be higher than 0.25 mg/kg (Zinedine et al. 2007). Zearalenone has an affinity to react with estrogen receptors present in reproductive tissues and causes estrogenic effects (Gajęcki 2002).

Fumonisins (Fms) are primarily neurotoxic, but also have potential for carcinogenic effects. These are very hard to study as they are hydrophilic and not soluble in organic solvents. Fms. particularly FmB1 causes disruption of sphingolipid metabolism by intervention of sphingosine N-acyltransferase enzyme. In addition, these mycotoxins also affect liver function, protein metabolism and urea cycle in animal body (Richard 2007). Pigs are mostly affected by level of 0.2 mg FmB1/kg. In animal feed, the European Commission recommended maximum levels of Fms. Some text is deleted in maize is 0.06 mg/kg and it is 0.005 mg/kg for pigs. Fms. have a molecular structure similar to that of sphinganine (Sa) and sphingosine (So), which are components of sphingolipids and affect Sa/So ratio. An increased Sa/So ratio in serum from pigs fed FmB1 at concentrations of $\geq$5 mg/kg has been found (Galvano et al. 2005). It appears that below 100 mg FmB1/kg diet, pig performance is mostly affected (Santin 2005). Table 4 presents summary of permissible concentrations of mycotoxins in swine feeds (Gajęcki 2002; Battacone et al. 2010; Maresca 2013; Marin et al. 2013; Pereira et al. 2019).

Effects on Poultry Birds

Almost all poultry species are affected by aflatoxicosis. Continued feeding of aflatoxin contaminated diet at low level shows some harmful effects, however, mortality may occur at relatively higher contamination level (Ditta et al. 2018).

Comparatively, layer birds show greater resistance to aflatoxicosis than young birds; therefore, these birds it accepted some changes should not receive contaminated level above 0.05 mg/kg. Aflatoxins may cause reduced feed intake, reduced egg size, poor eggshell, lower egg production and fertility problem in layer hens. Since eggs are preferably consumed by humans and aflatoxins metabolites have been observed in egg yolks, therefore, feed manufacturers should find out another alternative energy source for these birds rather than corn which is more susceptible to aflatoxins. (Ditta et al. 2018).

T2-toxin is considered to be the most potent for poultry sector. It may induce some lesions in mouth, digestive tract, organs, and skin. Some other effects are low egg production, inhibition of protein, DNA and RNA synthesis (Akande et al. 2006). Usually, its contamination in feed is low; therefore, its immunosuppressive effects and secondary infections often make diagnosis difficult. During disease outbreak, if any modification in diet leads to health and subsequently better bird performance, this may be a clue toward mycotoxin poisoning (Sokolovi et al. 2008).

Poultry are rarely affected by acute effects of DON mycotoxin under normal conditions, but under field conditions, it can cause reduced feed consumption in layers and broiler breeders, which can be an indication of presence of T2-toxin. However, DON with 5 mg/kg in diet and even below this level can cause reduced production, poor immune system and greater susceptibility to infectious diseases (Murugesan et al. 2015).

Effects on Equine

Toxic effects of mycotoxins on horses are not well described due to unavailability of enough literature, however, under field conditions, their effects seem to be of greater significance. Several health problems like colic problem, neurological disorders, hypersensitivity, and brain lesions have been reported in equine as the mycotoxins related issues. Likewise, aggregate influence of mycotoxins present in diet at low levels may affect feed intake, growth rate, fertility and respiration rate in horses. Reduced feed intake is reported when horses are fed on a DON contaminated diet at 15 mg/kg (Raymond et al. 2003). North Carolina University reported 100, 31 and 44% of colic cases in horses fed with DON, T-2 toxin and zearalenone contaminated feed. Relationship between these mycotoxins and colic is not understandable which needs to be clarified (Gomaa et al. 2022).

Among Fumonisins, FmB1 at 10 mg/kg is well reported for leukoencephalomalacia in horses. A multifocal neurologic disease in a herd of horses has been observed related to Fms. Equine leukoencephalomalacia, also called moldy corn poisoning which affects horses in particular while mules occasionally and causes unstiffening of brain (Richard 2007). Increased level of enyzmes such as sorbitol dehydrogenase (SDH) and gamma glutamyl transferase (GGT), causing liver damage in horses**,** has been linked with AFB1 at 2 mg/kg of diet. However, some literature also reports death of horses due to consumption of AFB1 contaminated feed even at 0.3 mg/kg (Riet-Correa et al. 2013).

Horses are the simple stomach animals with a considerable microbial digestive ability present in the large intestine. Surprisingly, horses are more vulnerable to mycotoxicosis because in horse’s major absorption of nutrients occurs prior to fermentation in small intestine compared to the ruminants where absorption occurs after microbial degradation in rumen (Riet-Correa et al. 2013).

Table 4: Maximum Level of mycotoxins incidence in swine feeds

Mycotoxin	Swine type	Max. tolerable level (mg/kg)	Toxic effects
Aflatoxins	Growing pigs Finishing pigs Breeding pigs	<0.001 <0.2 <0.1	Reduced feed intake, reduced feed efficiency, decreased appetite, anorexia, epistasis, low milk production, carcinogenic, immunosuppressant.
Ochratoxins	Pigs	<0.2	Nephrotoxic, hepatotoxic, immunotoxic , terategenic, depression, reduced feed intake, reduced body weight gain, diarrhea, polyuria, polydipsia, dehydration and high mortality
Zearalenone	Growing pigs Finishing pigs Breeding pigs	0.2 0.3 0.1 <0.5 in grain and grain products	Swollen vulivas, vaginal prolapses, enlarged uterus, shrunken ovaries, enlarged mammary glands and decreased fertility, variation in progesterone level and teratogenic responses in pigs
Deoxynivalenol (DON)	Pigs	<20% of the diet. < 0.001 in complete feeds	Decreased feed intake, reduced weight gain, vomiting, hemorrhagic skin, nausiea, diarrhea and gastrointestinal tract lesions
T-2 toxin	Pigs	< 0.001	Feed refusal, weight loss, poor cellular immune response, inhibiting protein synthesis and damage of DNA
Fumonisins	Pigs	>0.002	Reduced weight gain, reduced feed efficiency, damage to liver and pancreas, immune suppressive, reproductive difficulties, porcine pulmonary edema, hepatotoxic and nephrotoxic

Table 5: Tolerance levels of mycotoxins in ration (mg/kg) of horses

Mycotoxin	Horses	Source
Aflatoxin	0.01 mg/kg	(Ahmed et al. 2017)
Deoxynivaleol (DON)	2 mg/kg or 5 mg in grain feed and or should not be above 40% of diet	(Raymond et al. 2003)
Fumonisins	5 mg/kg as a maximum limit and or should not exceed 20% of the diet on DM basis.	(Riley et al. 1993)
Zearalenone	1 mg/kg had no effect on ovarian function	(Juhasz et al. 2000)
T-2 toxin	1 mg/kg diet had no effect on ovarian function	(Juhasz et al. 2000)

Horses at productive stage, late gestation, early lactation and those used for intensive work have high energy requirements which are generally fulfilled from grain feeding. Therefore, horses have greater exposure to mycotoxicosis in term of grain affinity. On the other hand, horses used for light work are generally kept on hay or forage. Under poor management conditions, these feeds are contaminated with molds and mycotoxins. Usually, moldy forages are less palatable than non-moldy forages and when horses are fed on these feeds, they refuse feed before ingesting enough feed to cause severe damage to intestinal tract and one of the typical examples in horses observed in such cases is mild colic (Gomaa et al. 2022).

Regrettably, due to greater palatability of grains even infected with molds would not affect feed intake of horses. As a result, horses are most frequently exposed to mycotoxins (Skelly 2015). Some tolerance levels of mycotoxins in ration of horses are given in Table 5.

Effects on Dairy and Beef Cattle

Mycotoxins, especially aflatoxin contaminated feed not only affects animal productivity and health, but it also impairs milk production. It is secreted into milk as aflatoxin M1 residues which account almost 1.7% of dietary level on an average. Considering the hazards of aflatoxin M1 residues in milk, dietary level of aflatoxin contamination should not be more than 0.025 mg/kg. Aflatoxicosis in dairy animals results in reduced feed intake, loss in body weight; less feed conversion ratio, reduced reproduction capacity, lameness, immunosuppression, hepatotoxicity, deleted nephrotoxicity and eventually may cause mortality in calves at higher contamination level. Considering different levels of AF in dairy feeds and consequences reported in various studies, chronic aflatoxicosis is a threat in dairy sector (Komboi et al. 2020).

In dairy animals, reduced feed intake, lower milk production, higher milk somatic cell counts, liver damage, impair rumen fermentation and reduced reproductive efficiency are some of the associated impacts of DON. Milk production is reduced when DON contamination is greater than 0.3 mg/kg (Charmley et al. 1993).

Generally, zearalenone is characterized by estrogenic effects in dairy cattle. Some common effects are low feed intake, reduced milk production, poor reproductive performance, and mammary gland enlargement. This mycotoxin can also cause abortions in dairy animals at higher contamination. deleted some text. Zearalenone can be a good marker for mycotoxin presence in feed and its level in feed should not exceed 0.25 mg/kg (Chang et al. 2017).

Main effects of T-2 toxin in dairy cattle are feed refusal, ataxia, gastroenteritis and reduced immune response in calves and reduced milk production in cows. At higher contamination, it causes death of animal. Therefore, a practical recommendation under best conditions is that contamination of T-2 toxin in ration of growing and lactating animals should not be more than 0.1 mg/kg. (Whitlow and Hagler 2010; EFSA et al. 2011).

Fumonosins are the most predominant in dairy animal feeds; therefore, their risks are very common to cattle. Dairy cattle are less sensitive to mycotoxicosis because of their higher potential for mycotoxin degradation in rumen. Cattle show 60 to 90% ruminal degradation of fumonisin. Nevertheless, when degree of mycotoxin susceptibility among dairy and beef cattle is compared, it appears that beef cattle are more resistant to mycotoxins due to variability in feed consumption and reduced stress factors like calving. Though, microbial degradation of mycotoxins in rumen might be a defensive factor for cows against acute toxicity. But even lower mycotoxin level may intermingle with other stressed factors to cause poor reproductive performance and subclinical losses. These losses have a greater economic impact than acute health problems but are more difficult to detect (Whitlow and Hagler 2010).

Beef cattle are also affected by aflatoxins, although complications are usually less critical as compared to monogastric animals Reduced growth rate in calves and rectal straining and prolapsed rectum are noticeable effects of aflatoxins at higher level (Agag 2004).

Since cattle in tropical and sub-tropical regions are usually fed on high roughage diets and they are fed on grain as a supplement. Therefore, aflatoxin contamination in grains at moderate level can occur. One can calculate proportions of grains in total ration based on 2.5% of BW and then acceptable level of aflatoxin in grain. This can be explained by an example of growing calves with BW of 272 kg will consume about 6.8 kg of total feed (272 kg multiplied by 2.5% equals 6.8 kg). In case of feeding 1.4 kg of grain plus forage to appetite, the grain will make up about 20% of total diet (1.4 kg divided by 6.8 kg equals 20%). In this case grain may contain up to 0.5 mg/kg of aflatoxin (0.1 mg/kg divided by 20% equals 0.5 mg /kg). Based on Thumb rule and personal expertise which is usually applied in calculation of mycotoxin level in grain portion of ration in tropical and subtropical zones. Gastroenteritis, intestinal hemorrhage, bloody faeces and immune suppression are T-2 toxin induced effects in beef cattle. While reduced feed intake, reduced meat production and diarrhea are important effects of DON. Toxic effects of zearalenone are vulvovaginitis, embryo mortality and cystic ovaries (Gajęcki 2002; Harčárová et al. 2020).

Economic Importance of Mycotoxins Intervention in Feed and Livestock Industry

Mycotoxins are more likely to influence almost 25% of the world's crops annually (Iheshiulor et al. 2011). In developed countries like US and Canada, estimated evaluating cost of mycotoxins is about $5 billion (Madhysatha and Marquardt 2019). Most of the foods and feeds are lost during manufacturing and uncontrolled storage conditions in developing countries which, however, can be consumed or available for trade purposes (Aidoo 1991). One of the major sources of economic losses and greater management cost in animal husbandry is mycotoxins in animal feed (Adamse et al. 2012).

Mycotoxin contamination of different feed products cause noteworthy economic issues at all trading stages. Therefore, without following the Codex Alimentarius Commission's guidelines for risk assessment and acceptable procedures, countries dealing with import of these products have restrictions and deleted some text have adverse impacts on economy of these, deleting some text countries (Baht and Vashanti 1999). Considering level of mycotoxin toxicity and its prevalence in each country, mycotoxins regulatory limits for animal feedstuffs are variable and even in some countries, there are no guidelines (Charmley and Trenholm 2021).

Nutritional worth of forages and most of the cereal crops, and subsequently animal productivity are badly affected by mycotoxicosis (Iheshiulor et al. 2011). When fungal infestation occurs in crops, nutrients are utilized for fungal growth. This affects animal feed intake due to reduced nutrients and energy content in particular and therefore, decreased animal productivity (Golob 2007). The economic losses due to mycotoxicosis include crop losses, loss of animal and human life, expenses of increased health care, and veterinary care, low animal productivity, disposal of contaminated foods and feeds, and cost on mycotoxins regulatory programs for control measures (Zain 2011).

Risk Management: Prevention of Mycotoxins in Feeds

Considering toxic effects and high economic losses due to mycotoxins, different risk management strategies have been established which mainly include.

1. Prevention of mycotoxin contamination.
2. Degradation and/or detoxification of mycotoxins
3. Inhibition of mycotoxin absorption in the gastrointestinal tract (Santos et al. 2010).

Pre and Post-harvest Preventive Measures

Fungal contamination and mycotoxins productions in the crops usually occur at pre and post-harvest stages (Omotayo et al. 2019). Control of pre-harvest mycotoxin contamination is getting more attention globally and some advanced techniques are being applied for this purpose. Breeding resistant crops, established agronomic practices to prevent plant stress, deleted and reduced soil fungi forming mycotoxins and harvesting at the optimum stage of maturity are some of the important mitigation measures for mycotoxicosis during pre-harvest stage (Xu et al. 2022).

Mitigation of kernels from insect infestation is one of the vital strategies to control propagation of *A. flavus* and *A. parasiticus* at pre-harvest stage (Lopez-garcia et al. 1999). Optimum stage of maturity for crop harvest is very important for later use and good quality product (Aidoo 1991). Field heat causes rapid deterioration, fungal colonization and mycotoxin formation; therefore, it is very necessary to harvest crop early during the day at sunset time. Mechanical damage and delayed harvest favor mycotoxin contamination (Peraica et al. 2002; Kabak et al. 2007).

Reducing moisture content before storage is one of the simple and most economical means of safe storage. Therefore, grains must be dried by natural conditions before storage. Mycotoxin problems in silage occur only through oxygen exposure, when it is not tightly covered. It is very necessary to store feedstuffs at suitable temperature and humidity. It is commonly observed that the spoiled product at pre-harvest stage contains deleted a significant mycotoxins load at storage. Therefore, removing and/or reducing toxic effects in the food and animal feeds, physical, chemical and biological detoxification strategies are very necessary (Pemberton and Simpson 1991).

Physical Strategies

Some of the important physical techniques for reducing or inactivating mycotoxins in feeds are cooking, boiling, baking, frying, roasting and extrusion (Aiko and Mehta 2015). These procedures eradicate mycotoxins from contaminated grain products and their presence in the gastrointestinal system (He and Zhou 2010). Mycotoxins in feedstuffs can be degraded through heat treatment; however, this may destroy vitamins and denature proteins (Samarajeewa 1991).

Mycotoxins in various feeds can be extracted using solvents. The most common solvents for this purpose are ethanol (95%), aqueous acetone (90%), isopropanol (80%), hexane-methanol, methanol-water, acetonitrile-water, hexane-ethanol-water, and acetone-hexane (Kabak et al. 2007). However, this approach cannot be used on large-scale due to its high cost and issues of disposal of toxic extract (Rustom 1997).

Bioavailability of mycotoxins can be reduced through incorporation of adsorbents into feeds which reduce mycotoxin uptake and transport to target organs. These are substances with high molecular weight having binding ability for mycotoxins in GIT. Adsorbents inhibiting mycotoxin absorption are excreted from body through faeces as adsorbent-toxin complex (Santos et al. 2010). These do not dissociate in GIT and prevent animals against mycotoxin exposure. Carbon based organic polymers and silica based inorganic compound are important adsorbing agents. Most commonly used inorganic adsorbents are natural clay products, and synthetic polymers (Huwig et al. 2001; Stoev 2013). Organic binders have been highly proposed, because of their effectiveness against a wide range of mycotoxins. These are decomposable and therefore will not contaminate the environment after being excreted from animals. While inorganic binders are integrated at high frequency as these are collected in animal manure and then spread in the field and cause contamination to environment (Jouany 2007).

Chemical Methods

Some chemicals are very effective against reduction, destruction, and/or inactivation of mycotoxins like acids, bases, oxidizing agents and reducing and chlorinating compounds. Although most of these chemicals are effective against mycotoxins, but chemical detoxification of mycotoxins is not appropriate because these often reduce nutritional value of chemically treated feeds (Abdel-wahhab and Kholif 2008).

Biological Detoxification of Mycotoxins

Biological detoxification of mycotoxins means application of microbes, their enzymes and metabolites for binding and degradation of mycotoxins. The microbiota in application should be safe, nonpathogenic, having degradation potential, free of improper odor or taste and preserve nutrients in food (Varga et al. 2010). A diversity of bacteria, yeasts, and molds has mycotoxin degradation potential. The clue behind this is using enzymes precisely for breakdown of a single mycotoxin or group of mycotoxins into a non-toxic molecule (Ji et al. 2016).

Probiotics are live microorganisms which after incorporation in foods, drugs and animal diets in sufficient quantities exert positive effects on the host health. Probiotic bacteria like *Lactobacillus* strains (LAB) have a very promising mycotoxin detoxification potential. LAB bacteria cause detoxification of AFB1. An assessment on five *Lactobacillus* strains including *L. rhamnosus* GG, *L. rhamnosus* LC705, *L. acidophilus*, *L. gasseri* and *L. casei* shows that these strains have detoxification efficacy up to 80% (Haskard et al. 2000) and *L. rhamnosus* GG causes 70% disappearance of ZEN (El-Nezami et al. 1998). Similarly, *L. acidophilus* strain (VM 20) can remove OTA by 90% (Fuchs 2008).

Some actino-bacterial strains in soil have mycotoxin binding ability and detoxification potential. AT8 strain can effectively detoxify OTA up to 52.61%. deleted and *Streptomyces spp*. and *Aspergillus flavus* (NRRL 62477) in combination can also remove AFB1 and AFB2 in vitro up to 73%. *Lysinibacillus ssp*. strain isolated from chicken large intestine digesta has greater removal ability of ZEN mycotoxin (Nahle et al. 2022).

S. cerevisiae, a yeast strain used in food industries has ability to degrade and detoxify OTA and AFB1 and can decrease AFM1 contents in milk (Piotrowska and Zokwska 2005).

Some fungal species of Aspergillus can convert AFB1 to AFB2 through various enzymes (Ji et al. 2016). White rot fungi can degrade AFs up to 87% through laccase enzyme (Alberts et al. 2009) while *A. niger* (ND-1) up to 58.2% (Zhang et al. 2014) through laccase and Mn-peroxidase (Singh and Mehta 2022).

Conclusion

Mycotoxins are toxic secondary metabolites of toxigenic fungi. Mycotoxin contaminated feeds affect animal health and productivity. Contamination of feeds may occur during pre- and post-harvests. Huge economic losses occur annually in the feed and animal sectors. Consequently, some measures are needed to eliminate and/or deactivate mycotoxins in feedstuffs. Various preventive measures for mycotoxin production and its drawbacks are being applied globally. These decontamination measures include biological, chemical and physical techniques. Nevertheless, physical and chemical methods have inadequate efficacy, safety concerns, palatability losses, and are costly. They have also been condemned due to loss in nutritive value of the feeds, and negative effects on animal and human health. Using of adsorbents and microorganisms/enzymes may be more appropriate. Further research is warranted to figure out potential of biological methods at molecular level in comparison with other decontamination procedures.

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