



Review

Mycotoxin toxicity and residue in animal products: Prevalence, consumer exposure and reduction strategies – A review

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ABSTRACT

Mycotoxin residues are transferred from feed to animal products, yet, less attention has been paid to it in developing countries like Nigeria, India, Mexico etc. There is a need to find alternative alleviation material for reducing the impact of mycotoxin. This review is meant to elucidate different additives that can reduce mycotoxin residue in animal products in the world, especially in developing countries. There is evidence of relationship between mycotoxin residue in breast milk of nursing mothers and mycotoxin exposure through crop and animal product (egg and milk) intake, especially in Asia, Africa, Middle East, Latin America, and some parts of Europe. Younger livestock tends to have more toxin residues in their tissue compared to older animals. Grazing animal are also exposed to mycotoxin intake which corresponds to high level of mycotoxins in their products including meat and milk. This review shows that phytogetic, probiotic, and prebiotic additives can decrease mycotoxin residues in milk, eggs, meat liver and other tissues of livestock. Specifically, bentonites, difructose anhydride III, yeast (*Trichosporon mycotoxinivorans*), *Bacillus* spp., or their biodegradable products can reduce mycotoxin residue in animal products. In addition, Ally isothiocyanates from mustard seed were able to mitigate mycotoxins in silo-simulated system. Evidence shows that there are now low-cost, accessible, and eco-friendly feed additives, which could alleviate the effect of mycotoxin in feed and food. There is a need for aggressive public awareness and farmers' education on the prevalence, and danger caused by mycotoxins as well as possible additives that can reduce toxin absorption into animal products.

1. Introduction

The presence of mycotoxins in humans apart from animals and their products is a serious problem in safeguarding consumers' health globally. The challenge however, is that many developing countries and transitional nations are unaware of the prevalence of mycotoxin residues in the animal products while many do not have strict monitoring and surveilling practices regarding animal products. The challenging problem is that the livestock management practices mainly focus on increasing the production and yield without considering the safety issues. Since the relation between aflatoxin and human hepatic disorders became known, research has shown that aflatoxin is a global issue affecting animal and human health (Coppock et al., 2018).

Toxic residues in animal products are mainly related to consuming contaminated feed or forages. Furthermore, animal derived products viz., meat, milk, and eggs are obtained after consumed feed has been subjected to enzymatic and microbial transformations leading to production of absorbable metabolites in the gut. During this process, nutrients, volatile fatty acids, and metabolites (toxic and beneficial) are absorbed into the bloodstream and are later excreted through urine and feces. The toxins that are not excreted generally remain as residues in the edible organs and muscles.

At times, low-level contamination may not affect animal's growth or performance noticeably, but there is still possibility of detecting level of toxin such as AF residues in animal liquid and tissue products (Fowler et al., 2015). For example, egg production and weight were not affected in laying birds fed 25–100 µg AF/kg feed, yet there was

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residue in eggs (Aly and Anwer, 2009). This suggests the need to reduce mycotoxins level in feed or forages so as to decrease their residues in meat, milk, and eggs to a “less risky level”. Unfortunately, at present, there is no legal regulation for AFB1 in livestock derived products, such as liver and meat (European Commission, 2010). Mycotoxin residues poses a risk to food security and safety because increased residues in animal product increase food wastage by causing rejection in the global and local market ultimately aggravating the micronutrient insecurity especially in developing countries. Mycotoxin residues poses a risk to food security and safety because increased residues in animal product increase food wastage by causing rejection in the global and local market ultimately aggravating the micronutrient insecurity in developing countries. Besides, other concerns about mycotoxin are that it cannot be destroyed easily by temperature, chemical, or physical treatment. Although the application of heat treatments like pasteurization or ultra-high temperature may degrade some AFM1 metabolites (Jawaid et al., 2015), the residues are stable enough to survive in raw and processed milk (Mohammadi, 2011) and boiled egg (Aly and Anwer, 2009). Therefore, the best option is to prevent or reduce its presence in animal products.

In technologically advanced countries, feeds are consistently scrutinized for mycotoxins so as to protect animal health and improve productivity and farmers’ income (Gambacorta et al., 2019).

The use of feed additives to adsorb toxicants and toxins are is widely practiced in livestock feed industry. Yeast, phytogetic feed additives, enzymes, essential oils etc., have been used to improve animal productivity, digestibility, product yield, and for therapeutic purposes worldwide. Such attention has not been paid globally to mycotoxin reduction in animals and their products. Toxin binders from companies such as Biomin® and Alltech® have been used in feed to alleviate the effects of mycotoxins. Farmers make use of binders or absorbents that binds to the mycotoxins and prevent their absorption through the gut and into the blood circulation, thus, alleviating the effect of mycotoxins in animals. These anti-aflatoxigenic products are being employed for detoxification of mycotoxin-contaminated grains yet; however, not all the products are efficient in preventing the accumulation of residues. For instance, about 50% of UHT contaminated milk samples were found to contain AF concentration more than 0.05 µg/L (Bayezit et al., 2019). Therefore, cost-effective, non-toxic, and ecofriendly natural additives are needed to prevent mycotoxins contamination and reduce their residues in fresh and processed livestock products such as milk, meat, and egg. This review is meant to elucidate different additives that can reduce mycotoxin residue in animal products, in both developing and developed countries. Furthermore, it aims to present an overview on the prevalence of mycotoxin in animal product especially in developing countries, and perhaps serve as awareness to farmers, food safety organization in developing countries, as well as to elucidate on the extent of mothers and infants exposure of to mycotoxins.

2. Types and sources of mycotoxins

Studies have shown that over 300 mycotoxins exist; among those, mycotoxins of economic significance affecting both humans and animals include aflatoxin (AF), ochratoxins (OTA), ergot, fuminosins, trichothecenes (TH), patulin (PAT), citrinin (CIT), and zearalenone (ZEA), etc. Mycotoxins have both health and economic implication on crop producers as well as consumers. The most common casualty crops for mycotoxins include maize, millet, wheat, sorghum, soybean, groundnut, and their products, as well as their by-products, especially those derived from contaminated main ingredients. Mycotoxin-based sources for livestock intake could be cereals, leguminous seeds, oilseeds, crop by-products, industrial by-products like brewer dry grain and rice bran, food garbage, moldy bread, cottonseed, spices, and other foods diverted to animal feeds (Coppock et al., 2018). Among various contamina-

tion sources, fungi (*Aspergillus*, *Fusarium*, *Penicillium* *Alternaria*, and *Claviceps*) or saprophytic molds are the most common contaminants, which attack crops during both pre- and post-harvest periods.

Although it is believed that good agricultural practices, quality control, and good storage systems reduce the risk of developed countries exposure to mycotoxin, a report showed that many developed regions are at mycotoxin prevalence risk from severe to extreme level. For instance, mycotoxin prevalence in North America, Central America, and South Asia are at extreme level while other regions like South East Asia, Oceania, and Europe have moderate to high risk of mycotoxins’ prevalence (Biomin Biomin Mycotoxin Survey, 2019). Surprisingly, grains, concentrate, and silage are not the only means whereby livestock are exposed to mycotoxins. Grazing and free-grazing animals are also exposed to Mycotoxins, which is evident in the residues in their products. For example, T-2 toxin and HT-2 toxin, the members of TH and ZEA have been found in natural grasses intended for grazing (Nichea et al., 2015) and AFM1 have been found in milk of free-grazing cows (Oluwafemi et al., 2014) even beyond European limit. This indicates that livestock are exposed to mycotoxin irrespective of production system practices, whether intensive, extensive, or intermediate. So nomadic and mixed crop-livestock system, which depend on forages, crop, and animal by-products are not exempted from mycotoxin exposures.

3. Mycotoxin consumption and consequences

The current trends in climate change tend to have favoured fungal colonization and mycotoxin contamination of agricultural crops and products. In most cases, these produces are exposed to fungi infestation and subsequently mycotoxins because of the inadequate storage facilities. Mycotoxin production potentials, toxigenic fungal growth, and contamination levels have been aggravated in many regions because of the interacting factors of climate change (; Battilani et al., 2016; Bandyopadhyay et al., 2016). For instance, *Fusarium* mycotoxins, which are referred as temperate mycotoxins, are known to contaminate food and food products originating from sub-Saharan Africa (SSA). In the tropical sub-African region, fungal contamination by *Fusarium* and *Aspergillus* may be prevalent (Liew and Mohd-Redzwan, 2018; Kagot et al., 2019); whereas, *Penicillium* are common in the temperate (Denli and Perez, 2010). A recent study has predicted that aflatoxin B1 (AFB1) will become a significant food safety issue in Europe, especially with regard to the maize crop infestation (Battilani et al., 2016). Although the Serbia and Hungary are considered safe regarding aflatoxin infestation, prolonged hot and dry climate have caused detectable levels of AF in these countries too (Medina et al., 2015; Dobolyi et al., 2013). Hence, it is evident that the incidences may increase with rise in global temperatures.

Mycotoxins are non-infectious toxins produced mainly by *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria*, and *Cladosporium* genera (Liew and Mohd-Redzwan, 2018; Bryden, 2012) among others. They are highly harmful substances in humans and animals when ingested, inhaled, or absorbed through the skin. Lack of awareness, dietary patterns, and lack of limiting regulations are the major causes of consumption of food and feed contaminated with mycotoxin. Although several studies have been geared toward controlling or reducing the extent to which humans and animals are exposed to mycotoxin contamination, non-existence of regulatory laws and enforcement, poverty, ignorance, lack of awareness, and lack of good storage or process facilities especially in the developing world like Africa have become a stumbling block toward achieving this goal (Kagot et al., 2019). In order to reduce the incidence of mycotoxins and their toxic health effects on humans and animals, strict regulation, and enforcement, public awareness on need to apply good agricultural and proper storage practices are paramount.

4. Mycotoxin on animal health

4.1. Factors influencing mycotoxin absorption in livestock

Mycotoxin contamination could be detrimental to livestock health, production, and welfare. Mycotoxins prevalence in feed or feed ingredients are influenced by season and varies with climate. The warm, wet, tropical, or subtropical climates are the predisposing factors for mycotoxin contaminations (Jenkins, 2018). Stage of lactation, gut segment, and age, influences the efficiency of AF absorption. For examples, cows in early lactation can excrete 3.8–6.2% of the dietary AFB₁ intake as AFM₁ in the milk compared to 1.8–2.5% in late lactation; and AF absorption rate in duodenum, jejunum, and rumen is higher in rat and cattle than other segments of the gut (Coppock et al., 2018). Deoxynivalenol (DON) in sows' milk, is known to influence the exposure of the neonates to mycotoxins (Sayyari et al., 2018). Further, age is also known to affect the residue of AFB₁ in animal tissue. Older birds tend to have lesser tissue residues of AFB₁ compared to birds of younger age (Hussain et al., 2010; Jia et al., 2016). This could be because of well developed organs in older birds, which aid quick removal of harmful metabolites from the body. Another reason might be the presence of growing tissue in younger birds compared to older birds, which limits the ability to absorb toxins selectively due to not fully developed or non-functional tight junctions of the intestinal villus. Other factors that influence susceptibility, and exposure to mycotoxins are season, production system, feeding program, breed, and sex of animal. For example, male animals are more susceptible to AF than females (Jonsyn-Ellis, 2001) and indigenous pigs had a higher level of urinary AFM₁ (Lee et al., 2017).

4.2. Mycotoxin influence on livestock physiological functions

Mycotoxins are associated with anorexia, release of pro-inflammatory cytokines, and high levels of serum AST and ALT in livestock. All these changes indicate liver challenge in animals and suppression of immune system. In non-ruminants, few reports revealed higher ammonia build-up in litter of birds exposed to citrinin, presumably due to increased stimulation for water intake (Brake et al., 2000). Further, oral lesions have been linked with TH ingestion (Brake et al., 2000). In addition, studies have shown that mycotoxins disrupt the metabolism and distribution of nutrients in animals.

Osborne et al. (1982) observed a decrease in digestive enzymes such as pancreatic lipase, trypsin, amylase, as well as reduction in the concentrations of bile salts during aflatoxicosis. Mycotoxins are also shown to exert negative effects on the tissue circulation of vitamins and minerals (Surai, 2002). At low concentration (20–40 µg/kg), mycotoxin in animal feed can lead to decreased conception rate, libido, testicular weight, spermatogenesis, and testosterone concentration (Gajecki et al., 2010). Apart from these, several cases of pseudo-pregnancy, agalactia, stillbirths, hematuria, estrogenic vulval swelling, and immunosuppression have been reported (Fink-Gremmels and Malekinejad, 2007; Shi et al., 2018). In a more recent study, Aupanun et al. (2019) studied the combined effects of deoxynivalenol, nivalenol, and fusarenon-X and found a marked nuclear condensation and fragmentation of lymphocytes in Peyer's patches and spleen (lymphoid tissue).

The effect of mycotoxin seems pronounced in nonruminants compared to ruminant due to the ability of rumen microbes, mainly protozoa, in metabolizing various mycotoxins (Zebeli and Metzler-Zebeli, 2012; Schaumberger, 2015). Yet, greater production demand and modern feeding system of high grain to concentrate diet compromises gut health integrity (both foregut and hindgut) through depression of gut pH, thereby causing microbial shift (Faniyi et al., 2019) such as reduction in protozoa population. Hence, high grain diets predis-

pose ruminants to mycotoxins, at excessive levels, ultimately leading to the condition of diseased and death. This is because, AFB₁ could be absorbed via rumen wall before reaching the intestine, and transformed into AFM₁ by the mitochondrial cytochrome P450 oxidative system in the liver of dairy cattle within a short time of intake (Moschini et al., 2007). A recent study revealed that ruminants are predisposed to a wide range of toxic effects such as mastitis, laminitis, hepatocellular injuries, gastroenteritis, diarrhea, immune dysfunction, kidney lesions, low testicular development, sperm count, and ovarian cysts as a result of consumption of mycotoxins (DON, ZEA, and AFB₁) mycotoxin-contaminated feed (Fantinati, 2018). In India, improper storage of rice straw by farmers led to fungal (*A. flavus* and *P. notatum*) contamination, which causes mycotoxicosis and result in necrosis, weakness, emaciation, edema, and gangrene in legs, tail, and ear (Reddy et al., 2016).

5. Animal derived product contamination

Mycotoxins are may be excreted through urine, feces, and milk, and can also be stored in egg, meat, and visceral organs. Aflatoxin residues are predominant in the liver, gizzard, kidney, milk, eggs, and meat and these livestock organs and products consumption are one of the most important sources of mycotoxin intake in humans. This mycotoxin contamination causes wide range of harmful effects in human beings. For instance, consuming food contaminated with zearalenone mycotoxin may affect the reproduction in females because of the structure-activity relationship between human estrogenic activity and zearalenone mycotoxins (Shier et al., 2001). Therefore, preventing mycotoxins from entering feed chain is imperative. Mycotoxins invariably transfer from feed to milk; hence, AF limits allowed in dairy feeds are 20, 10, and 5 µg/kg in USA, China, and Europe, respectively (Guo et al., 2019). AFM₁ is known as a detoxication by-product of AFB₁. In spite of the greater extent of mycotoxin detoxification in ruminants, the residue contents are higher in milk. It is estimated that there are about 0.3 µg/kg of AFB₁ residue in an egg for every 10 mg/kg of AFB₁ (equivalent of 10 000 µg AFB₁/kg). This is about 0.003% of AFB₁ residue for every 10 mg/kg of AFB₁ compared to turnover of 0.3–2.2% AFB₁ mammalian milk and in 0.05% for FB₁ and T₂-toxin (EFSA 2009) (Table 1, Fig. 1).

6. Incidence of mycotoxin residue in monogastric product

In developing countries like Nigeria and India, not much attention is paid to mycotoxin residues in animal products; rather, the focus is on how to reduce mycotoxin in feed and to alleviate its effects on animal productivity and health. However, such uninformed or unintentional overlook by farmers and the public is no excuse. Aflatoxin residue has been found in eggs, muscle, and organs and its concentration is high in liver, egg, kidney, and thigh region (Herzallah, 2013).

6.1. Poultry

Literary report shows that aflatoxin residues can be found in both eggs and meat. A study found 0.05 and 9.01 µg/kg residue of AFB₁ in muscle and gizzard of laying hen exposed to 5 mg/kg AF-contaminated feed. Surprisingly, the residues were still found in eggs and gizzard even after withdrawing the contaminated feed (Fernández et al., 1994). Similarly, 0.56–22.54 ng/g residues of OTA and 0.03–1.44 ng/g of AF was found in breast, kidney, and liver of breeder hen exposed to 5 mg/kg OTA or AFB₁. These residues remained in the eggs 3- to 5-day post contamination (Hassan et al., 2012). Pandey and Chauhan (2007) found AFM₁ residue in egg and breast muscle of laying hen fed diet containing 2.5–3.91 mg/kg AFB₁. At times, there are single or multiple mycotoxin contaminants in diet; as such, there could be multi-toxin residues in poultry products. Feeding diet contaminated with aflatoxin (123.0 µg/kg), or AF and ZEA (123.0 and 260.2 µg/kg, respec-

Table 1
Summary of prevalence of mycotoxin in animal product.

Product	Species	Exposure level	References
Muscle and gizzard, egg	Laying birds	5 mg/kg AF	Fernández et al. (1994)
0.56–22.54 ng/g of OTA and 0.03–1.44 ng/g of AF in breast, kidney and liver and residue remained 3–5 days in egg post contamination	Breeder hen	5 mg/kg OTA or AFB1	Hassan et al. (2012)
Egg and breast muscle containing 2.5–3.91 mg/kg AFB1	Laying hen fed diet	Not specified	Pandey and Chauhan 2007
0.01–0.21 µg/kg aflatoxin residue in egg	Laying birds	AF (123.0 µg/kg), or AF and ZEA (123.0 + 260.2 µg/kg respectively),	Jia et al. (2016)
0.04–0.07 µg/kg AFB1 in egg	Laying birds	(25–100 µg AF/kg feed) contaminated diet	Aly and Anwer (2009)
6.97 and 3.27 ng/g in liver and muscle	Broiler chicken	6400 µg/kg AFB1	Hussain et al. (2010)
0.05–2.99 µg/kg in organs and muscle of health and sick birds	Broilers	Not specified	Khan et al. (2013)
6.45 ng/g in the liver, kidney and muscle	Swine	524 ng/g AF contaminated diet	Beaver et al. (1990)
OTA in fermented sausages and ham were 5–10 higher than the 1 µg/kg limit	Swine animal product	NA	Pleadin et al. (2015)
2–4 µg/L in cow milk and ice cream	Dairy product	NA	Atanda et al. (2007)
75% of milk from free grazing cow had AF and 48% had AFM1 between 0.051 and 0.5 µg/L.	Cow	NA	Oluwafemi et al. (2014)
94% of milk had over 0.05 µg/L in Northern Nigeria	Nomadic cow	NA	Makun et al. (2016)
0.02–0.09 µg/kg AFB and 0.02–0.07 µg/kg AFG in fresh liver, kidney, beef and heart obtained from market	Cattle product in market south western Nigeria	NA	Oyero and Oyefolu (2010)
17% of 210 had AFM1 above 0.05 µg/kg	Cow milk sample in Kenya	NA	Kang'ethe et al. (2017)
0.15 and 0.17 µg/in milk from subsistence and commercial farms	Milk from Southern Africa	NA	Mwanza and Dutton (2014)
0.10–0.25 µg/kg AFM1 residue in milk	Lactating goat	NA	Ronchi et al. (2005)
83% of sampled milk had over 3 ng/kg AF with level ranging from 8 to 720 ng/kg	fluid milk and powdered milk in brazil	NA	Jajić et al. (2018)
54% of 52 samples had AF above European limit	Small farm in brazil	NA	Gonçalves et al. (2017)
70% of 84 samples were above EU and USA Limit	Sampled milk in Pakistan	NA	Jawaid et al. (2015)

Note, AF-aflatoxin; AFM1-aflatoxin M1; ZEA-zearalenone; OTA-ochratoxin A; NA-not applicable.

tively) resulted in the AF residues in egg at the range of 0.01–0.21 µg/kg (Jia et al., 2016).

Although farmers may pay attention to quality of feed and feed safety, carry-over effect of AF to egg may still occur in birds exposed

to low levels of AF. About 0.04–0.07 µg/kg AFB₁ was found in eggs of laying hens exposed to low-level AF (25–100 µg/kg) contaminated diet (Aly and Anwer, 2009). In a chinese study the residues of DON and ZEA compounds (ZEA α -zearalenol, β -zearalenol) were found in egg and meat, respectively (Wang et al., 2018). Consuming such meat may pose a risk to consumer's health.

Nowadays, broiler chickens are reared for 4–6 weeks and are slaughtered at an early age. The young age may affect clearance level of AF in tissues and hence may act as a carrier of mycotoxin residues. Broiler chicken exposed to 6400 µg/kg AFB₁ had up to 6.97 and 3.27 ng/g in liver and muscle. This residue was still found for longer duration in the younger birds even after toxin withdrawal (Hussain et al., 2010), which is an indication of slow clear out. Few unscrupulous farmers and butchers sell meat from both healthy and sick livestock either live or processed (if processed, infected animal may not be identified easily). A study in Pakistan found aflatoxin residues in the organs and muscle of healthy and sick broiler; and about 14–49.2% of the muscle samples had residue levels higher than 0.05 µg/kg (Khan et al., 2013). Quail is one of the recently domesticated birds and their eggs and meat are promoted to have low cholesterol, which encourage the consumption. It is noteworthy that the AF residues were found at a higher rate in the liver and muscle portions of quail compared to duck, hen, and broiler (Bintvihok et al., 2002).

6.2. Swine

The pig industry and pork value chain in Asia is highly developed due to the demand and frequency of its product consumption. Although the recent African swine fever outbreak is have a devastating impact of the reputation and output of the industry it is still a product that is much appreciated. Prevalence of mycotoxin residue in pork will put the Asian populace, in fact, a large portion of humanity at risk. Therefore, safe pork is of paramount importance. Decades ago, residues of AF B₁, B₂, and M₁ have been found in all tissues of pigs fed contaminated diet (Furtado et al., 1979). Similarly, AF residues at 6.45 ng/g were found in the liver, kidney, and muscle of swine fed 524 ng/g aflatoxin-contaminated diet (Beaver et al., 1990). The mycotoxin residues in pork-based products remain intact even in processed products, presumably because of their stability in high temperatures. In Croatia, OTA found in fermented sausages and ham were 5–10 times higher than the 1 µg/kg limit set in some European countries (Pleadin et al., 2015). Similarly, sampled meat products in Croatia were found to contain multiple toxins such as CIT, AFB₁, and OTA (Markov et al., 2013).

7. Incidence of mycotoxin residue in ruminant product

Ruminants play a crucial role in human nutrition because of the supply of high quality protein through milk and meat. However, these products could be a source of contamination for consumers, especially farmers. AF transfer with increase in animal exposure to mycotoxins. High yielding cows have a transfer rate of dietary AFB₁ to milk AFM₁ up to 6% while the rate is 1–2% in low yielding cows (Britzi et al., 2013). As a precautionary procedure, the milk limit of AFM₁ in USA and China are 0.5 µg/L and 0.05 µg/L in Europe (Guo et al., 2019). The limit level for AFs in feedstuffs meant for dairy animals is lower than AFs in diets fed to (Guo et al., 2019) beef cattle because of the lack of withdrawal period for milk production (Coppock et al., 2018). The developing countries in Africa and Asia are more exposed to AF-contaminated milk because lack of implementation of good agricultural and storage practices, lack of mycotoxin surveillance, as well as non existence and/or implementation of regulatory limits. Accordingly, a Nigeria study found high AFM₁ in cow milk and ice cream between 2 and 4 µg/L (Atanda et al., 2017). Another study reported 75% of the milk samples collected from free-grazing cows in a state in southwestern Nigeria to be contaminated with AF, with 48% contain-

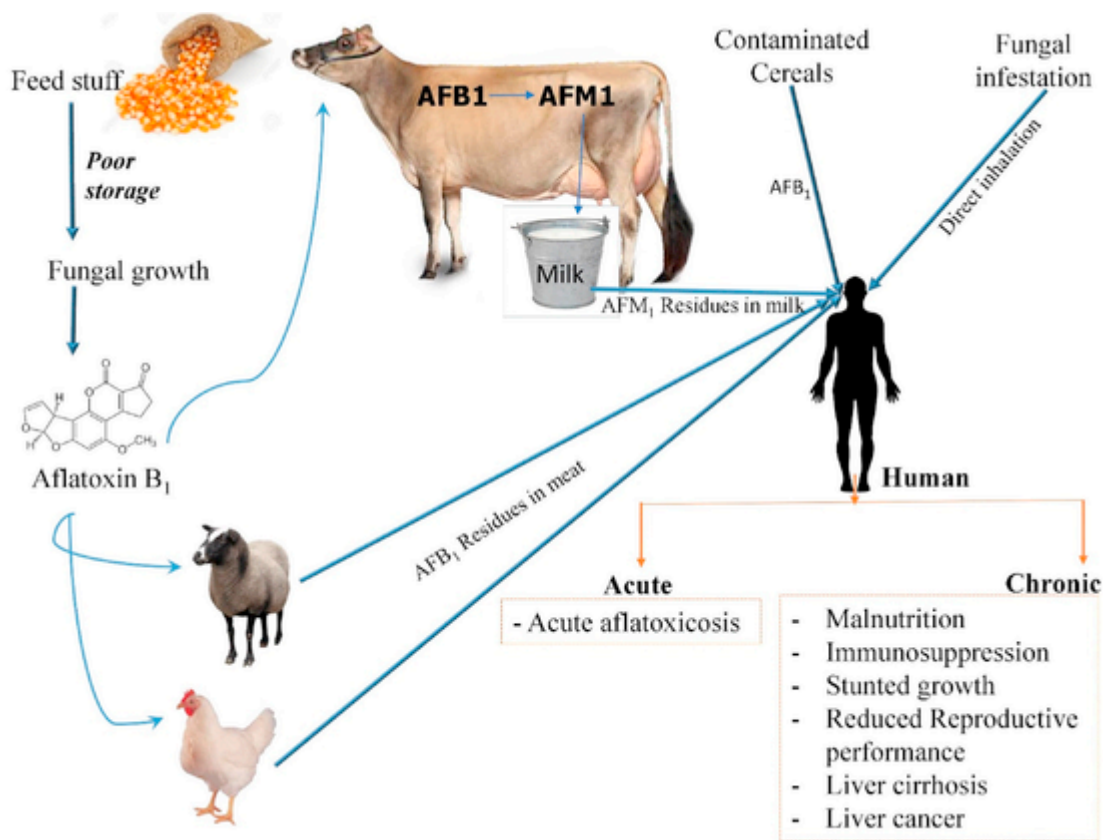


Fig. 1. Different Sources of Contamination of Aflatoxins to humans.

ing AFM₁ between 0.051 and 0.5 µg/L (Oluwafemi et al., 2014). This implies that the cows were actually fed on contaminated forages, eventually exposing humans especially children and pregnant women in Nigeria to AF at high levels.

Although large population in Nigeria prefer industrially processed liquid or powdered milk to fresh cow milk, there is still preference for fresh milk in northern part of the country. Sixteen out of 20 nomadic cattle milk samples from Northern Nigeria had AFM₁ in a range of 0.01–1.35 µg/L and 94% were above 0.05 µg/L (Makun et al., 2016). Apart from milk products, a Nigerian study found 0.02–0.09 µg/kg AFB and 0.02–0.07 µg/kg Aflatoxin G (AFG) in fresh liver, kidney, beef, and heart bought from 5 major markets (Oyero and Oyefolu, 2010). In Kenya, 17% of 210 cow milk samples had AFM₁ higher than 0.05 µg/kg (Kang’ethe et al., 2017). About one-third of raw cow milk sampled in southern Iran contained AFM₁ concentration higher than the standard limit set by European Union (Hashemi, 2016). In Southern Africa, AFM₁ was found between 0.15 and 0.17 µg/L in milk from rural subsistence and commercial farms (Mwanza and Dutton, 2014). The same study revealed the presence of AFM₁ between 0.01 and 3.1 µg/L in retail milk (Mwanza and Dutton, 2014). Milk samples obtained in Serbia in markets over a period of 4 years had an average of 0.21 µg/kg AFM₁ (Jajić et al., 2018). In Brazil, 83% of sampled milk had over 3 ng/kg AF with levels ranging from 8 to 720 ng/kg (Iha et al., 2013). A more recent study in Brazil revealed that 28 out of 52 fresh milk samples from small farm had AFM₁ above European limit (Gonçalves et al., 2017). Similarly, 96% of 84 sampled milk in Pakistan were contaminated with AFM₁ in a range of 0.01–0.76 µg/L and over 70% were above European and United States limits (Jawaid et al., 2015). Animal farming plays an indispensable role in the economy of all the aforementioned nations. This prevalence of mycotoxin in milk and milk product could be the reason why milk from many of the developing nations are rejected. It is clear that mycotoxins are distrib-

uted in animal products irrespective of the production systems, be it nomadic or sedentary. Therefore, the residues of AFB₁ and AFM₁ and other metabolites in animal products should be monitored and mycotoxin contaminated feed ingredients should be avoided to reduce the transfer into animal products. However, if mycotoxin contamination is inevitable, toxin binder, that are natural, affordable, and rapidly accessible should be used by farmers or feed producers especially smallholder farmers that contribute significantly to the animal products.

8. Animal product consumers

Animal products in developing countries are sold in both formal and informal markets. Because of the extreme poverty in developing countries, many of the consumers cannot afford animal products (usually processed and packaged) sold in formal markets, which are presumably known to possess some standard of hygiene. Less public awareness of the prevalence of mycotoxin residue in animal products and its effect on consumers is evident by the nonchalant behavior of farmers and laissez-faire attention of consumers towards the safety of the animal products consumed by them. About 4.5 billion people are suffering from tumors of the liver, kidneys, urinary, and digestive tracts that are linked to mycotoxins (Kensler et al., 2011) and up to 28% of liver cancers are linked to consuming AF-contaminated food ingredients (Liu and Wu, 2010).

Apart from animal products, contaminated feed predisposes consumers to air-borne AFB₁, which are considered under occupational hazards. Workers in feed processing units have been found to have high concentration of urinary AF (Ferri et al., 2017), possibly through the inhalation of feed mill dust. Consuming products of animals fed contaminated diets could lead to double exposure and a potential health hazard. Stunting in children under 5 years has been associated with ingestion of low to moderate levels of aflatoxins (Gong et al., 2004). Besides, mycotoxin (AF and FB) residue has been detected in high concen-

trations in urine, liver, lungs, and brain of children suffering from protein malnutrition disorders such as kwashiorkor (Al-Jaal et al., 2019) which could be due to increased intake of contaminated cereals. Mycotoxins have been associated with hepatic carcinogenesis and even affect immune system by triggering inflammatory responses, consequently leading to immunosuppression (Iqbal et al., 2013; Zhang et al., 2016a, 2016b) -(Fig. 2).

8.1. Mycotoxin in breast milk and some predisposing factor

Aflatoxin M₁, a metabolized form of AFB₁ has been found in human breast milk (Mulunda et al., 2013). Although carcinogenicity of AFM₁ is about 10 times lower than that of AFB₁; it exerts direct cytotoxicity on human cells in the absence of metabolic activation (Iqbal et al., 2013).

In Papua New Guinea, 76.1% of 874 breast milk of lactating mother has AFM₁ and 10.2% were higher than threshold safe limit for baby consumption in Australia and New Zealand (Temple et al., 2017). The habit of food consumption has been reported to be a principal factor affecting the extent of mycotoxin exposure. In Indonesia, children within the age of 3–5 years were more exposed to AFM₁ through the frequent consumption of contaminated milk (Sumantri et al., 2019). Intake of bakery products and cured pork meat were reported to influence the contamination of breast milk with OTA in Italy (Galvano et al., 2008) (Table 2). Similarly, the content of AFB₁ in the breast milk of urban and rural dwellers in Iran was strongly ($p < 0.05$) related to bread and egg consumption (Azarikia et al., 2018). In northern Nigeria, 82 of 100 breast milk samples collected were positive for AFM₁ at higher than 0.05 µg/L. Surprisingly, these women consumed milk and meat along other cereal grains like corn and rice 3 days before milk collection (Alegbe et al., 2017). Similarly, consumption of milk and white chesse-based products was associated with AFM₁ contamination of breast milk of lactating mothers in Lebanon (Elaridi et al., 2017).

Pregnant and lactating women consuming animal products with mycotoxin residues could expose their fetus and infant to the toxins. For instance, in northern Nigeria where nomadic cattle rearing system is prevalent, 77.5% of 40 sampled breast milk had AFM₁ at a range of 0.0010–0.6012 µg/L; and 48% of the samples were above Euro-

pean limit (0.05 µg/L) (Makun et al., 2016). In South America, 89% of 112 breast milk in Mexico had AFM₁ in a range of 3.01–34.24 ng/L with 7% exceeding European regulation for AFM₁ in infant milk formula, and exposure was associated with the consumption of egg, cola drink and sunflower seed oil (Cantú-Cornelio et al., 2016). In Asia, ingestion of egg high in DON and ZEA contributed to a large proportion of the maximum tolerable daily intake (1 µg/kg body weight/day), especially in children and elder adults in China (Wang et al., 2018). Besides, ZEA family are known to have estrogenic effect and children exposed to contaminated food containing ZEA have been found to have precocious sexual development (Ca, 1984; Metzler et al., 2010). These facts reveal the ease of transfer of mycotoxin especially aflatoxin from food into human. In lieu of this, Manique et al. (2008) detected ochratoxin A levels with concentrations ranging from 0.011 to 0.208 and 0.008–0.11 ng/mL in morning and evening urine samples, respectively, collected from Coimbra city in Portugal and Valencian community in Spain (Table 3).

With the ever-increasing human population, changing dietary lifestyle, and increasing demand for animal products such as milk and milk products, there could be health challenges for human and infant if mycotoxins contaminated products are unchecked. Hence, preventing the entry of mycotoxins into food chain is a matter of urgency, especially in developing nations, which are just featuring on mycotoxin contamination list due to effect of climate change.

9. Mode of action

Advancing technology and interdisciplinary approach in research have made the transfer of techniques from other fields to agriculture easier. Because of this, we now understand that the molecular, transcriptional, cytoplasmic structure, and physically alteration occurs on using additives. Probiotics and prebiotics help to improve intestinal barrier integrity or bind to toxin, which prevents toxin absorption into the blood stream. Probiotic species like *Bacillus* increases serum and liver antioxidant parameters like total superoxide dismutase and glutathione peroxidase apart from reducing AF residues in the liver (Zhang et al., 2016a, 2016b) or degrading the mycotoxins' chemical structure including lactone ring and methoxyl group (Hathout et al., 2011). The yeast cell wall could adsorb mycotoxins from the gut due to the existing weak hydrogen and van der Waals bonds (Jouany et

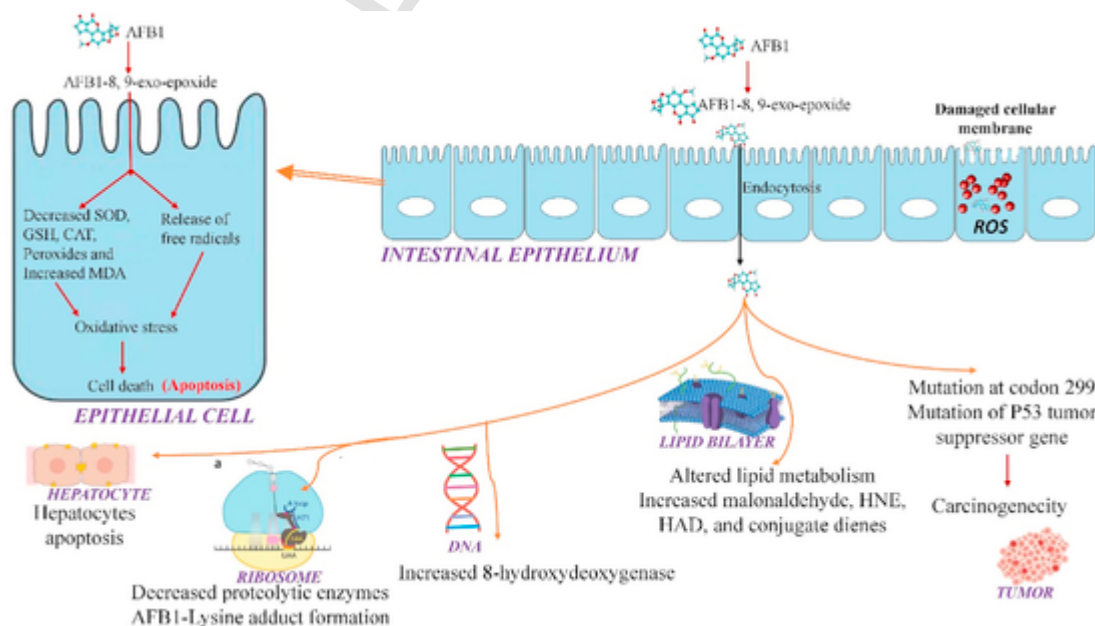


Fig. 2. Effects of Aflatoxin on host system.

Table 2
Causative factor of mycotoxin in consumers.

Country	Product	Mycotoxin	References
Indonesia	Intake of contaminated milk and frequency of contaminated milk consumed in Indonesia	Aflatoxin	Sumantri et al. (2019)
Italy	Intake of bakery products and cured pork meat	Ochratoxin A	Galvano et al. (2008)
Iran	Bread and egg consumption.	Aflatoxin	Azarikia et al., (2018)
Northern Nigeria	Consumed milk and meat among other cereal like corn and rice	Aflatoxin	Alegbe et al. (2017)
Lebanon	Consumption of milk and white chesses	Aflatoxin	Elaridi et al. (2017)
Mexico	Consumption of egg, cola drink, and sunflower seed oil	Aflatoxin	Cantú-Cornelio et al. (2016)

Table 3
Prevalence of mycotoxin in consumers.

Country	Product	species	References
Not specified	Human urine	Feed mill workers	Ferriet et al., (2017)
Papua New Guinea,	76.1% of 874 breast milk has AFM1	Lactating mothers	Temple et al. (2017)
Iran	0.01–0.08 ng/L AFB1 found in the breast milk or urban and rural dwellers	Lactating mothers	Azarikia et al. (2018)
Northern Nigeria,	82 of 100 breast milk samples collected had AFM1 (higher than 0.05 µg/L)	Lactating mothers	Alegbe et al. (2017)
Northern Nigeria	48% of 40 sampled breast milk had presence of AFM1 above European limit (0.05 µg/L).	Lactating mothers	Makun et al. (2016)
Mexico	89% of 112 breast milk had AFM1 between 3.01 and 34.24 ng/L with 7% exceeding European regulation for milk infant formula	Lactating mothers	Cantú-Cornelio et al. (2016)

al., 2005), which enhance their interactions. Application of clay offers non-nutritional benefits to alleviate mycotoxin effects by binding or adsorbing toxin, which further prevents its bioavailability and therefore the residue in tissues. Modified palygorskite alleviated the effect of *Fusarium* mycotoxins in broiler chickens by improving the immunity, oxidative status, and increasing the intestinal barrier function and gene expression such as mucin 2 and zonula occludens-1, claudin-2, jejunal secreted immunoglobulin A concentration (Cheng et al., 2018). Bentonite clay binds and adsorbs mycotoxins due to increasing interlayer spaces or suitable pore sites, and cation exchange capacity. This modifies the structure of phyllosilicate clay to increase efficacy and cation exchange capacity (Phillips et al., 1995; Onal and Sarikaya, 2008). Other additives might adhere to mycotoxin by strong electrostatic interaction, which exists because of zeta potential differences between them.

10. Mitigation strategies

Amelioration of mycotoxin residues in animal products is essential for food product safety, acceptance in international market, and safety of food consumers. Strategies to reduce mycotoxin residue in animal products such as tissues, meat, milk, and eggs need to be safe and environmental friendly for easy acceptability and eco-sustainability.

Thus, there is a need to develop methods that can be applied in field, or during storage to inhibit the growth of toxigenic fungi and mycotoxin. However, the complete elimination of fungi and their secondary metabolites during pre- and post-harvest is difficult. Hence, devising methods to detoxify or eliminate mycotoxins in either food or feed chain is of paramount importance. Our understanding on the use of microorganisms, botanicals, clay, and other harmless biosynthesized materials can be used to address such toxin residue in animal products; these antimycotoxigenic products have been applied for this purpose and hence, will be discussed herein (Table 4).

10.1. Poultry

Grains and legumes are the main ingredients in the composition of poultry diets. Yet, they have been identified as potential sources of mycotoxin contamination in feed. A recent study revealed that cereals (maize, sorghum, millet) and their processed products (*ogi*) obtained from different agro-ecological zones in Nigeria were contaminated by *Fusarium* mycotoxins ranging from normal or even exceeding the maximum limit set by European Union (Chilaka et al., 2016). Similarly, the mycotoxigenic effect observed in liver of poultry fed on diet containing groundnut cake, made it of lesser usage by feed manufacturing companies in Nigeria. In rainy seasons, new maize is used by poultry farmers or toll millers to reduce the cost of feed production. The maize sellers engage in dubious acts by mixing old (dry) and new (wet) maize. Unfortunately, the maize grains possess higher moisture content that might provide a congenial environment for fungi growth and mucotoxin production, and consequently resulting in toxic effects on the animal and carry-over residues in their products. Once AF enters the system, the toxins may primarily be transformed in the liver by cytochrome P-450 associated enzymes, thereby generating AFM1 and AFB2 (Biehl and Buck, 1987). Contaminated feed containing AF is detoxified mainly in the liver and kidney, the principal sites for residues accumulation (Hussain et al., 2010). Aside from the organs, meat and egg quality are reduced as a result of contamination with AF residues and these products still enters both formal and informal market without any monitoring. Employing anti-mycotoxigenic additives to reduce mycotoxin residue in poultry-based products is important.

10.1.1. Clays

Clays are naturally occurring materials composed primarily of fine-grained minerals. They contain phyllosilicate mineral montmorillonite and possess the ability to interact strongly with adsorbates, which makes it an effective adsorbent (Adeyemo et al., 2017). So instead of importing adsorbent or generating other adsorbents through rigorous processes, clay could be an important option to reduce residue. Surprisingly, clays are rarely used in commercial feed production in Nigeria despite its distribution. They are mainly seen as building construction materials, materials for pottery rather than adsorbent. These clays lack toxicity and contain high surface area and cation exchange capacity. Their adsorption efficiency is influenced by temperature. For example, heat treatment of bentonite clay between 25 °C to 700 °C reduced mycotoxin bioavailability between 49% and 97% depending upon the subjected temperature (Wongtangtintan et al., 2014). Natural and modified clay removes and alleviates the effect of toxins in livestock through adsorptive means. Although there are many forms of AF (AFB₁, AFB₂, AFG₁, and AFG₂), AFB₁ is the most biologically active component (Busby and Wogan, 1981). Many clays are used in livestock as additives such as bentonite, kaolinites, montmorillonite, and palygorskite. Of these, bentonites resulting from the decomposition of volcanic ash are highly promising AFB₁ adsorptive material. They are effective at decreasing the inhibitory effects of dietary AFB₁ (Biomim Mycotoxin, 2018) and its residues in animal products. Broiler chicken are fattened birds, which have a rapid growth rate that could reach up to 1 kg in

Table 4
Summary of additives with mycotoxin mitigation effects.

Additives	<i>In vivo/In vitro</i>	Doses	Mycotoxin	Effect	References
Bentonite clay	Broiler	(3.7 and 7.5 g/kg)	0.1–0.6 mg/kg AFB1	decreased liver AFB1 residue by 41–87%.	Bhatti et al. (2017)
Sodium bentonite	Broiler	0.3%	diets containing 50 µg/kg AFB1.	decreased liver residue by 62.5% when broilers were fed AFB1 in diet	Magnoli et al. (2010)
Zeolite	Laying duck	2%	70 pb b AFB1	numerical decreased AFB1 residue in egg and liver but significantly decreased AFB1 residue in duck meat by 65%.	Sumantri et al. (2018)
Yeast (<i>T. mycotoxinivorans</i>)	Broiler diet	2 g/kg Yeast	0.15–1.0 mg/kg OTA	decreased its liver residue by 38–78%.	Bhatti et al. (2017)
Bacillus biodegradable product	Laying birds	1000 g/ton	AF only (123.0 µg/kg) or AF + ZEA group (123.0 + 260.2 µg/kg)	decreased AF residues in eggs by 50–81% and 57–76%, respectively	Jia et al. (2016)
<i>Bacillus subtilis</i> ANSB060	Duck	500–2000 g/ton	22.44 µg/kg aflatoxin	improved antioxidant system and decreased liver AFB1 and AFM1 residue by 41.67–58.33% and 40–50% respectively. 86	Zhang et al. (2016a, 2016b)
Hydrated sodium calcium aluminosilicate (HSCAS)	Pig	0.5%	524 ng/g AF	decreased total AF residues in swine tissue (liver, kidney and Muscle) by 62%	Beaver et al. (1990)
Modified maifanite	Pig	1%	1.11 mg/kg of ZEN	decreased ZEA residue in liver and muscle by 54.96% and 42.41% respectively.	Chen et al. (2015)
Maifanite	Piglet	1%	5.3 and 372.8 µg/kg AFB1	decreased AFB1 residue in kidney and liver by 29.6% and 41.2% respectively.	Fu et al. (2013)
Sodium bentonite	Lactating goat	1%	100 part per billion AFB1	Reduced AFM1 excretion and carry over by about 66% and 65% respectively.	Nageswara Rao and Chopra, 2001
Clay and <i>S. cerevisiae</i> fermentation product	Lactating goats	200 g/h/day of clay or 35 g/head/day of clay and <i>S. cerevisiae</i> fermentation product	1725 µg of AFB1/head	decreased milk concentration of AFM1 and AFB1 transfer rate by 66–85% and 65–77% respectively.	Jiang et al. (2018)
Bentonite or montmorillonite	Goat	20 g/kg DM concentrate	56.7 µg/kg AFB1 and 112.5 µg/kg ZEA	Decreased rumen concentration of AFB1 and ZEA, decreased aflatoxin M1 in milk and ZEA in feces.	Gouda et al. (2019)
Clay (containing vermiculite, nontronite, and montmorillonite)	Holstein cow	1–2% of dietary dry matter intake	100 µg of AFB1/kg dry matter intake	400% decreased rumen fluid AFM1, 38–80% decreased AFM1 in milk, 22–68% reduced AFM1 excretion in milk, reduced AFM1 transfers by 40–81% and decreased fecal AFB1 by 84–88%.	Sulzberger et al. (2017)
Difrutose anhydride III	Cattle	40 g DFA III/day	0.22–0.27 mg/kg ZEA	Decreased urinary excretion of total ZEA (ZEA and its metabolite, α -ZOL and β -ZOL) by 51–69.71%.	Toda et al. (2018)
Yeast cell wall extract (1 \rightarrow 3)- β -d-glucan (β G)	Dairy goat	3 g β G/d	25 µg AFB1/kg dry matter intake	Lower milk AFM1 concentration, milk AFM1 excretion, and carryover of milk AFM1.	Aazami et al. (2019)
Modified <i>S. cerevisiae</i> walls extract	Dairy ewes	2 g/kg	60 µg of AFB1/kg of feed	Increased cumulative fecal concentration of AFM1 by 71%, decreased urine AFM1 by 39% on the long-term exposure while fecal AFB1 was decreased in a range of 37–39%.	Firmin et al. (2011)
<i>B. subtilis</i> ANSB060 biodegradation product		2 g/kg	63 µg/kg AFB1	decreased AFM1 concentration in milk by 27%, AFM1 excretion by 28% and transfer rate from feed to milk by 28%.	Guo et al. (2019)
Allyl isothiocyanates (AITC)	100 L Small-Scale Silo System	gel dispositive 5 mL of AITC for 60 days.	<i>A. flavus</i> and <i>P. verrucosum</i>	Decreased OTA production by <i>P. verrucosum</i> , and reduced AF production	Quiles et al. (2019)
Low yeast fermenting (<i>L. thermotolerans</i>) volatile organic compound, and inactivated yeast cell wall	<i>In vitro</i>	Not specified	<i>A. parasiticus</i> and <i>F. graminearum</i>	AF and DON synthesis by 82% and 93% respectively	Zeidan et al. (2018)
Thai bentonite (containing montmorillonite).	<i>In vitro</i>	Heating treatment of 25 °C–700 °C	NS	Mycotoxin adsorption between 49 and 97%	Wongtangtintan et al. (2014)
Inactivated cell wall removed	<i>In vitro</i>	NS	NS	Decreased 71–82% of OTA.	Zeidan et al. (2018)

Note, AF - aflatoxin; AFB1 - aflatoxin B1; AFM1 - aflatoxin M1; ZEA - zearalenone; OTA - ochratoxin A; α -ZOL - α -zearalenol, β -ZOL - β -zearalenol (β -ZOL), *A.* - *Aspergillus*; *B.* - *Bacillus*; *F.* - *Fusarium*; *L.* - *Lachancea*; *P.* - *Penicillium*; *S.* - *Saccharomyces*; *T.* - *Trichosporon*; NS - Not specified.

4 weeks. The rapid growth rate corresponds with higher feed intake; as such, the young age and growing tissue could slow down their ability to eliminate toxins from their body, resulting in higher residues in the tissues. Generally, organs and muscles of chicken are regarded as meat and eating contaminated organs (usually contain higher residue) will pose a serious threat to consumers. Bentonite clay (3.7 and 7.5 g/

kg) added to broiler diet contaminated with AFB₁ (0.1–0.6 mg/kg) decreased liver AFB₁ residue by 41–87% (Bhatti et al., 2017).

The high swelling property of sodium bentonite helps to adsorb toxic compounds, thus reducing the bioavailability even at a lower level (Denli et al., 2009). The sodium bentonite at 0.3% decreased the toxin residue in the liver by 62.5% on feeding the broilers with diets containing AFB₁ (50 µg/kg) (Magnoli et al., 2010). This study re-

veals the efficacy of bentonite in adsorbing the toxin even at a low level of contamination. Addition of zeolite at 2% level to a diet contaminated with 70 ppb AFB₁ caused a significant decrease in AFB₁ residue in duck meat by 65% (Sumantri et al., 2018). A recent study revealed that the supplementation of sodium bentonite and coumarin at 5 g/kg is beneficial in ameliorating the toxicity of aflatoxin at 0.25 ppm of the rabbit's diet (Hassan et al., 2019).

However, zeolite, kaolinite, and montmorillonites have poor adsorption capacity of both polar and non-polar mycotoxin compounds such as *Fusarium* mycotoxin, presumably due to their negatively charged hydrophilic surfaces (Vila-Donat et al., 2018). This *Fusarium* mycotoxin could alter intestinal morphology and barrier functions, thereby increasing epithelial permeability (Martens et al., 2018). Modifying clays could help to increase their hydrophobicity and adsorptive ability to non-polar mycotoxins (Li et al., 2018). Palygorskite is a naturally magnesium-rich silicate clay mineral with a weak affinity for nonpolar mycotoxin molecules (Cheng et al., 2018). Therefore, modification could increase its affinity to mycotoxin. About 1 g/kg of modified palygorskite in a ZEA contaminated broiler diet attenuated liver damage and reduced renal ZEA accumulation. This could be due to improved intestinal barrier, which prevented the compromise of the tight junction integrity, thus reducing toxin absorption into the bloodstream (Xu et al., 2018).

10.1.2. Prebiotic

The use of microorganisms or enzymatic preparations as a biological detoxification tool provides promising results (Taylor and Draughon, 2001). Besides detoxification, they could help regulate gut pH and improve gut microflora, feed digestibility, or nutrient efficiency. Yeast compounds are being promoted due to their beneficial effects on livestock health and performance. Low fermenting yeast (*Lachancea thermotolerans*) and *Trichosporon mycotoxinivorans* have exhibited some mycotoxigenic inhibitory and alleviation tendencies. For instance, 2 g/kg yeast (*Trichosporon mycotoxinivorans*) co-fed with 0.15–1.0 mg/kg OTA in broiler diet decreased its toxin liver residue by 38–78% (Bhatti et al., 2017).

An egg per day is popularly recommended as good for human health. As per FAO (2018), egg plays an indispensable role in meeting the nutrient requirements of the growing population. Increase demand for egg intensifies the risk of exposure to toxin residues, especially in countries with no strict regulation and monitoring. *Bacillus* spp., may be used in animal feed because of their unique extended shelf life and resistance to environmental conditions. *Bacillus* genus is considered as the most promising probiotics (Shivaramaiah et al., 2011). Adding *Bacillus*-based biodegradable product (composed of 40% *B. subtilis* ANSB060, 40% *B. subtilis* ANSB01G, and 20% carrier -rice husk meal) at the rate of 1000 g/ton to diets containing AF only (123.0 µg/kg) or AF + ZEA group (123.0 + 260.2 µg/kg) decreased the toxin residues in eggs by 50–81% and 57–76%, respectively (Jia et al., 2016). Rather than adsorbing or binding toxins to cell wall, *B. subtilis* degraded AF by destroying the chemical structures like lactone ring and methoxyl group of AFs and ZEA (Hathout et al., 2011; Kasmani et al., 2012).

Ducks are not able to efficiently metabolize AF, which makes them highly susceptible to its negative effects (Dalvi, 1986) *Bacillus subtilis* ANSB060 has strong ability to detoxify toxins, and degrades AFB₁, M1, and G1 by over 60% (Ma et al., 2012). As such, 500–2000 g/ton of *Bacillus subtilis* ANSB060 added to duck diet containing 22.44 µg/kg AF improved antioxidant system and decreased liver AFB₁ and AFM₁ residue by 41.67–58.33% and 40–50% respectively (Zhang et al., 2016a, 2016b). Although examples on detoxifying potentials reported in this review were on liver, additives that reduce toxin residue of the liver suggest that such adsorbent will also decrease toxins in meat

and egg. Thus, adding yeast and *Bacillus* spp to poultry diet will reduce toxin residue in animal tissue.

10.2. Swine

Pigs are one of the most deprecated livestock species due to religious reasons which creates a perception that they are unclean. However, in the intensive system of rearing pigs demarcates their feeding, sleeping, and defecating spots, thereby maintaining the cleanliness, which counteract the aforementioned religious reason. Swine feeding with kitchen waste, bakery waste, and other edible wastes is the common practice in pigs, which increases the susceptibility to infection. High consumption of corn contaminated with AF or DON above the United State food and drug administration action level (20–200 µg/kg AF) and advisory level (1000 µg/kg DON) (FDA, 1984) by pigs increases the threat of toxin residue in their products and subsequently exposes consumers. Many sources found residues of OTA, CIT, and AF in the pigs' processed products. In developing countries like Nigeria, pigs are fed with a wide range of feed, including, formulated feed, kitchen waste, rotten food, fruit waste, and cassava peels. Many of these ingredients contain toxins and sometimes the long storing of wastes before consumption may lead to mould growth. The evidence of mycotoxin found in the pork products in countries such as Croatia with strict antimycotoxigenic measures suggests that the mycotoxin contamination might be at alarming levels in developing countries like Nigeria, with little or no monitoring procedure systems.

Pork is consumed in high quantity in Asian countries and toxin residue in pork could be a major challenge on humanity, because about 60% of human population are Asians. The pork value chain in Asia is expected to produce hygienic and safer pork for consumption. However, AFM₁ found in urine samples collected in slaughterhouses from 5 provinces in Vietnam (Lee et al., 2017) suggests that these pigs were exposed to AF. As such, consuming the AF imbedded pork will increase exposure to the toxin and put the health of a large population at risk. Maifanites could help to reduce mycotoxin adsorption in swine. In many countries globally, swine liver is marketed and consumed as meat. Liver provides high biological value protein and micronutrient for humans. Therefore, mycotoxin adsorbent additives are needed in the feed of swine meant for consumption. Supplementation of 0.5% hydrated sodium calcium aluminosilicate (HSCAS) to pig diet contaminated with 524 ng/g AF decreased ($P < 0.001$) total AF (B₁, B₂ and M₁) residues in swine tissue (liver, kidney and Muscle) by 62% (Beaver et al., 1990). The additive acted by binding to AF residues in the gut to prevent its absorption and normal distribution in the gut and circulatory system (Phillips, 1999).

Maifanite contains aluminosilicate as its main component, and exhibit high porosity and surface area, but its impurities may hinder its adsorptive effects (Chen et al., 2015). A modified form of maifanite could serve as a new adsorptive additive. Supplementing 1% modified maifanite to pig diet pre-contaminated with 1.11 mg/kg of ZEA decreased ZEA residue in liver and muscle by 54.96% and 42.41%, respectively. Besides, the addition of 1% maifanite to piglet diet containing 5.3 and 372.8 µg/kg AFB₁ decreased AFB₁ residue in kidney and liver by 29.6% and 41.2%, respectively (Fu et al., 2013). Therefore, application of clay maifanite could be viewed as a promising strategy to increase the food safety of pig carcass.

10.3. Ruminant

Rumen protozoa are important in degrading mycotoxins such as T-2 toxin, OTA, and ZEA (Kiessling et al., 1984). Dietary changes in ruminant feeding practices with the inclusion of rapidly fermentable ingredients have increased the potential for gut integrity to be compromised. The absorbed mycotoxin are either excreted through urine

and feces or transferred to milk and meat (Fink-Gremmels, 2008) which is higher in wet season than dry or hot seasons (Bilandžić et al., 2010). Considering the indispensable role of milk in children's diet, it is vital to reduce the toxicants in milk and milk products to safe or minimum levels. Hence, evaluation of the carry-over effect is essential in accessing the risk of exposed animals to contaminants and safety of consumers. In order to solve protein malnutrition or insufficiency, the ruminant intensification techniques have been adopted in developing nations. Consequently, the phenomenon may increase the use of grain-based concentrate feed and silages and hence the risk of mycotoxin carry over from feed to product. Evaluation of the carry over effect is important in accessing the risk of exposed animals to contaminants, and its transfer to milk and meat for the safety of consumers. Thus, there is a need to decrease bioavailability of toxin in the circulatory system and its excretion into milk. Considering the indispensable role of milk in children's diet, it is important to reduce the toxicants in milk and milk products to safe or minimum levels.

10.3.1. Clays

Local milk produced in Nigeria is consumed in both fresh and processed forms such as “nono” (fermented form) or “wara” (coagulated form). The milk used to produce such dairy products is sourced from nomadic and free grazing cattle. Indeed, several studies reported the presence of mycotoxins in milk acquired from such nomadic systems (Oluwafemi et al., 2014; Makun et al., 2016). Contamination of cattle milk with mycotoxin residue will increase the exposure of consumers of all ages to toxins. Promising results such as decreased toxicity observed when clay is mixed with livestock feed has stimulated research on clay additives (Jaynes and Zartman, 2011). Companies such as Biomin® and Alltech® produce approved toxin binder for addition into livestock feed. Several adsorptive clays such as kaolin, mica, talc, pyrophyllite, kaolinite, illite, chlorite, smectite, and montmorillonite types have been used with varying results. These inconsistency depend on the level of high or low cation exchange capacity, cohesion and adhesion ability, and selection and specific surface area (Phillips et al., 1995; Pimpukdee et al., 2004).

Aflatoxin can be transferred from feed to milk of goats. Clays like bentonites detoxify by forming complexes with the toxins, which prevent their absorption across the intestinal epithelium (Manafi, 2011). In a study, supplementing lactating goat with 1% calcium bentonite or 1% activated charcoal to the diet pre-contaminated with AFM₁ at 100 ppb concentration resulted in the decreased excretion of the concerned toxin in milk. The range of AFM₁ reduction was 44–48%, whereas AFM₁ concentration, excretion, and carryover were increased by 225%, 223%, and 172%, respectively, in non-supplemented group (Mugerwa et al., 2015). Similarly, inclusion of 1% sodium bentonite in diet containing 100 ppb AFB₁ reduced AFM₁ excretion and carry-over by about 66% and 65%, respectively (Nageswara Rao and Chopra, 2001). The reduced excretion may be due to the adsorption of toxins, which might have reduced its absorption by the intestinal villi (Maki et al., 2017). Impeding the bioavailability of toxins in the gut or intestine is a feasible and cost-effective strategy to reduce the transfer of toxins and their derivatives into animal products. Oral supplementation of clay (vermiculite, nontronite, and montmorillonite) at a rate of 1–2% of dietary dry matter intake in a diet contaminated with 100 µg of AFB₁/kg of dietary dry matter intake decreased AFM₁ in rumen fluid by 80%, AFM₁ in milk by 38–80%, AFM₁ excretion in milk by 22–68%, AFM₁ transfers by 40–81%, and fecal AFB₁ by 84–88% in Holstein cow (Sulzberger et al., 2017). These reductions by clay indicate the ability of clay to reduce AF bioavailability for absorption in ruminant.

Inclusion of two natural products in animal diet could work synergistically to improve functionality. This permits the synergy of different mechanisms of action and limits bioavailability of toxin, although

there is a possibility of interference between the additives. Supplementation of clay at 200 g/h/day or clay at 35 g/head/day along with *Saccharomyces cerevisiae* in the diet of lactating goats containing 1725 µg of AFB₁/head resulted in the transfer rate of AFM₁ and AFB₁ by 66–85% and 65–77% into milk, respectively, (Jiang et al., 2018). The clay at high concentration showed the highest clearance impact on AF in product and excrement. The clay minerals were able to adsorb AF on their external surfaces because each silica molecule is positively charged and surrounded by four negatively charged oxygen ions, forming a porous structure that can trap AF (Velde and Meunier, 2008). Similarly, adding bentonite or montmorillonite at 20 g/kg DM of concentrate in diet containing 56.7 µg/kg AFB₁ and 112.5 µg/kg ZEA decreased concentration of AFB₁ and ZEA in the rumen, AFM₁ in milk and ZEN in feces (Gouda et al., 2019).

10.3.2. Probiotic and prebiotic

Probiotics and prebiotics are also used in livestock production because of their non-nutritional benefits such as enhanced microbial proliferation, improved feed usage, improved gut morphology, and adsorption of toxins from the gut. The use of prebiotics and non-digestible oligo-saccharides is of interest because oligosaccharides can improve gut morphology and integrity apart from modulating the immune responses of epithelial cells. Difructose anhydride III (DFA III), an oligosaccharide, could be viewed as a novel prebiotic. Adding 40 g DFA III/day to the diet of cattle exposed to 0.22–0.27 mg/kg ZEA decreased urinary excretion of total ZEA and its metabolites α-ZEA and β-ZEA by 51–69.71% (Toda et al., 2018). This reduction in urinary excretion implies that most of the ZEA in the rice straw was not absorbed by the gut into the bloodstream ultimately lowering the possibility of excretion into milk. Thus, oligosaccharides may be associated with the protective effect of additives on integrity of intestinal barrier by regulating the tight junction of intestinal epithelium. In addition, supplementing the extract of yeast cell wall (1 → 3)-β-d-glucan (βG) at 3 g βG/d along with 25 µg AFB₁/kg DMI to dairy goats lowered the milk AFM₁ concentration, excretion, and carryover (Aazami et al., 2019). Therefore, increased elimination of mycotoxin residues from the circulatory system is essential.

Addition of *Saccharomyces cerevisiae* walls extract at 2 g/d to the diet of dairy ewes containing 60 µg of AFB₁/kg of feed for 3–21 days increased cumulative fecal concentration of AFM₁ by 71% and decreased urine AFM₁ concentration by 39% (Firmin et al., 2011). The increased fecal excretion of AFB₁ consequently reduced the concentration of AF found in milk and tissues (Sulzberger et al., 2017). Addition of *Bacillus subtilis* ANSB060 biodegradation product at 2 g/kg in a total mixed ration containing 63 µg/kg AFB₁ decreased AFM₁ concentration in milk by 27%, (483 vs. 665 ng/L), AFM₁ excretion by 28% (9.14 vs. 12.71 µg/d) and transfer rate from feed to milk by 28% (0.76 vs. 1.06%). Therefore, supplementing with *Bacillus* spp. could help alleviate mycotoxin effect on livestock and reduce the residue effects on animal-based meat products. Prebiotics and probiotics alleviate mycotoxin effect in animals by adsorbing the toxins, thus, reducing their availability and preventing their absorption by the intestine. The nonabsorbed mycotoxins are flushed out of the body system through feces and urinary output.

11. Other antimycotoxigenic options 11.1 yeast

Although biocontrol agents are selected based on their inability to produce toxins (AF) AND other metabolites such as cyclopiazonic acid, aspertoxin, aflatrem, kojic acid, leporin C, and sterigmaticystin could be produced by strains of aflatoxigenic and non-aflatoxigenic *Aspergillus* species (Kagot et al., 2019; Okoth et al., 2018). There is a need for novel biocontrol agents that are non-toxic and safe. Low yeast fermenting (*Lachancea thermotolerans*) derivatives reduced AF and DON synthesis by 82% and 93%, respectively, due to the action of the 2-

phenylethanol- yeast metabolite on suppressing the genes involved in AF synthesis (Zeidan et al., 2018). The same study revealed that yeast inactivated cell wall removed 71–82% of OTA.

11.1. Silo-system

Poor storage system is a challenge in many developing nations, especially in Africa. Available mitigation technologies like hermetic storage may be too expensive for small-scale farmers, especially in developing nations like Nigeria and India (Okello et al., 2010). This stresses the necessity of alternative strategies in improving food and feed safety. Isothiocyanates, which originate from the enzymatic breakdown of glucosinolates, are known to possess a dose-dependent antimicrobial property (Adegbeye et al., 2018; Dufour et al., 2012). Quiles et al. (2019) demonstrated through a small-scale silo system that allyl isothiocyanate (AITC) reduced *A. flavus* and *P. verrucosum* growth and cereal (corn, wheat and barley) contamination in 60 days. The OTA production in wheat and barley was reduced by 90.0–99.5% in 30 days and 78.2–92.0% in 60 days, respectively, while AF production in corn was reduced beyond detection levels. Thus, applying AITC in a small enclosed place or grinding mustard seeds and enclosing such in a small cloth will allow the AITC odour to permeate the containers and could serve as a good additive to mitigate mycotoxins production in cereal storage. It is proposed that the electrophilic central carbon atom in–N.C. S group enables the ITC to bind to thiol and amino groups of amino acids, peptides, and protein, which are present in OTA-amino group and AF-carboxylic group (Quiles et al., 2019; Luciano and Holley, 2009; Zhang, 2004).

12. Conclusion

The food and feed industry could benefit from the use of natural, low cost, and eco-friendly material to reduce mycotoxin residue in animal products. Most *in vivo* test show that the material can only adsorb many of these toxins. The review has been demonstrated that the prevalence of mycotoxin residue in animal product is very high in both developed and developing countries. The application of clay such as bentonites, zeolites, HSCAS, and palygorskite are shown to be potential additives to reduce the mycotoxin residue in meat, milk, organs, and eggs. Supplementation of prebiotics and probiotics such as yeast (*Trichosporon mycotoxinivorans*), *Bacillus* spp., or their biodegradable product, and difructose anhydride III could also reduce the mycotoxin in animal product below European limit. Mycotoxins could be reduced in the milk product by adding adsorbent clay to the formulation of salt or mineral lick in free-grazing animals. Grains could be stored in large silo-based systems or enclosed plastic containers to reduce mycotoxin contamination by application of the volatile compound of isothiocyanate family and this material may be obtained from mustard seed. Since allyl isothiocyanate is volatile, mustards seed could be ground and packed in a small sack, and the volatile compound in mustard could escape and saturate the container to inhibit the growth of mycotoxin. The prevalence of mycotoxin in animal product call for the attention of food safety organization in developing countries to create awareness on the presence of toxins in animal products and ensure strict regulations are put in place. Such a body should put up a team of veterinarians, toxicologists, and food safety practitioners. This review revealed infants' exposure to mycotoxin through breast milk and the prevalence of mycotoxins in animal products including egg, meat and meat.

Statement of animal rights

The research was performed in accordance with the ethical standard laid down in the 1996 declaration of Helsinki and its later amendments. However, this is a review article.

Uncited references

Allcroft et al., 1967; Galvano et al., 1998; Marin et al., 2013; Zhang, 2004.

Declaration of competing interest

The authors declare no conflict of interest.

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