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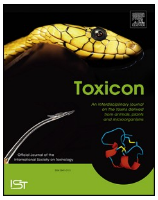

Review

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. 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 ones. 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 phytogenic, 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 additives, which could alleviate the effect of mycotoxin in feed and food. In addition, there is need for aggressive public awareness and farmers' education on the prevalence, and danger caused by mycotoxins, as well as detoxification strategies that can reduce toxin absorption into animal products.

1. Introduction

The presence of mycotoxins in agricultural crops and animal products is a serious problem globally and calls for efforts to safeguard consumers' health globally. However, the challenge is that, many developing countries and transitional nations are unaware of the prevalence of mycotoxins in animal products while most do not have strict monitoring and surveillance practices regarding safety of animal products. The livestock management practices mainly focus on increasing the production and yield without much consideration on the safety of animal product. Since the knowledge of relation between aflatoxin and human hepatic disorders, 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 the consumption of contaminated feed or forages. Animal derived products viz., meat, milk, and eggs are obtained after consumed feedstuff has been subjected to enzymatic and microbial transformations leading to the production of absorbable metabolites in the gut. During this process, nutrients, volatile fatty acids, and metabolites (toxic and beneficial) are absorbed into the bloodstream of the animal and may be later excreted through urine and feces. The toxins that are not excreted generally remain as residues in the edible organs and muscles.

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Although in some cases low-levels of mycotoxin contamination may not affect animal's growth or performance, but may be carried over into 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 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 AFB_1 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 products cause economic losses through border rejection in the global and local market ultimately aggravating the macro- and micro-nutrient insecurity especially in developing countries. Besides, other concerns about mycotoxins are that it cannot be easily destroyed by temperature, chemical, or physical treatments. Although the application of heat treatments like pasteurization or ultra-high temperature may degrade some AFM_1 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).

In technologically advanced countries, feeds are consistently scrutinized for mycotoxins so as to protect animal health and improve productivity as well as farmers' income (Gambarcorta et al., 2019). The use of feed additives to adsorb toxicants and toxins is widely practiced in livestock feed industry. Yeast, phytogenic 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 as it regards 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-mycotoxigenic products are being employed for detoxification of mycotoxin-contaminated grains; however, not all the products are efficiently effective. 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 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), 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 susceptible 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 contamination sources, fungi (*Aspergillus*, *Fusarium, Penicillium Alternaria,* and *Claviceps*) or saprophytic molds are the most common contaminants, which attack crops during 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 currently have high risk (severe to extreme level) of mycotoxin prevalence. 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 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 practiced, 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 contamination because of the inappropriate storage practices. 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). *Fusarium* mycotoxins, referred as temperate mycotoxins are known to contaminate food and food products originating from sub-Saharan Africa (SSA). A recent study has also predicted that aflatoxin B_1 (AFB_1) will become a significant food safety issue in Europe, especially with regard to the maize crop (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 (Medina et al., 2015; Dobolyi et al., 2013). Hence, it is evident that the incidences may increase with rise in global temperatures even in countries regarded as safe.

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 food insecurity status 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 AFB_1 intake as AFM_1 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 influences the exposure of the neonates to mycotoxins (Sayyari et al., 2018). Further, age is known to affect the residue of AFB_1 in animal tissue. Older birds tend to have lesser tissue residues of AFB_1 compared to birds of younger age (Hussain et al., 2010; Jia et al., 2016). This could be a result 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 non fully 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 AFM_1 (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 leads 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 non-ruminants 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 predispose ruminants to mycotoxins, at excessive levels, ultimately leading to the condition of disease and death. This is because, AFB_1 could be absorbed via rumen wall before reaching the intestine, and transformed into AFM_1 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 AFB_1) mycotoxin-contaminated feed (Fantinati, 2018). In India, improper storage of rice straw by farmers led to fungal (*A. flavus* and *P. notatum*) contamination, which caused mycotoxicosis and resulted in necrosis, weakness, emaciation, edema, and gangrene in legs, tail, and ear (Reddy et al., 2016).

5. Animal derived product contamination

Mycotoxins 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. Mycotoxin contamination causes wide range of harmful effects in human beings. For instance, consuming food contaminated with ZEA 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 is 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). AFM_1 is known as a detoxication by-product of AFB_1. 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 AFB_1 residue in an egg for every 10 mg/kg of AFB_1 (equivalent of 10 000 μg AFB_1/kg). This is about 0.003% of AFB_1 residue for every 10 mg/kg of AFB_1 compared to turnover of 0.3–2.2% AFB_1 mammalian milk and in 0.05% for FB_1 and T_2-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 risky and could have unintended consequences.

6.1. *Poultry*

Literary report shows that aflatoxin residues can be found in both eggs and meat. Aflatoxin residue has been found in eggs, muscle, and organs and its concentration is high in liver, egg, kidney, and thigh region (Herzallah, 2013). A study found 0.05 and 9.01 μg/kg residue of AFB_1 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 AFB_1. These residues remained in the eggs 3–5 days post contamination (Hassan et al., 2012). Pandey and Chauhan (2007) found AFM_1 residue in egg and breast muscle of laying hen fed with diet containing 2.5–3.91 mg/kg AFB_1. At times, there are single or multiple mycotoxin contaminants in diet; as such, there could be multi-toxin residues in poultry products. Feeding birds diet contaminated with aflatoxin (123.0 μg/kg), or AF and ZEA (123.0 and 260.2 μg/kg, respectively) resulted in the AF residues in eggs between 0.01 and 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 AFB_1 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 and 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

Table 1
Summary of prevalence of mycotoxin in animal product.

Product	Species	Exposure level	References
Muscle, gizzard and 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 AFB_1	Hassan et al. (2012)
Egg and breast muscle containing 2.5–3.91 mg/kg AFB_1	Laying	Not specified	Pandey and Chauhan (2007)
0.01–0.21 µg/kg AF 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 AFB_1 in egg	Laying birds	25–100 µg AF/kg feed	Aly and Anwer (2009)
6.97 and 3.27 ng/g in liver and muscle	Broiler	6400 µg/kg AFB_1	Hussain et al. (2010)
0.05–2.99 µg/kg in organs and muscle of healthy 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 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 AFM_1 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	NA	Oyero and Oyefolu (2010)
17% of 210 had AFM_1 above 0.05 µg/kg	Cow milk	NA	Kang'ethe et al. (2017)
0.15 and 0.17 µg/in milk from subsistence and commercial farms	Milk	NA	Mwanza and Dutton (2014)
0.10–0.25 µg/kg AFM_1 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	NA	Jajić et al. (2018)
54% of 52 samples had AF above European limit	Fresh milk	NA	Gonçalves et al. (2017)
70% of 84 samples were above EU and USA limit	Sampled milk	NA	Jawaid et al. (2015)

Note, AF-aflatoxin; AFM_1-aflatoxin M_1; ZEA-zearalenone; OTA-ochratoxin A; NA-not applicable.

AF in tissues and hence may act as a carrier of mycotoxin residues. Broiler chicken exposed to 6400 µg/kg AFB_1 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 to mention that AF residues were also 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. Athough the recent African swine fever outbreak is having a devasting impact on the reputation and output of the pork industry, it is still a product that is much appreciated in Asia. 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 to Asians, as much as it is to every other consumer. Decades ago, residues of AF (B_1, B_2, and M_1) 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 to 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, AFB_1, 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 increase with animal exposure to mycotoxins. High yielding cows have a transfer rate of dietary AFB_1 to milk AFM_1 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 AFM_1 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 beef cattle because of the lack of withdrawal period for milk production (Coppock et al., 2018; Guo et al., 2019). The developing countries in Africa and Asia are more exposed to AF-contaminated milk because of 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 AFM_1 in cow milk and ice cream between 2 and 4 µg/L (Atanda et al., 2007). 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% containing AFM_1 between 0.051 and 0.5 µg/L (Oluwafemi et al., 2014). This suggest that the cows 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 the northern part of the country. Sixteen out of 20 nomadic cattle milk samples from Northern Nigeria had AFM_1 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 in Nigeria (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 AFM_1 concentration higher than the standard limit set by European Union (Hashemi, 2016). In Southern Africa, AFM_1 was found between 0.15 and 0.17 µg/L in milk from rural subsistence and commercial farms (Mwanza and Dutton, 2014). The

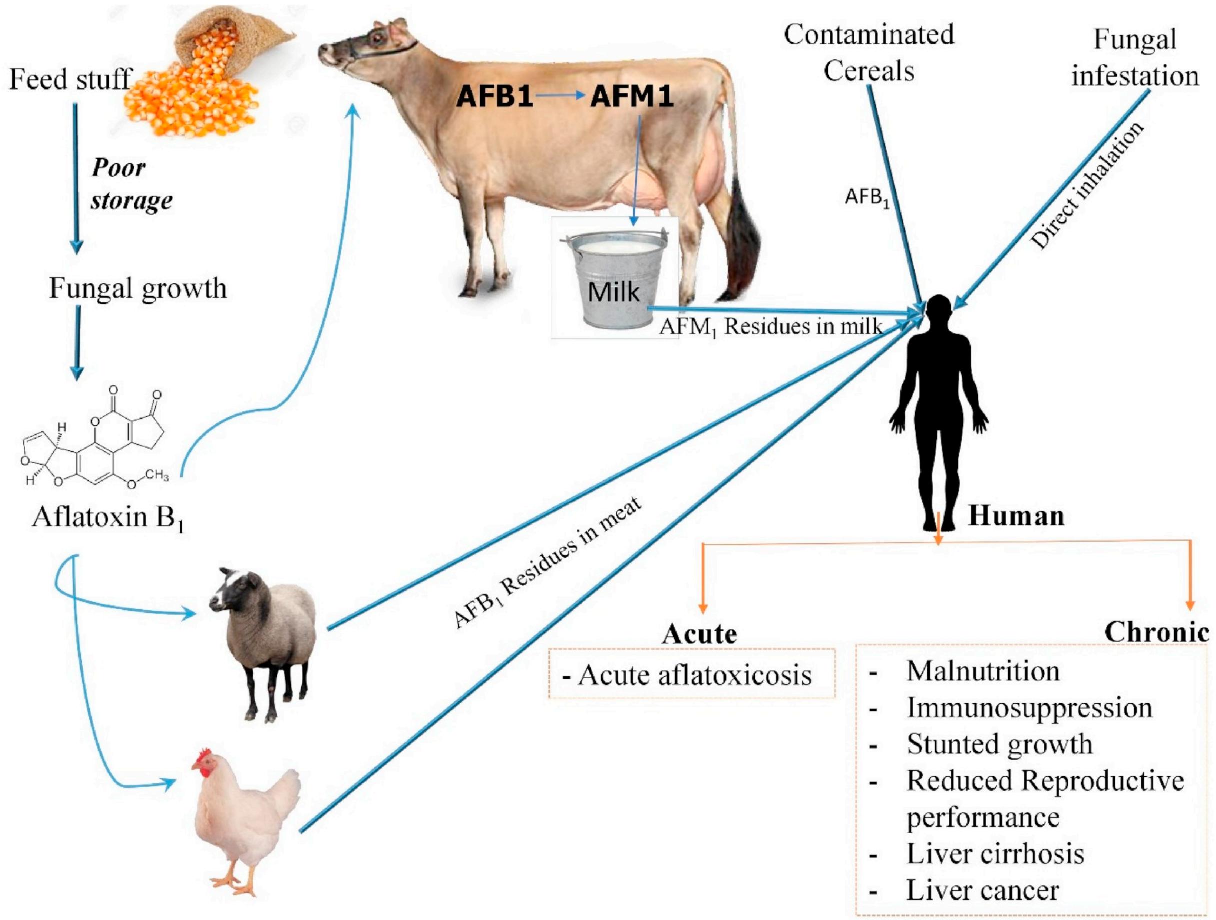

Fig. 1. Different Sources of Contamination of Aflatoxins to humans.

same study revealed the presence of AFM_1 between 0.01 and 3.1 μg/L in retail milk. Milk samples obtained in Serbia markets over a period of 4 years had an average of 0.21 μg/kg AFM_1 (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 revealed that 28 out of 52 fresh milk samples from small farm had AFM_1 above European limit in Brazil (Gonçalves et al., 2017). Similarly, 96% of 84 sampled milk in Pakistan were contaminated with AFM_1 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 a key role in the economy of all the aforementioned nations. This prevalence of mycotoxin in milk and milk products could be the reason why milk from many of the developing nations are rejected in the global market. It is clear that mycotoxins are distributed in animal products irrespective of the production systems, be it nomadic or sedentary. Therefore, the residues of AFB_1 and AFM_1 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 laisser-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 AFB_1, 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 concentrations 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,b) (Fig. 2).

8.1. Mycotoxin in breast milk and some predisposing factor

Aflatoxin M_1, a metabolized form of AFB_1 has been found in human breast milk (Mulunda et al., 2013). Although carcinogenicity of AFM_1 is about 10 times lower than that of AFB_1; it exerts direct cytotoxicity on human cells in the absence of metabolic activation (Iqbal et al., 2013).

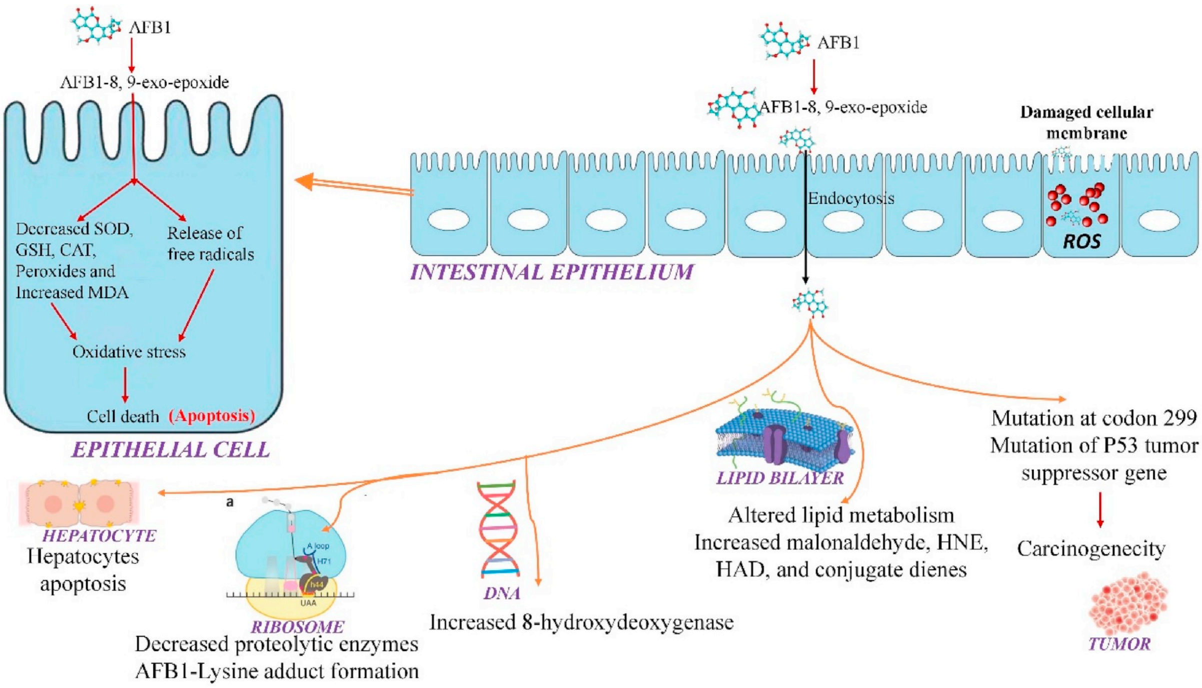

Fig. 2. Effects of Aflatoxin on host system.

In Papua New Guinea, 76.1% of 874 breast milk of lactating mother has AFM_1 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. Children within the age of 3–5 years were more exposed to AFM_1 through the frequent consumption of contaminated milk in Indonesia (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 AFB_1 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 AFM_1 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 AFM_1 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 AFM_1 between 0.0010 and 0.6012 μg/L; and 48% of the samples were above European limit (0.05 μg/L) (Makun et al., 2016). In South America, 89% of 112 breast milk in Mexico had AFM_1 in a range of 3.01–34.24 ng/L with 7% exceeding European regulation for AFM_1 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 ZEAcontributed 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 AF 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).

Table 2
Causative factor of mycotoxin in consumers.

Country	Product	Mycotoxin	References
Indonesia	Intake of contaminated milk and frequency of contaminated milk consumed	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 cereals 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	Ferri et al. (2017)
Papua New Guinea	76.1% of 874 breast milk has AFM_1	Lactating mothers	Temple et al. (2017)
Iran	0.01–0.08 ng/L AFB_1 found in the breast milk of urban and rural dwellers	Lactating mothers	Azarikia et al. (2018)
Northern Nigeria	82% of breast milk samples collected had AFM_1 (higher than 0.05 μg/L)	Lactating mothers	Alegbe et al. (2017)
Northern Nigeria	48% of 40 sampled breast milk had presence of AFM_1 above European limit (0.05 μg/L).	Lactating mothers	Makun et al. (2016)
Mexico	89% of 112 breast milk had AFM_1 between 3.01 and 34.24 ng/L with 7% exceeding European regulation for infant milk formula	Lactating mothers	Cantú-Cornelio et al. (2016)

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 molecular, transcriptional, cytoplasmic structure, and physically alteration which 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,b) 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 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

Table 4
Summary of additives with mycotoxin mitigation effects.

Additives	*In vivo/In vitro*	Doses	Mycotoxin	Effect	References
Bentonite clay	Broiler	3.7 and 7.5 g/kg	0.1–0.6 mg/kg AFB$_1$	Decreased liver AFB$_1$ residue by 41–87%.	Bhatti et al. (2017)
Sodium bentonite	Broiler	0.3%	diets containing 50 μg/kg AFB$_1$.	Decreased liver residue by 62.5% when broilers were fed AFB$_1$ in diet.	Magnoli et al. (2010)
Zeolite	Laying duck	2%	70 pbb AFB$_1$	Numerically decreased AFB$_1$ residue in egg and liver but significantly decreased AFB$_1$ residue in duck meat by 65%.	Sumantri et al. (2018)
Yeast *(T. mycotoxinivorans)*	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)
Bacillus subtilis ANSB060	Duck	500–2000 g/ton	22.44 μg/kg AF	Improved antioxidant system and decreased liver AFB$_1$ and AFM$_1$ residue by 41.67–58.33% and 40–50% respectively.	Zhang et al., 2016a, b
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 AFB$_1$	Decreased AFB$_1$ residue in kidney and liver by 29.6% and 41.2% respectively.	Fu et al. (2013)
Sodium bentonite	Lactating goat	1%	100 ppb AFB$_1$	Reduced AFM$_1$ excretion and carry over by about 66% and 65% respectively.	Nageswara Rao and Chopra (2001)
Clay and *S. cerevisiae* fermentation product	Lactating goats	200 g/h/day of clay or 35 g/head/day of clay and *S. cerevisiae* fermentation product	1725 μg of AFB$_1$/head	Decreased milk concentration of AFM$_1$ and AFB$_1$ transfer rate by 66–85% and 65–77% respectively.	Jiang et al. (2018)
Bentonite or montmorillonite	Goat	20 g/kg dry matter of concentrate	56.7 μg/kg AFB$_1$ and 112.5 μg/kg ZEA	Decreased rumen concentration of AFB1 and ZEA, decreased AFM$_1$ 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 AFB$_1$/kg dry matter intake	80% decrease in rumen fluid AFM$_1$, 38–80% decreased AFM$_1$ in milk, 22–68% reduced AFM$_1$ excretion in milk, reduced AFM$_1$ transfers by 40–81% and decreased fecal AFB$_1$ by 84–88%.	Sulzberger et al. (2017)
Difructose anhydride III	Cattle	40g 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 → 3)-β-d-glucan (βG)	Dairy goat	3 g βG/d	25 μg AFB$_1$/kg dry matter intake	Lower milk AFM$_1$ concentration, milk AFM$_1$ excretion, and carryover of milk AFM$_1$.	Aazami et al. (2019)
Modified *S. cerevisiae* walls extract	Dairy ewes	2 g/kg	60 μg of AFB$_1$/kg of feed	Increased cumulative fecal concentration of AFM$_1$ by 71%, decreased urine AFM$_1$ by 39% on the long-term exposure while fecal AFB$_1$ was decreased in a range of 37–39%.	Firmin et al. (2011)
B. subtilis ANSB060 biodegradation product		2g/kg	63 μg/kg AFB1	Decreased AFM$_1$ concentration in milk by 27%, AFM$_1$ excretion by 28% and transfer rate from feed to milk by 28%.	Guo et al. (2019)
Allyl isothiocyanates (AITC)	100L small-scale silo system	Gel dispositive 5 mL of AITC for 60 days.	*A. flavus* and *P. verrucosum*	Decreased OTA production by *P. verrucosum,* and reduced AF production.	Quiles et al. (2019)
Low yeast fermenting (*L. thermotolerans*) volatile organic compound, and inactivated yeast cell wall	*In vitro*	NS	*A. parasiticus* and *F. graminearum*	Decreased AF and DON synthesis by 82% and 93% respectively	Zeidan et al. (2018)
Thai bentonite (containing montmorillonite).	*In vitro*	Heating treatment of 25°C–700 °C	NS	Mycotoxin adsorption between 49 and 97%	Wongtangtintan et al. (2014)
Inactivated cell wall	*In vitro*	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;* PPB: part per billion; NS - Not specified.

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 mycotoxin 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 AFM_1 and AFB_2 (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 (AFB_1, AFB_2, AFG_1, and AFG_2), AFB_1 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 AFB_1 adsorptive material. They are effective at decreasing the inhibitory effects of dietary AFB_1 (Biomin, 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 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 AFB_1 (0.1–0.6 mg/kg) decreased liver AFB_1 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 AFB_1 (50 μg/kg) (Magnoli et al., 2010). This study reveals 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 pbb AFB_1 caused a significant decrease in AFB_1 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). Beside 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. 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 1000g/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) ˙*B. subtilis* ANSB060 has strong ability to detoxify toxins, and degrades AFB_1, M_1, and G_1 by over 60% (Ma et al., 2012). As such, 500–2000 g/ton of *B. subtilis* ANSB060 added to duck diet containing 22.44 μg/kg AFimproved antioxidant system and decreased liver AFB1 and AFM1 residue by 41.67–58.33% and 40–50% respectively (Zhang et al., 2016a,b). 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 demonised 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 afformentioned religious reason. Furthermore, modern-day pig production system differs from the ancient times to advancement in vaccination, medication and other veterinary practices which aid preventive and therapeutic management of livestock. 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) (Food and Drug Administration (FDA), 1994) 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 the pork value chain in Asia, is expected to produce hygenic and safer pork for consumption fo Asians which are about 60% of human population. However, AFM_1 found in urine samples collected in slaughterhouses from five provinces in Vietnam (Lee et al., 2017) suggests that these pigs were exposed to AF contaminated diet. 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 (B_1, B_2 and M_1) 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 AFB_1 decreased AFB_1 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.

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 AFM_1 at 100 ppb concentration resulted in the decreased excretion of the concerned toxin in milk. The range of AFM_1 reduction was 44–48%, whereas AFM_1 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 AFB_1 reduced AFM_1 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 (1–2% dietary dry matter intake) in a diet contaminated with 100 µg of AFB_1/kg of dietary dry matter intake decreased AFM_1 in rumen fluid by 80%, AFM_1 in milk by 38–80%, AFM_1 excretion in milk by 22–68%, AFM1 transfers by 40–81%, and fecal AFB_1 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 only at 200 g/h/day and clay plus *Saccharomyces cerevisiae* at 35 g/head/day in the diet of lactating goats containing 1725 µg of AFB_1/head/day resulted in decreased transfer rate of AFM_1 and AFB_1 into milk by 66–85% and 65–77% 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 dry matter of concentrate in diet containing 56.7 µg/kg AFB_1 and 112.5 µg/kg ZEA decreased concentration of AFB_1 and ZEA in the rumen, AFM_1 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 AFB_1/kg dry matter intake to dairy goats lowered the milk AFM_1 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 AFM_1 by 71% and decreased urine AFM_1 concentration by 39% (Firmin et al., 2011). The increased fecal excretion of AFB_1 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 AFB_1 decreased AFM_1 concentration in milk by 27%, (483 vs. 665 ng/L), AFM_1 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 non-absorbed mycotoxins are flushed out of the body system through feces and urinary output.

11. Other antimycotoxingenic 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.

11.2. 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).

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 AITC 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.

Declaration of interest

The authors declare no conflict of interest.

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