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Review Article

Mitigating the Health Risks of Mycotoxins: Concerns and Solutions Vis-à-Vis Food Web

Atul Kumar[1]*, Ankaj Thakur[2], Anil Patyal[3], Rashmi Thakur[4], Himani Sharma[5] and Sanjay Shakya[3]

[1]Department of Veterinary Public Health and Epidemiology, DGCN COVAS, CSK HP Agricultural University, Palampur, Himachal Pradesh, INDIA
[2]Department of Livestock Farm Complex, DGCN COVAS, CSK HP Agricultural University, Palampur, Himachal Pradesh, INDIA
[3]Department of Veterinary Public Health and Epidemiology, COVS & AH, CGKV, Durg, Chhattisgarh, INDIA
[4]Veterinary Hospital, Pangna, Distt. Mandi, Himachal Pradesh, INDIA
[5]Department of Veterinary Public Health, COVAS, GBPUAT, Pantnagar, Uttarakhand, INDIA

*Corresponding Author: dratul9@gmail.com

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Abstract

With the growth in worlds population, adequate access to safe food supply will remain a global priority. However, contamination of food by various environmental contaminants is a major global food safety issue. Among many contaminants, the world has experienced an increase in mycotoxin contamination of food grains in recent years. This could be attributed to climatic and agronomic changes that encourage fungal growth during crop cultivation, harvest and storage. More than 500 mycotoxins have been identified, and most animal feedstuffs are likely to be contaminated with multiple mycotoxins. Exposure of animals to mycotoxins mainly through contaminated feed may lead to carryover of toxicants and their metabolites into animal products such as milk, meat and eggs, posing a serious threat to animal and human health. In light of this, the present review focuses on mycotoxins contamination of animal feed, human foodstuffs, their economic impacts, implications on health and productivity, as well as various methods for their prevention and control to safeguard animal and human health.

Keywords: Animal Products, Feedstuffs, Mycotoxins, One Health, Strategies

Introduction

Fungi are astonishing organisms that produces a wide range of natural products known as secondary metabolites. Although, these metabolites are not essential for fungal life and their benefits to the producing fungal organisms are also unknown but they provide the fungi an ecological advantage in certain environments (Bu'Lock, 1961). These highly diverse secondary metabolites include plant growth regulators (e.g., auxins, gibberellins), pharmaceutically useful compounds (e.g., penicillin, lovastatin), pigments (e.g., carotenoids, melanins), and mycotoxins (Rao *et al*., 2017).

Mycotoxins are naturally occurring toxic compounds. Under warm, damp and humid conditions, fungi can grow and produce them on numerous crops and foodstuffs including cereals, spices, dried fruits and nuts. Upon exposure, mycotoxins may lead to the development of diseases (mycotoxicoses) in humans and animals (Nagarajan *et al*., 2016). The problems associated with mycotoxin contamination of foodstuffs' under various environmental conditions are worldwide. According to various estimates, almost 25% of the world's crops are often affected by fungal growth every year (Streit *et al*., 2012). Whether crop is produced in tropical, sub-tropical or temperate regions, but if rainfall and humidity are experienced in the harvest season, infection of the grains by the extremely adaptable fungi is likely. Although, mycotoxins produced by fungi can contaminate various agricultural commodities before, during and post-harvest but generally, crops that are stored for long durations become a potential target for fungal growth and mycotoxins production. This implies that mycotoxins are present all around especially in those parts of the world where (i) there are poor methods for the pest control of crops, (ii) food substances are not well preserved & storage facilities are inadequate, (iii) transportation facilities are poor (iv) poor implementation of food scrutinizing policies, and (v) where, regulations relating to mycotoxins in food are not stringent (Omotayo *et al*., 2019). The high levels of poverty in some societies has also been considered as a major determinant for exposure of mycotoxins to humans. In future, the susceptibility to the lower level of foodborne mycotoxins will be enhanced due to overconsumption of mycotoxin contaminated food stuff and malnutrition. However, mycotoxins can also occur naturally, so their presence in food and human environment may be absolutely unavoidable.

Fungal spoilage of crops not only have serious economic consequences but potential exposure of mycotoxins and their metabolites to animals and humans may result from consumption of contaminated plant derived feed and animal food products, respectively. Exposure of animals to mycotoxins through contaminated feed, air or dust may lead to carryover of mycotoxins and their metabolites into animal products such as milk, meat and eggs. In absence of strict regulations and preferable food, such available contaminated animal products gain entry into the human food chain, which pose a significant health risk to consumers. Therefore, concerns about food safety are incessantly increasing in both developed and developing regions of the world (Kumar *et al*., 2018; Thakur *et al*., 2019). In light of this, the present review focuses on mycotoxins that have been previously detected and commonly found in animal feed, human foodstuffs, their economic impacts, implications on human health, animal health and productivity, and the possible means of their prevention or reduction of contamination to the barest minimum.

Common Mycotoxins in Feed and Food

The formation of mycotoxins in nature and their subsequent presence in wide variety of feedstuffs used in animal feeds is considered as a global problem depending upon the season and geography. However, in certain geographical areas of the world, some mycotoxins have been detected more readily and commonly than others. Mycotoxins are regularly found in feed ingredients such as maize, sorghum, barely, wheat, rice meal, cotton seed meal, groundnuts and other legumes. Although more than 500 mycotoxins have been identified globally but the most commonly encountered mycotoxins in feedstuffs and foods are aflatoxins, ochratoxins, fumonisin, zearalenone, trichothecenes (T-2), vomitoxin etc. (Table 1).

Table 1: Common mycotoxins, representative fungi that produce them and major commodities contaminated by them

Mycotoxins	Associated Fungi	Commodities
Aflatoxin B1, B2. G1, G2	*Aspergillusfalvus, A parasiticus*	Nuts, corn, cottonseed, cereals, figs, spices
Aflatoxin M1 (Metabolite of Aflatoxin B1)	*Aspergillusfalvus, A parasiticus*	Milk and milk products
Ochratoxins	*Aspergillusochraceus, Penicilliumverrucosum,Aspergilluscarbonarius, Aspergillusniger*	Legumes, cereals, coffee beans, chocolates
Fumonisins B1, B2, B3	*Fusariumverticillioides, F proliferatum*	Maize and other cereals
Zearalenone	*Fusariumgraminearum, Fusariumculmorum*	Maize, wheat, barley, sorghum, oats
Trichothecens	*Fusariumtricintum*	Wheat, corn
Patulin	*Penicilliumexpansum, Aspergillusgiganteus*	Apples, grapes
Deoxynivalenol	*Fusariumgraminearum, Fusariumculmorum*	Cereals, cereal products

Aflatoxins

Aflatoxins are commonly produced in humid climatic conditions like those existing in Asian and African countries and certain parts of Australia. Among all mycotoxins, aflatoxins are one of the most important mycotoxins because they are extremely toxigenic and mutagenic in nature. These extremely toxic secondary metabolites are produced by *Aspergillus flavus*, *A. parasiticus* and *A. nomius*. The problem of aflatoxicosis came into light when more than 1,00,000 young turkeys died in England from a apparently new disease that was termed as Turkey X disease, i.e. hepatic necrosis in 1960 (Alcaide-Molina *et al*., 2009). There are more than 20 known aflatoxins, but the four major ones are B1, B2, G1 and G2 (also named AFB1, AFB2, AFM1 and AFM2). Among all, AFB1 is the most potent natural carcinogen known and is the major aflatoxin produced by toxigenic strains of fungi (Makun *et al*., 2011). Cow milk contains AFM1 and AFM2, which are hyroxylated metabolites of AFB1 and AFB2 found in animal feed, respectively. When ingested, inhaled, or absorbed through the skin, aflatoxins have carcinogenic, hepatotoxic, teratogenic and mutagenic effects on human health, even at very small concentrations (Zain, 2011).

Ochratoxins

Ochratoxins are metabolites produced by *Aspergillus* and *Penicillium* species. Among various ochratoxins, ochratoxin A (OTA) has been found to be the major metabolite of toxicological significance. Produced mainly by *Aspergillus ochraceus* and *Penicillium viridicatum*, Ochratoxin A is a contaminant of cereal grains, beans and peanuts (Krogh, 1987). This mycotoxin is known for its teratogenic effects in rat, hamster and chick embryo along with potential to cause damage to the liver, gut, lymphoid tissue and renal tubules.

Fumonisins

Fumonisins are naturally occurring toxins produced by several species of *Fusarium* including *F. moniliforme, F. verticillioides*, *F. proliferatum* and *F. fujikuroi* (Marasas, 2001). A number of different types of fumonisin are known, but fumonisins B1, B2 and B3 (also named FB1, FB2 and FB3) are the major forms found in food. Maize and maize-based products contain the highest amounts of fumonisins. In all animal species tested, FB1 has been associated with a wide range of adverse health effects, owing to its mutagenicity, immunotoxicity, teratogenicity and fat depleting behavior.

Zearalenone (ZEN)

Zearalenone is a non–steroidal estrogenic mycotoxin produced mainly by *Fusarium graminearum*, *Fusarium equiseti* and *Fusarium culmorum* (Bennett and Klich, 2003). These species are regular contaminants of cereal crops worldwide. Zearalenone mimics the effect of the female hormone estrogen and at low doses, thereby leading to increase in the size or early maturity of mammary glands and reproductive organs. Alcohol metabolites of ZEN (i.e. α-zearalenol and β-zearalenol) are also estrogenic and the estrogenic activity of α-ZOL is 3–4 times higher than that of the parent compound Zearalenone (Minervini *et al*., 2005).

Trichothecenes

Trichothecenes, a family of over 200 toxins, are one of the major classes of mycotoxins, causing a significant economic impact on cereal and grain crops each year (McMullen *et al*., 1997). These are produced by several fungal genera, which include Trichothecium, Fusarium, Myrothecium, Spicellum, Stachybotrys, Cephalosporium and Trichoderma. Among all trichothecenes, T-2 toxin and vomitoxin are perhaps, the most commonly detected mycotoxins. T-2 toxin is one of the earliest investigated and amongst the most toxic members of the family as compared to other mycotoxins (Adhikari *et al*., 2017). T-2 produced mainly by *Fusarium tricinctum*, was the first trichothecene to be found as a naturally occurring grain contaminant in the United States (Hsu *et al*., 1972). T-2 toxin is predominantly found in grains, such as wheat, corn, barley, rice, soybeans and particularly in oats and products thereof. Following ingestion, T-2 toxin causes acute and chronic toxicity and induces apoptosis in the immune system and fetal tissues (Li *et al*., 2011).

Vomitoxin, also called as deoxynivalenol (DON), is a very stable mycotoxin which survives storage, processing, milling, cooking and does not degrade at high temperatures. It is produced by fungi of the genus *Fusarium* and the most common producer of vomitoxin is *Fusarium graminearum.* It often occurs in many plant products, particularly in cereal crops such as wheat, corn, barley, oats and rye. It has been associated with reduced milk production in dairy cattle, vomiting by swine consuming contaminated feed or their refusal to eat feed containing the toxin, and inhibiting reproductive performance and immune function in several animal species (Jones *et al*., 1994). Due to their high cytotoxic and immunosuppressive properties vomitoxins pose a significant risk to human and animal health.

Effects of Mycotoxins on Animal Health and Productivity

Harmful effects of mycotoxins on animals are widely known and well documented (Table 2). Owing to their carcinogenic, mutagenic, teratogenic potentials, mycotoxins are associated with wide range of adverse health effects in farm animals. Mycotoxins produce a variety of diseases, directly or in combination with other primary stressors such as microbial pathogens. The economic impact of reduced animal productivity, increased incidence of disease due to immunosuppression, damage to vital organs, reduced growth and reproductive efficiency are some of the negative effects produced by mycotoxins in farm animals including poultry. Although, these effects of mycotoxins on animal health and productivity depends on various factors such as amount of contaminated feed ingested, number and concentrations of occurring toxins, type of mycotoxins involved, duration of exposure and animal sensitivity but it has been observed that ruminants are generally more tolerant of feed contaminated by mycotoxins than non-ruminant species due to the detoxifying capabilities of rumen microorganisms, especially protozoa. Swine are generally the most sensitive with poultry (Broilers are less sensitive than Turkey and Ducks) having intermediate sensitivity (Khetmalis *et al*., 2018). It has been seen that in comparison to their individual effects, mycotoxins in combination exert greater negative impact on the health and productivity of farm animals (Smith and Seddon, 1998). However, exposure of mycotoxins can induce health problems in animals that are specific to each toxin as shown in Table 2.

Table 2: Effect of mycotoxins on different livestock species

Mycotoxin	Species Affected	Effects	References
Aflatoxin	Poultry	Systemic effects (Hepatitis, Renal failure), overall effects on growth, performance and production	Smith *et al*.,1998; , Mughal *et al*., 2017
	Cattle	Decreased production, immune system function, and rumen metabolism, immunosuppression	Choudhary *et al.*, 1998
	Horses, Dogs	Liver damage, carcinogenic, immunosuppressive, teratogenic	Asquith,1991
Fumonisin	Pigs	Neurological disorders, liver damage, pulmonary oedema	Ross *et al*., 1990
	Poultry	Mild to moderate toxiccity	Murugesan *et al*., 2015
	Horses	Leukoencephalomalacia and acute neurotoxicity	Cantú-Cornelio *et al*., 2016
Zearalenone	Pigs	Estrogenic and reproductive disorder	Glávits and Vanyi, 1995
	Dairy animals	Decreased fertility, abnormal estrus cycles and reduced milk production	Weaver *et al*., 1986
Vomitoxin	Pigs	Dermatotoxic, feed refusal and vomition	Bitay *et al*., 1979
	Dairy animals	Reduced milk production	Jones *et al*., 1994
Ochratoxin	Pigs	Nephrotoxic, gout	
	Poultry	Liver damage, decreased feed utilization, teratogenic malformations	Bitay *et al*., 1979
	Dogs	Nephrotoxic	Bird, 2000
T-2 toxin	Pigs	Reproductive disorders	Hussein and Brasel, 2001
	Poultry	Reduced feed intake and Mouth lesions	Brake *et al*., 2000
	Cats	Hypovolemia and death	Pitt and Miller, 2016
	Cattle	Immunosuppression, Infertility and abortions	Mann *et al*., 1984; Placinta *et al*., 1999

Effects of Mycotoxins on Human Health

Globally the incidence of food borne illness due to consumption of contaminated food is increasing and due to the diversity of their toxic effects and their synergistic properties, mycotoxins are considered risky to ignorant consumers of contaminated foods (Bennett and Klich, 2003; Thakur *et al.*, 2012). The human exposure of mycotoxins occurs mainly through consumption of contaminated plant-derived foods, or from the carry-over of mycotoxins and their metabolites to the foods of animal origin such as milk, meat and eggs etc. (Table 3). Sometimes, the exposure to contaminated air and dust may also result in adverse health effects (Niculita-Hirzel *et al*., 2016). However, the negative impacts of mycotoxins on health of humans are often influenced by demographic characteristics such as age, sex, weight, diet and quantity/concurrent presence of other mycotoxins (synergistic effects) and pharmacologically active substances in the food commodity. For example, the effects of mycotoxins are more in infants or young individual than in adults. Moreover, the severity of effects by mycotoxins can also be intricated by factors such as low-calorie intake, alcohol abuse, vitamin deficiency, or the presence of concurrent infection (Zain, 2011; Bennett and Klich, 2003). There are number of human diseases which are associated with exposure to mycotoxins. For example, toxins released by *Fusarium* spp. are associated with occurrence of akakabio-byo, alimentary toxic aleukia, neural tube defects and oesophageal tumors in humans. *Aspergillus* spp. as source of mycotoxins has been associated with hepatocarcinoma, kwashiorkor, cardiac beriberi and Reye’s syndrome in humans (Bryden, 2007). In various parts of world, the low level but regular intake of mycotoxins through different sources has resulted in significant impact on human health. This is evident from the fact that, in one of the studies conducted by Cantú-Cornelio and co-workers (Cantú-Cornelio *et al*., 2016) in Mexico, a high occurrence and noticeable levels of AFM1 were detected in breast milk of mothers who were consuming sunflower oil, eggs and cola drinks. This observation made them draw a very alarming conclusion that breast-fed infants in the central region of Mexico may be exposed to noticeable levels of mycotoxin through breast milk. There are number of other possible consequences because of this insidious exposure resulting in impaired growth and development, immune dysfunction and the disease consequences of alterations in DNA metabolism (Bryden, 2007). Since mycotoxins have the ability to cause headaches and various gastrointestinal illnesses including abdominal pain, vomiting, and diarrhea, therefore they are considered as the potential candidates responsible for millions of human deaths annually. This is evident from the historical perspective too, wherein the ergotism breakout in Europe led to hundreds of thousands of deaths in the last millennium. They were held responsible for alimentary toxic aleukia which killed many people in Russia between 1942 and 1948 (Pitt and Miller, 2016).

Table 3: Occurrence of mycotoxins in foods of animal origin

Matrix	Country	Mycotoxin	Sample size (% positive)	Concentrations	Reference
Milk	Kenya	AFM1	474 (67.93)	-NA-	Kang'Ethe *et al*., 2017
Milk	Japan	AFM2	208 (99.5%)	-NA-	Nakajima *et al*., 2004
Milk	China	α-zearalenol	30(9.3%)	Nd-73.5 ng/Kg	Huang *et al*., 2014
Milk	South Korea	AFM1	100 (48%)	0.002-0.08 µg/L	Lee and Lee, 2015
Milk	Thailand	AFM1	240 (100%)	0.05-0.101 µg/L	Ruangwises and Ruangwises, 2010
Milk	Pakistan	AFM1	-NA-	Nd-100.04	Muhammad *et al*., 2010
Milk	Serbia	AFM1	678 (56.3%)	0.282-0.358 µg/L	Tomašević *et al*., 2015
Milk	China	AFM1	10(71%)	0.004-0.845 µg/L	Iqbal *et al*., 2013
Milk	France	Ochratoxin A	264 (1%)	5-6 ng/L	Boudra *et al*., 2007
Milk	USA	Fumonisin B1	155 (0.6%)	1290 ng/L	Maragos and Richard, 1994
Milk	India	AFM1, AFM2, OTA	29 (62%)	Nd->500pg/mL	Mehta *et al*., 2019
	India	AFM1	168 (5.4%)	0.006-0.13 ng/mL	Moudgil *et al*., 2019
	India	AFM1	150 (42.6%)	0.052->0.5 µg/kg	Sharma *et al*., 2020
	India	AFM1	230 (51%)	0.006-4.19µg/L	Patyal *et al*., 2020a
	India	AFM1	189 (58%)	0.007-13.1µg/L	Patyal *et al*., 2020b
Infant Formula	India	AFM1	18 (94%)	0.143-0.77 µg/L	Rastogi *et al*., 2004
Cheese	Iran	AFM1	72(59)	30-1200ng/kg	Fallah *et al*., 2011
Butter	Turkey	AFM1	92(100%)	0.01-7.0 µg/L	Tekinşen and Uçar, 2008
Poultry Meat	Not available	Ochratoxin A	14 (36%)	4-29 µg/Kg	Scott, 1978
Pig Kidney	NA	Ochratoxin A	401 (31%)	2-104 µg/Kg	Krogh, 1972
Sausages	Italy	OTA	100 (45%)	7-8 µg/Kg	Iacumin *et al*., 2009
Sausages	Egypt	AFB1	150 (06%)	7 µg/Kg	Aziz and Youssef, 1991
Eggs	Belgium	DON	20	Not available*	Tangni *et al*., 2009
Eggs	Jordan	AFB1, AFB2, AFG1, AFG2	40 (12.8%)	0.20-5.80 µg/Kg	Herzallah, 2009

* *Information not available*

Detection of Mycotoxins in Different Matrices

The recognition that mycotoxins affect human health and productivity of animals has led to intensive research on counteracting methods over the last few decades, including their efficient detection. Moreover, to enforce the restrictive regulation on xenobiotics in different food matrices such as animal feed, milk, meat, eggs and honey etc., the rapid, reliable, sensitive, and accurate detection techniques are required (Kumar *et al*., 2020). Detection of mycotoxins in samples is usually accomplished by methods that include certain common steps such as sample collection, homogenization, sample preparation (extraction, clean-up and concentration) and finally the detection and quantitation which can be executed by various instrumental and non-instrumental techniques (Alshannaq and Yu, 2017). Among all, enzyme-linked immune sorbent assay (ELISA) has been extensively used for mycotoxin detection (Kav *et al*., 2011; Turner *et al*., 2009). But, occasional pseudo-positive and inaccurate outcomes of ELISA, limits its diagnostic applications (Sforza *et al*., 2006). Therefore, more selective, sensitive, confirmatory and quantitative methodologies have been developed which are primarily based on gas chromatography (GC) (Valle-Algarra *et al*., 2005), high-performance liquid chromatography (HPLC) (Liu *et al*., 2012) and GC/LC combined with mass spectrometry (MS) (Oueslati *et al*., 2012). The recently developed, technique using ultra-performance liquid chromatography coupled to (tandem) mass spectrometry (UPLC-MS/MS) has further enabled us to detect multiple mycotoxins simultaneously in a sample (Huang *et al*., 2014; Xia *et al*., 2009).

International Regulatory Standards for Mycotoxins in Food/Feed Commodities

Since, mycotoxins poses significant risk to human and animal health, therefore, to ensure the quality and safety of food and feed products, many countries are investing in mycotoxins research and initiating administrative actions for elaboration of legislation and implementing regulatory measures for their control. Presently, more than 100 nations have specific regulations or detailed guidelines for mycotoxin control in various food commodities and animal feed. The Hazard Analysis and Critical Control Point (HACCP) is an internationally recognized food safety management system.

Table 4: Regulatory limits of mycotoxins in different commodities

Country/Region	Food stuffs	Mycotoxin type	Limits (µg/kg)	References
Australia	Peanuts	Total Aflatoxin	15	ANZF, 2016
USA	All foods except milk and dairy animal feeds	Total Aflatoxin	20	Ren *et al*., 2007
India	Milk and milk products	AFM1	0.5	FSSAI,2011
	Skimmed milk powder	AFM1	6	
	Whole Milk Powder	AFM1	4	
	Wheat, barley and rye	Ochratoxin A	20	
	Apple juice	Patulin	50	
	Wheat	Deoxynivalenol	1000	
	Pulses	Total Aflatoxin	15	
	Cereal and Cereal products	Total Aflatoxin	15	
China	Corn, peanuts and their products	Total Aflatoxin	20	IFST, 2018
	Dairy products	AFM1	0.5	
	Animal feed	AFB1	10	GB, 2017
	Animal feed	Ochratoxin A	100	
	Animal feed	Zearalenone	500	
European Union	Cereals, peanuts, tree nuts, dried fruits	Total Aflatoxin	4	EC,2006
	Milk and milk products	AFM1	0.05	
	Dairy animal feed	AFB1	5	
	Infant formula	AFM1	0.025	
	Baby foods for infants and young children	AFB1	0.1	
	Baby food	Ochratoxin A	0.5	
	Baby food	Zearalenone	20	
	Baby food	Patulin	10	
Japan	All foods	Total Aflatoxin	10 (B1)	IFST, 2018
Malaysia	Nuts (ready to eat)	Total Aflatoxin	10	
South Africa	Peanuts	Total Aflatoxin	15	
Pakistan	Milk	Total Aflatoxin	10	Ashiq, 2015
	Chili, turmeric and curry powders	Total Aflatoxin	20	

However, the application of HACCP principles to mycotoxin control is a relatively new approach, but is based on some very sound reasoning according to the European Mycotoxin Awareness Network (European Mycotoxin Awareness Network, 2012). Throughout the world there are many advisory bodies concerned with food safety, including the World Health Organization (WHO), Food and Agricultural Organization (FAO), Codex Alimentarius Joint Expert Committee for Food Additives and Contaminants (JECFA), US Food and Drug Administration (FDA), and the European Food Safety Authority (EFSA) (Kumar *et al*., 2018; Kumar *et al.,* 2020). These organizations acknowledge the likely health risks associated with food and feed-borne mycotoxin intoxication to humans and animals and therefore, tackle this problem by embracing regulatory limits for major mycotoxin classes and selected individual mycotoxins. They regularly assess the risk from mycotoxins and advise on controls to reduce consumer exposure. In India, the Food Safety and Standards Authority of India (FSSAI) is responsible for ensuring mycotoxin safety. To safeguard public health, the regulatory limits of various mycotoxins in different commodities have been established by European Union and other countries as shown in Table 4.

Strict food regulations for the mycotoxins is not a matter of great concern in the developed countries but it can be a problem in the low- and middle-income countries, which already have shortage of food. Lowering the standards for the level of mycotoxins will lead to food shortages and increased cost. Thus, prevention and cost-effective methods should be developed to deal with this issue in such countries.

Strategies to Counteract Mycotoxins

Owing to different chemical structure, all the commonly occurring mycotoxins vary in their physical, chemical and biochemical properties. Although, much efforts have been made to prevent the occurrence of mycotoxins in food and agricultural products, but no single method has yet been proven to be completely effective. Therefore, considering the great variations in the properties of mycotoxins, different strategies have to be combined in order to specifically target them. The broad strategies may include physical, chemical, or biological detoxification. However, the dietary management and associated strategies are among the most recent approaches to counteract the problem of mycotoxins.

Physical Strategies

This methodology involves thorough cleaning of feed grains to remove dust and dirt and may also involve washing with water or sodium carbonate solution (0.1 M). The feed/food storage area should be kept at temperatures at which fungi does not grow and produce mycotoxins. Storage facilities should be sufficient to eliminate moisture migration, condensation, or leaks. In addition, storage facilities should always be checked for overheating and molding (Whitlow and Hagler, 2004). Food grains stored for more than 2 weeks should be kept aerated and cool. This is also important as aeration reduces the growth and spread of moulds that can cause mycotoxin contamination. Anyhow if contamination of food is suspected, it has been shown that the exposure of food items to very high temperatures, of at least 150^{o}C, which is above cooking temperature, can reduce the mycotoxin content of food. In a study conducted by Blanchard and Manderville (Blanchard and Manderville, 2016), 84% loss of mycotoxins in food was observed after exposure of food items to temperature of 150^{o}C and above. But the food exposed to high temperatures might not be beneficial to the body because there is of loss of essential components and nutrients at high temperatures.

Other physical ways may include the decrease in moisture content of crops after harvest and during storage, the use of fungicides and preservatives against fungal growth, the prevention of insect infestation in stored products, as well as the removal of contaminated seeds may reduce the contamination levels. Furthermore, Whitlow and Hagler (Whitlow and Hagler, 2004) suggested that insect resistant seeds, which can resist insect damage and also fungal disease, must be planted as this will prevent the contamination of crops by mycotoxins while they are still in the field. They also reported that there should not be a delay in harvesting the crops, as this increases the chances of mycotoxin contamination. In addition, during harvest, the contact of the soil with agricultural products should be prevented, as this will also help to prevent the spread and contamination of these foods by mycotoxins.

Chemical Strategies

Several chemical compounds such as alkaline hydrogen peroxide, sodium hydroxide, monomethylamine or ammonium with calcium hydroxide acids, formaldehyde etc. have been found to be very effective in eliminating various mycotoxins. For example, ammoniation is used for the detoxification of aflatoxins or ochratoxin-contaminated feeds and has been applied successfully in several countries including USA and France (Nathanail *et al*., 2015). Although, ammoniation does not lead to the formation and subsequent accumulation of toxic breakdown products of mycotoxins in agricultural products, but it leads to changes in sensory and nutritional qualities, such as a brown color of the treated cereals and decreases in lysine and sulfur-containing amino acids. In stored grains, chemicals such as sodium bisulfite, ozone, and ammonia can be used to prevent the growth of fungi and the biosynthesis of mycotoxins (Park and Price, 2001). The control of moulds producing mycotoxin has also been achieved by using plant extracts and essential oils (Choudhary and Kumari, 2010). Nowadays, toxin binders are more popular among feed producers and farmers. A high-quality toxin binder needs to fulfill several requirements. Besides, high binding efficiency against certain single mycotoxins, it should also be able to perform well under multitoxin contaminations. This multitoxin binding ability is essential as there are rarely only one or two mycotoxins in the feed. The cross contamination and synergistic interactions of several mycotoxins at rather low concentrations make it difficult to predict real danger for the animals as well as risk assessment for the humans through consumption of food of animal origin containing variable amount of mycotoxins. Quality control often becomes circumstantial and the risk for multitoxin contamination increases. Each of these mycotoxins has its specific characteristics (e.g. polarity, surface area etc.). Therefore, it is unrealistic that one toxin binder ingredient is able to bind all mycotoxins without binding valuable nutrients. As each toxins binder ingredient has its binding affinity towards certain mycotoxins, a combination of different ingredients is essential for a binding spectrum. In the current situation of Indian poultry feed industry, the quality of toxin binder is even more important than usual. Feed millers still need to ensure a safe feed, even with critical qualities. Low feed quality, and safety is dangerous especially for layer and breeder performance due to long term effects which already start during pullet rearing. The use of clay-based materials in the diet as toxin binders or entero-sorbents is a very old practice of mankind to improve health (Carretero, 2002). However, nowadays, various sorbents have been widely adopted and accepted by the farm animal industry for reducing toxin bioavailability and exposure from contaminated feeds in animals. These sorbents have been labeled as toxin binders, enterosorbents, sequestrants, adsorbents, trapping agents, interceptor molecules etc. These materials and/or their mixtures usually contains smectite clays, kaolinite, zeolites, mica, silica, charcoal, and other biological constituents like lactic acid bacteria, chlorophyllins, yeast products, plant extracts, and some algae (Miller *et al*.,2014). However, all such mycotoxin deactivators must be subjected to comprehensive sets of toxicity assays along with in vitro, ex vivo, and in vivo experiments for their final approval.

Microbiological Strategies

There are several reports describing microbial and enzymatic deactivation of mycotoxins. Since, entero-sorbents has better efficacy to adsorb aflatoxins and they have been shown to be ineffective for adsorbing trichothecenes (Vekiru *et al*., 2007). Therefore, alternative approaches are required to combat the effects of non-absorbable mycotoxins. One such approach is use of microorganisms and their enzymes to detoxify mycotoxins. Although, various microorganisms and their enzymes have been shown to be effective against mycotoxins, but very few (*Trichosporon mycotoxinivorans* and BBSH 797) have shown their practical utility in animal nutrition. *T. mycotoxinivorans* is a yeast strain capable of detoxifying ochratoxin A and Z earlenone (Politis *et al*., 2005; Vekiru *et al*., 2010). BBSH 797 is anaerobic rumen bacterium belonging to Genus Novus of family Coriobacteriacae which detoxifies trichothecenes. It has been ascertained that lactic acid bacteria, propionic acid bacteria, and *Bacillus* spp. can inhibit the growth of fungi and mycotoxin production (Bunaciu *et al*., 2015). Some enzymes, such as carboxypeptidaseA lipases from *Aspergillus niger* and some commercial proteases have also been identified as capable of performing this reaction (Abrunhosa *et al*., 2010).

Managemental Strategies

There are many strategies which can be considered in general as part of managemental strategies. Some of them includes, prevention and control of mould growth in crops and foodstuffs using crop rotation techniques, cultivating and harvesting at the appropriate time and seasons/conditions, mechanical sorting of clean products from moldy products and, continuous mycotoxin residue surveillance programme for crops and other food products etc.. The application of HACCP (Hazard Analysis and Critical Control Points) principles during production process may also prove beneficial in reducing mycotoxin contamination (Bryden, 2007). But, certain developing regions of the world which are facing food security issues, such processes nay not be economical feasible to adopt. The aforesaid elaborations highlight the need to develop strategies that minimize the production of mycotoxins in food commodities both before and after harvest. Furthermore, various techniques on dietary manipulation have been reported to reduce the adverse effects of mycotoxins. For example, studies have shown that feed supplements such vitamins (A, E, C and D) along with trace elements like Selenium and Zinc can be used for protection of poultry against harmful effects of AFB1(He *et al*., 2014; Denli *et al*., 2003). Vitamins A, E, and C act by enhancing antioxidative effects. Selenium exerts protective functions through its direct ability to enhance immunity, by affecting the metabolism of carcinogens, by playing a crucial role in protein synthesis, cell division, and the formation of anticancer metabolites, and last but not the least, its antioxidative abilities (Wang *et al*., 2014). Whereas, Zn has been found to exert its ubiquitous effects on immune function, disease resistance, and general health (Mughal *et al*., 2017).

Conclusion

Currently, food security and safety are major issues which the whole world is facing. Given the extensive occurrence of different types of mycotoxins in various food commodities such as food grains, dairy products, animal tissues, meat, eggs etc., their exposure should be considered as a global food safety risk. Since, mycotoxin contamination of the food chain also has a major economic impact, therefore, it becomes very imperative to adopt measures to minimize food contamination and increase the awareness of good agricultural and storage practices along with international action to facilitate world trade.

Conflict of Interests

There is no conflict of interest.

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