

Mycotoxicosis and its control in poultry: A review

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Abstract

Mycotoxins are secondary metabolites produced by various toxigenic fungi mainly belonging to three genera *Aspergillus*, *Fusarium* and *Penicillium*. Ubiquitous occurrence, heat stability and lipophilic nature pose serious threats in terms of toxic syndromes i.e. mycotoxicoses in animals and poultry. Toxicological spectrum of various mycotoxins is very wide encompassing different kind of toxicities viz. acute and chronic toxicities, carcinogenicity, genotoxicity, immunotoxicity, mutagenicity, and teratogenicity in animals and poultry. Feeds are frequently contaminated simultaneously by several moulds each of which is able to produce several mycotoxins. The synergism occurs naturally between different mycotoxins. The various *in vivo* and *in vitro* strategies have been tried to ameliorate/detoxify/remove the toxic effects of mycotoxins/mycotoxicosis. The physical and chemical methods are impracticable in terms of safeguarding the nutritive quality of food and feed, while the biological methods like use of additives, antioxidant substances and food components; and toxin binding agents are showing promising results in amelioration/detoxification of mycotoxins/mycotoxicosis in poultry.

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Introduction

Mycotoxins are biologically active, toxic metabolites produced by toxigenic fungi mainly belonging to *Aspergillus*, *Fusarium* and *Penicillium* species, which invade crops in the field and may grow on foods during storage under favourable conditions of temperature and humidity (Shamsudeen *et al.*, 2013). The Food and Agriculture Organization estimated that about 25% of human foods and animal feeds are contaminated with mycotoxins and strong efforts have been made to decontaminate them by the use of physical and chemical adsorbents but the success made so far is limited (Huwig *et al.*, 2001; Yiannikouris and Jouany, 2002; Shetty and Jespersen, 2006). Like other environmental pollutants, mycotoxins also adversely affect the health and productivity in animals and poultry (Zain, 2011; Katole *et al.*, 2013).

In India, the economy of poultry industry is heavily affected due to wide mycotoxin exposure or contamination of various agricultural commodities. The economic losses are primarily due to the decreased growth rate, feed conversion efficacy, carcass yield, carcass quality and increased susceptibility to other

diseases caused due to their immunosuppressive effects among the affected birds. Out of more than 350 mycotoxins identified in nature, aflatoxins (AF), citrinins (CIT), fumonisins (F), ochratoxins (OT) and tricothecenes are the most common and important in poultry.

Commonly occurring mycotoxicoses in poultry

Aflatoxicosis

Aflatoxins B₁ (AFB₁), the most common mycotoxin, produced by *Aspergillus flavus* and *A. parasiticus* is primarily hepatotoxic and secondarily nephrotoxic in poultry. The LD₅₀ single dose (mg/kg body weight) is 0.3 for ducklings, and 6.0-16.0 for chickens. According to World Health Organisation-International Agency for Research on Cancer (WHO-IARC, 1993), aflatoxins were also considered to be a potential human carcinogen (Group 1). Aflatoxins causing immunosuppression due to damage of thymus and bursa of Fabricius make the birds susceptible to

other infection like colibacillosis, chronic respiratory disease, and Ranikhet disease (Anilkumar *et al.* 2003). Aflatoxins are also responsible for poor immune-response of vaccine. In layers, the aflatoxin cause drop in egg production and poor hatchability.

The significant microscopic lesions include bile duct epithelium hyperplasia, degenerative and necrotic changes in hepatocytes, nodular hyperplasia of liver parenchyma with infiltration of polymorphonuclear lymphocyte cells in portal tracts, besides considerable changes in kidneys.

Citrinin toxicosis

Citrinin (CIT), a nephrotoxic mycotoxin produced by *Penicillium citrinum*, often co-occurs with OTA as a co-contaminant of various food commodities of poultry feed (Ostry *et al.*, 2013) and has been implicated as a causal factor for endemic nephropathy in poultry species (Stoev *et al.*, 2010). It is also reported to be embryotoxic, immunotoxic mycotoxin, neurotoxic and teratogenic in various animal species (Kumar *et al.*, 2008; Singh *et al.*, 2007; 2011; 2014). The kidney appears to be the primary site of action of CIT and produced degenerative and necrotic changes in the renal tubular epithelial cells. The enlargement in size and the increase in the relative weight of the liver during CIT toxicity in poultry might be due to hepatic degeneration and sinusoidal congestion (Uma and Vikram Reddy, 1995).

Fumonisin toxicosis

A number of fumonisins have been isolated and characterized, but Fumonisin B₁ (FB₁) remains the most toxic compound and mainly produced by fungus *Fusarium verticillioides*. FB₁ has been reported to occur naturally in corn and caused significant toxic effects in various avian species which primary pathological changes have been reported in the liver characterized by multifocal hepatic necrosis and hepatocellular and biliary hyperplasia (Bermudez *et al.* 1995; Weibking *et al.* 1993; 1995). Moreover, the nephrotoxic action of FB₁ was also studied and the changes were predominant and consistent in the proximal convoluted tubule (PCT) lining cells. Ultrastructurally, the distortion and dilatation of cisternae of endoplasmic reticulum leading to the formation of vesicular and tubular structures was a consistent finding noticed in the Japanese quail chicks fed with 200 ppm FB₁ in diet for 21 days (Khan *et al.*, 2013). FB₁ also reported to affect the performance and immune function in the turkey poult (Li *et al.*, 2000).

Ochratoxicosis

Ochratoxin A (OTA), mainly produced by *Aspergillus ochraceus* and *Penicillium verrucosum* in a

wide variety of climates and geographical regions (O'Brien and Dietrich, 2005). It is primarily nephrotoxic and in terms of LD₅₀, duckling appears to be the most sensitive species to OTA followed by broiler chicks, White Leghorn chicks, Turkey poult and Japanese quail chicks, where the values are 0.5, 2.14, 3.4, 4.63, and 16.5 mg/kg body weight, respectively (Van der Merwe *et al.*, 1965, Prior *et al.*, 1976, Chang *et al.*, 1981). OTA is a carcinogenic (Group 2B carcinogen), embryotoxic, genotoxic, hepatotoxic, immunotoxic, nephrotoxic, neurotoxic, and teratogenic, mycotoxin in various animal species (Patil *et al.*, 2006; Pfohl-Leszkowicz and Manderville, 2007; 2012). In poultry, along with nephropathy, the specific effects include anaemia, decreased skeletal integrity, impaired coagulation of blood, impaired phagocytosis and reduced growth rate, (Huff *et al.*, 1974; Dwivedi and Burns, 1986). It has been found to be embryotoxic and teratogenic in Japanese quail. OTA is considered as the most toxic mycotoxin for domestic fowl studied so far.

Grossly, a dry and firm gizzard sometimes with mucosal erosions, catarrhal enteritis, dehydration, emaciated carcass, and proventricular mucosal haemorrhages have been observed. Kidneys become enlarged, pale and swollen and change in colour from the normal mahogany to tan. Liver is enlarged, friable or haemorrhagic and pale. Extensive accumulation of urates occurs on the serosal surface of several organs. Breaking strength and diameter of the tibiotarsal bones are significantly reduced. Increase intestinal fragility, with rupture is another feature. Swelling and colour changes of the kidneys have been reported as one of the most consistent lesion, while decreased serum albumin and total protein levels are the most sensitive indicator of ochratoxicosis in chicken (Dwivedi and Burns, 1985).

Histopathologically and ultrastructurally, in kidney, degenerative/necrotic changes are most pronounced in proximal convoluted tubules (PCT) than in the distal tubules. Mitochondrial abnormality with characteristic ring forms is diagnostic in chickens and quails (Khan *et al.*, 2013; Patial *et al.*, 2013a, b). Severe distension, enlargement and hypertrophy of the renal PCTs and thickening of the glomerular basement membrane are seen commonly. Liver revealed increased accumulation of cytoplasmic glycogen in the hepatocytes (Dwivedi, *et al.*, 1984; Dwivedi and Burns, 1984 a, b).

Trichothecenes toxicosis

Trichothecenes, a group of over 100 fungal metabolites with the same basic structure, are produced by a number of species of the genus *Fusarium*. They are common contaminants of poultry

feeds and feedstuffs and can produce adverse effects on poultry health and productivity. T-2 toxin has been the most extensively studied trichothecene in poultry. The primary effect of T-2 toxicosis in young broiler chicks is buccal-oral ulcerations/necrosis. The three trichothecenes, crocic acid, diacetoxyscirpenol and T-2 toxin, cause oral necrosis and affect body weight gain in growing chicks. At a dietary inclusion rate of 5 µg/g of diacetoxyscirpenol, a body weight reduction of 24% resulted, whereas T-2 toxin produced an 11% reduction at the same incorporation rate. A more severe oral response was observed with diacetoxyscirpenol. No effect on body weight gain or oral inflammation or necrosis was observed with crocic acid fed at 10 µg/g. It is generally regarded that the presence of oral lesions in poultry is the primary means of diagnosing trichothecenes toxicosis in the field.

Moniliformin toxicosis

Moniliformin is a water-soluble secondary metabolic product of *Fusarium* species. The worldwide occurrence of this mycotoxin has been reported as contaminant of various commodities such as corn, wheat, barley and other crops which used for the formulation of poultry feed. Moniliformin has been found to be associated with severe cardiotoxicity in chicks, poults and Japanese quails characterized by hypertrophic cardiomyopathy (Reams *et al.*, 1997; Sharma *et al.*, 2012). Moreover, it has been found to have damaging effects on the liver and kidneys in poultry species (Morris *et al.*, 1999; Sharma *et al.*, 2012).

Managemental approach

Mycotoxin screening

Routine analysis of feed ingredients and feed stuffs for mycotoxin contamination before the formulation of poultry ration is important. Methods of mycotoxin detection are numerous and include: 1) Microcolumns; 2) Thin Layer Chromatography (TLC); 3) Enzyme Linked Immuno-Sorbent Assay (ELISA); 4) High Pressure Liquid Chromatography (HPLC); 5) Gas Chromatography; and 6) Tandem Gas Chromatography/Mass Spectrophotometry. The TLC and ELISA methods are relatively easy and rapid technologies for mycotoxin detection in contaminated feed/food (Asrani *et al.*, 2013).

Moisture/Temperature

Monitoring and control of moisture is critical in the prevention of fungal growth and mycotoxin production. Bulk storage bins of grains must be well

ventilated, and the materials must be protected from rain and wide fluctuations of temperatures. Moisture level of grains should be kept at below 13%. Aflatoxins and other mycotoxins produced by *Aspergillus* spp. are not likely to be produced at temperatures below 5 to 8°C.

Cleaning: Periodic cleaning of all feed handling equipments with 5 to 10% bleach solution will help control mould growth as well as actually destroy, to some extent the aflatoxins present.

Feed holding time

The level and incidence of mycotoxin contamination increases after feed is manufactured. Therefore, it is important to keep the time from the manufacture of feed to when it is consumed by the birds to as short as possible.

Managemental practices like withdrawal of mycotoxin contaminated feed/feed ingredients or change of feed at the farm could provide partial protection to poultry from the toxicity as well as mycotoxin residues.

Control strategies for mycotoxins or mycotoxicosis

Pre-harvest

Pre-harvest control is practically difficult but, development of resistant crop strains by both breeding and direct genetic modifications is possible. Pre-harvest control measures include prevention of insect infestation, crop residues and crop rotation, irrigation and soil condition and effective drying and storage regimens.

Harvest

During harvesting, it is important to control factors such as timeliness, clean-up, maturity and drying of the agricultural products. Timing of harvesting greatly influences mycotoxin production, harvesting should take place as soon as the crop is fully grown and the crop cycle is completed.

Post-harvest

In nature, mycotoxin(s) contamination is often unavoidable. Detoxification or ameliorative methods becomes very important. The decontamination process should 1) inactivate, destroy, or remove the mycotoxin; (2) not result in the deposition of toxic substances, metabolites, or by-products in the food or feed; (3) retain nutrient value and feed acceptability of the product or commodity; (4) not result in significant alterations of the product's technological properties; (5)

destroy fungal spores. In addition to these criteria, the process(es) should be readily available, easily utilized, and inexpensive. Post-harvest strategies involved various physical, chemical and biological methods to inactivate, destroy, or remove the mycotoxin (Galvano *et al.*, 2001).

Mycotoxin decontamination methods

Physical methods

Antimycotic agents: Antimycotic agents like sorbic acid and sorbate; propionic acid and propionate, benzoic acid, benzoates and parabens; and acetic acid and its derivatives are the chemicals that prevent mould growth and interfere with mycotoxin production. 1 % propionic acid inhibits mycotoxigenic *A. flavus*, *A. parasiticus*, *A. ochraceus* and *P. viridicatum* and mycotoxin production in stored corn (Vandegraft *et al.*, 1975). In silage, incorporation of 0.2% potassium sorbate, 0.7% methyl paraben and 0.2% sodium propionate completely inhibited fungal growth (Tong and Draughon, 1985). Phosphine was effective in inhibiting both fungal growth and toxin production. Potassium sorbate was very effective and completely inhibited aflatoxin and ochratoxin production at the levels 0.1 to 0.2% and 0.10 to 0.15 %, respectively. Herbs and spices like cloves, cinnamon oil, mustard, allspice, garlic and oregano have been shown to have strong antimycotic properties (Bullerman *et al.*, 1977). Low oxygen concentration (<1%) and/or increased concentrations of other gases (i.e., 90% CO₂) depress mould growth and mycotoxin formation

Density segregation: Density segregation of contaminated grain and oilseeds involves sorting and delineating good versus contaminated kernels by floatation. This method can notably decrease various mycotoxin concentrations in contaminated grains.

Irradiation: Gamma or electronic irradiation is highly effective for destroying the fungal spores. Fluorescent or ultraviolet (UV) rays decompose aflatoxins and ochratoxins. Applying UV light for 20 minutes at 25°C in the presence of peroxide (0.05%) decreased the concentration of aflatoxin M₁ in contaminated milk. Simple exposure of contaminated grains to sunlight (UV) substantially reduces mycotoxin levels.

Mechanical separation: Toxin levels decrease as clean product is physically separated from contaminated grains. Significant decreases in aflatoxin levels from electronic- and hand-sorted peanuts have been reported and are commonly utilized.

Processing of food: Most of the mycotoxins are generally stable at room temperature. Processing of food has been found to decrease the prior concentration. Wet milling, malting, brewing, cooking and dry and oil roasting are methods to eliminate the mycotoxins, effectively. Autoclaving at 132°C for 5 hours reduces the OTA concentration by 85 % (Madsen *et al.*, 1983). Roasting conditions decreased the aflatoxin content in the raw peanuts. OTA appears to be more readily destroyed in dry cereals than in the wet and damp cereals (unlike aflatoxin B₁ and patulin). Scouring step (removal of the outer layers of the pericarp) of cereal processing resulted in >50% reduction in OTA concentration. Simple water treatment of contaminated cereals may completely eliminate mycotoxins.

Solvent extraction: Most mycotoxins can be extracted efficiently from contaminated grains using carefully selected solvent mixtures. Although effective, such treatment is considered cost prohibitive and impractical for most applications.

Chemical detoxification

Ammoniation: Treatment with aqueous and gaseous ammonia or ammonium hydroxide, with or without heat and pressure to destroy the mycotoxin in contaminated food and feed is currently the best and effective method. Ammoniation not only detoxified several mycotoxins (85-100% reduction), but also inhibited mould growth (Madson *et al.*, 1983). Anhydrous ammonia, NH₃ (gas) or aqua-ammonia, NH₄ OH (liquid), can be used. 5% ammonia for 96 hours detoxified the ochratoxins in the feed at 70°C.

Ozonization: Ozone (O₃) gas, a powerful oxidant is a non-persistent chemical, which means that it decomposes very fast. Within 20 minutes half of the ozone is decomposed into oxygen (in aqueous environments). Several studies indicate that ozone degrades aflatoxins in corn and cottonseed meals and also degrades deoxynivalenol and moniliformin.

Sodium hydroxide: Warming of grain to 105°C in the presence of 0.5% sodium hydroxide detoxified various mycotoxins in the feed.

Structural degradation: Numerous chemicals including acids, bases, aldehydes, bisulfites, oxidising agents and various gases have been tested for their ability to degrade or detoxify AFB₁ and other mycotoxins. Although, most of them may successfully destroy mycotoxins. They must not be used owing to

the generation of toxic products and alteration of product quality.

Amelioration/ Biological Inactivation

Mycotoxin-binding agents

Numerous agents like, activated carbons (charcoal), bentonites, clay, hydrated sodium calcium alumino silicate, and zeolite, have currently been used to counteract the mycotoxicosis in poultry and its carry over effect through meat and eggs. The commercial available synergistic blends of the mycotoxin binders are found to be beneficial against the commonly occurring mycotoxins in poultry species (Patil *et al.*, 2005). These sorbents are nutritionally inert and reduce the bioavailability of various mycotoxins by absorption on their surface in intestinal tract.

Activated charcoal: Generally, the absorption properties of activated charcoal (AC) are strictly dependent on the source materials and physicochemical parameters, such as surface area and pore size distribution. *In vitro* it has high ability of binding with several mycotoxins. The adsorption property of AC was found effective against aflatoxin B₁ and ochratoxin A up to 95% and 91%, respectively, during *in vitro* studies (Galvano *et al.*, 2001). The informations on the amount of activated charcoal to be added to the feed and possibly long term effects on adsorption of essential nutrients are scanty. Charcoal at 2% level had shown beneficial effects, during *in vivo* studies.

Bentonites: Bentonites (hydrated aluminium silicate) are sorbents with layered (lamellar) crystalline microstructure and variable composition. Their absorption property mainly depends on the interchangeable cations (Na⁺, K⁺, Ca⁺⁺ and Mg⁺⁺) present in the layers (Ramos *et al.*, 1996). Sodium bentonite is more effective than calcium bentonite. Bentonite could bind aflatoxin to the extent of 66% while it was of little use in adsorbing OTA. Bentonite (0.5%) could not ameliorate the effect of OTA on body weight gains, feed consumption and conversion, haematologically, biochemically and histopathologically in broiler chicks (Rama Devi *et al.*, 1999; 2000 a, b).

Bovine serum albumin: Mycotoxins bind with serum albumin as observed during *in vivo* and *in vitro* studies. Bovine albumin competes with mycotoxins in the intestinal tract and helps to excrete it. Marked reduction of histological, biochemical and plasma and liver levels were recorded, during AFB₁ exposure to the day-old chick (Hirano *et al.*, 1994).

Cholestyramine: Recent studies have indicated that cholestyramine (CHA), an ion-exchange resin with strong affinity for bile salts, was found protective against OTA induced nephrotoxicity in rats. CHA added to the diet (5%) reduced the concentration of OTA in plasma (up to 50%) and increased its clearance by way of the faeces while decreasing the amount excreted in bile and in urine (Kerkadi *et al.*, 1998). It was found to be an effective absorbent of OTA in the gastrointestinal tract of ruminants (Madhyastha *et al.*, 1992).

Hydrated sodium calcium alumino silicate (HSCAS): Molecular surface of HSCAS gets saturated with water and attracts the polar structure of various mycotoxins (Santin *et al.*, 2002; Girish and Devegowda, 2006). In young broiler chicks, HSCAS (0.5%) was effective at reducing the toxicity of aflatoxin (Harvey *et al.*, 1993; Abo-Norag *et al.*, 1995) as well as combined toxicity with OTA (Huff *et al.*, 1974). Antibody titre levels against Newcastle Disease and Infectious Bursal Disease were also decreased in chicks with HSCAS supplementation to diet containing aflatoxin (500 ppb). However, its protective properties are very low towards OTA, zearalenone and nil towards trichothecenes.

Polyvinylpyrrolidone: Polyvinylpyrrolidone, a synthetic resin, at 0.4g/kg level can bind up to 50 g/kg of AFB₁ in feed. Partial amelioration was reported against AFB₁, when administered with bentonite to broiler chicks (Kececi *et al.*, 1998).

Microbiological binding agents

Mannan oligosaccharide (MOS) extracted from the cell wall of *Saccharomyces cerevisiae* has shown broad-spectrum efficacy against most of the mycotoxins (Raju and Reddy, 2000). *Saccharomyces cerevisiae* was found to have beneficial effect in poultry during mycotoxicosis and MOS was believed to be the responsible factor. MOS, esterified with glucan, bound AFB₁ (up to 81.6%) and showed significant binding over zearalenone, T2 toxin and moderate binding over OTA (25.5%), during *in vitro* studies (Raju and Reddy, 2000). It was found to significantly improve body weight and other parameters of economic importance (Raju and Devegowda, 2000; Sefton *et al.*, 2002; Girish and Devegowda, 2006). Feeding trial with the addition of MOS (0.11%) significantly increased concentration of Ig A and Ig G in turkeys (Savage *et al.*, 1997).

Certain strains of Bifidobacteria, Lactic acid bacteria and Propionibacteria have cell wall structures that can bind mycotoxins (Yoon and Baek 1999; El-Nemazi *et al.*, 1998) and limit their bioavailability in the body. The bacterial strains such as *Bifidobacterium*

animalis and *Lactobacillus acidophilus* were found to be highly effective against OTA and patulin, respectively (Fuchs *et al.*, 2008).

Certain micro-organisms (*Corynebacterium rubrum*) are also able to metabolise mycotoxins in contaminated feed or to biotransform them (*Aspergillus*, *Eurotium*, *Rhizopus*,) (Nakazato *et al.*, 1990). However, these biological processes are generally slow and have a low efficiency.

Antioxidant substances

The protective properties of antioxidants are probably due to their ability to act as superoxide anion scavengers, thereby protecting cell membranes from the mycotoxin induced damage.

Ascorbic acid (Vitamin C): Ascorbic acid has been shown to react directly with superoxide, hydroxyl radical and singlet oxygen in addition to direct quenching of reactive free radical. The addition of vitamin C to the diet containing OTA, partially protected laying hens against the toxic effect. The OTA induced reduction in feed intake was counteracted at 25°C by vitamin supplementation. It moderated the negative effect of ochratoxicosis, in plasma electrolyte concentration and plasma aspartate transaminase activity (Haazele *et al.*, 1993).

Phenolic compounds: The phenolic antioxidants, gallic acid, vanillic acid, protocatechuic acid, 4-hydroxybenzoic acid, catechin, caffeic acid, and chlorogenic acid were found to be effective against the fungal growth of ochratoxigenic *Aspergilli* and the OTA production (Palumbo *et al.*, 2007). Moreover, several antioxidant compounds have been shown to inhibit aflatoxin biosynthesis (Reverberi *et al.*, 2006).

Plant materials/Plant products: The use of plant materials/products like leaves, bark, berries etc of certain antioxidant rich plants like Sea buckthorn which were found to confer partial protection against various mycotoxins as evident at gross, microscopic, ultrastructural and biochemical assessment (Patil *et al.*, 2012; 2013a). Moreover, plant materials were found to exhibit immunomodulatory activity (Stoev *et al.*, 2000).

Vitamin A: Vitamin A possesses the antioxidant properties against the mycotoxin-induced damage. Carotenoids, mainly carotenes and xanthophylls present in carrots, palm oil and maize, not only possessed the antioxidant property but also had antimutagenic and anticarcinogenic properties and reduced the toxicities of OTA.

Vitamin E/Selenium: Supplementary vitamin E administration to chickens partially counteracts the formation of lipid peroxides due to single and combined exposure to OTA and T2 toxin (Hoehler and Marquardt, 1996). Higher vitamin E intake partially ameliorated oxidative stress caused by OTA (Hoehler *et al.*, 1996). It is known that reduced vitamin E (alpha tocopherol radicals) can be regenerated following single electron reduction by ascorbic acid. Vitamin C should, therefore, enhance the biological efficacy of vitamin E especially under stress condition. Vitamin E and selenium are involved in the formation of glutathione peroxidase, a compound vital in the cellular detoxification mechanism. Gregory and Edds (1984) reported that selenium enhanced the formation of water soluble conjugated forms of aflatoxin which promoted the clearance of the toxin and enhanced chick growth. It was concluded that the fungi may not utilize the minerals in chelated form as efficiently as in inorganic form, for aflatoxin synthesis in feed and the excess selenium either in organic or inorganic form was found to increase the aflatoxin production in maize (Shamsudeen *et al.*, 2013).

Food components and additives

Numerous food components, ingredients, or additives with or without antioxidant properties have been found to have ameliorative properties against mycotoxicosis.

Aspartame: Aspartame (L- aspartyl- L- phenylalanine methyl ester), a structural analogue of both OTA and phenylalanine, has been shown to have protective effect against OTA induced cytotoxicity in animals (Creppy *et al.*, 1996, 1998). Aspartame prevents typical cytotoxic effects of OTA including inhibition of protein synthesis, lipid peroxidation and leakage of certain enzymes, such as lactate dehydrogenase, gamma glutamyl transferase and alkaline phosphatase (Baudrimont *et al.*, 1997 a, b).

Crude proteins: Raising the protein levels of diet from 14-18% to 22-26% counteracted the OTA effects (Gibson *et al.*, 1989). The broiler chicks fed with diet containing 5 ppm aflatoxin, increasing the crude protein level from 20 to 30% alleviated the growth and depressing effects of aflatoxin (Smith *et al.*, 1971). Protein protected against the negative effects of OTA (Bailey *et al.*, 1989) presumably because of increased concentration of phenylalanine in the diet. Increasing dietary crude protein helped alleviate but did not eliminate the adverse effects of ochratoxin A on body weight and feed conversion; mortality rates did not appear to be affected (Gibson *et al.*, 1989). However,

increasing protein levels is a costly approach to mycotoxin control.

Dietary lipids: Inclusion of cottonseed oil at 2, 6, or 16% level into semi-purified diets containing 10 ppm aflatoxin, not only improved the body weight, but the mortality was also significantly reduced (Smith *et al.*, 1971). In a further study to evaluate the effects of different types of lipids, 2 or 16% olive oil, coconut oil, safflower oil, or animal fat were included in low fat diets with 10 ppm aflatoxin. The higher levels of dietary fat reduced mortality and in some instances, improved the body weights. Lipids exerted their effects in part by interfering with absorption of the aflatoxin. Supplementation with olive oil and safflower oil, both sources of unsaturated fatty acids, also improved body weight which suggested that diets containing higher levels of linoleic acid supported better feed conversion and lower mortality in chicks fed diets with aflatoxin (Lanza *et al.*, 1981).

L-Methionine: It has been reported to have a protective effect against many oxidant drugs. It plays an important role in preserving the structure of cell membrane and in modulating the antimicrobial activity of polymorphonuclear leucocytes in periodontal disease as well as behaving as a chemotherapeutic agent in hepatitis treatment.

L- Phenylalanine: OTA has been reported to inhibit protein synthesis by competition with phenylalanine in the *phenylalanine-tRNA synthetase* catalysed reaction. Supplementation of 0.8% to 2.4 % phenylalanine in broiler diets containing 4 ppm OTA decreased the mortality rate from 42.5% in non-supplemented chicken to around 14%. Phenylalanine moiety of OTA competitively inhibits at least 2 enzymes,

phenylalanine tRNA synthetase and *phenylalanine hydroxylase*, which result in altered tyrosine production from phenylalanine. Phenylalanine reduced OTA induced immunosuppression (Creppy *et al.*, 1980). Bailey *et al.* (1990) suggested that supplemental phenylalanine improved the health status of birds fed diets containing OTA.

Conclusions

The problem of mycotoxicosis is not so easy to solve and requires constant attention throughout the entire process of grain harvest, shipping, storage, feed manufacturing, and its formulation. Utilization of mycotoxin contaminated raw materials presents a major problem. Detoxification as well as routine mycotoxin analysis of feed ingredients is an important step in a control programme at field level.

Physical, chemical and biological methods are essential to counteract the level of contamination of mycotoxins in foods and feeds. The cost involved and reduction in nutritive value of feed are some of the constraints which limit the use of such procedures during the feed formulation. Various studies further suggest that the total elimination of moulds and their toxins is practically impossible, so there is a great need for the use of such agents that are able to bind the toxins selectively in the gut, thus limiting their bioavailability in the consumers. In addition, the possible presence of toxic residues in the poultry products (egg, meat), which enters into the food chain may have potential risk by their detrimental effects on human health. At present, no limits have been set in India for most of the mycotoxins known to produce adverse effects in poultry birds. There is an urgent need to set a rational limit for such mycotoxins for the economic growth of poultry industry.

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