Detoxification of aflatoxin in poultry feed: a review from experimental trials

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Introduction

Aflatoxins (AF) are a major concern in poultry production and public health because of serious economic losses and health problems. AF contamination causes reduced feed quality and reduced animal efficiency either through poor conversion of nutrients or problems such as reproductive abnormalities. Aflatoxicosis in poultry also causes listlessness, anorexia with lowered growth rate, poor feed utilization, decreased egg production and increased mortality. Additionally, anemia, reduction of immune function, hepatotoxicosis, hemorrhage, teratogenesis, carcinogenesis and mutagenesis are associated with aflatoxicosis. The toxicity of AF in poultry has been widely investigated by determining their teratogenic, carcinogenic, mutagenic and growth inhibitory effects. The biochemical-hematological, immunological, gross and histopathological toxic effects of AF have also been well described.

Preventing of mould growth and AF contamination in feed and feedstuffs is very important but when contamination cannot be prevented, decontamination of AF is needed before using these materials. Producers, researchers and governments aim to develop effective prevention management and decontamination technologies to minimize toxic effects of AF.

Practical and cost-effective methods of detoxifying AF-contaminated (AF-CT) feed are in great demand. Besides preventive management, approaches have been employed including physical, chemical and biological treatments to detoxify AF in contaminated feeds and feedstuffs. An approach to the problem has been to use non-nutritive and inert adsorbents in the diet to bind AF and reduce the absorption of AF from the gastrointestinal tract. Since the early 1990s, experiments with adsorbents such zeolites and aluminosilicates have proven successful, but high inclusion rates and possible potential interactions with feed nutrients are causes for concern. Also, possible dioxin contamination may be a risk factor for using natural clays in case of forest and trash fire near their source.

Possible solutions

Some studies suggested that the best approach for decontamination would be biological degradation such as yeast and yeast components which could allow removal of AF under mild conditions, without using harmful chemicals or causing appreciable losses in nutritive value and palatability. A successful detoxication process must be economical and capable of eliminating all traces of toxin without leaving harmful residues without impairing the nutritional quality of the commodity. As a result, researchers have directed efforts towards finding effective means of biological degradation of AF. Most studies have used greater concentrations of AF than are likely to be found under field conditions. The AF concentrations in these experiments ranged from 2 to 5 ppm, because these high concentrations were expected to elicit the toxic effects of AF and also any effects of the feed additive would be easily seen in a shorter experimental period.
The *in vivo* experimental trials performed by using adsorbents and biological products as a feed additive in poultry are briefly given below. A total of 155 studies (*in vivo* and in poultry species only) were examined and are listed for 35 countries according to the first author's institute.

The present review is based on an invited paper, written and published at the beginning of 2011 (Oguz, H., 2011). Since then, 20 new articles related to detoxification of AF in poultry feed were published and are included here.

Countries and researches

Argentina

- Miazzo *et al.* (2000) added synthetic zeolite (1%) to AF-CT (2.5 ppm) broiler diet and zeolite significantly diminished the adve of AF on performance and reduced the incidence and/or severity of hepatic histopathology lesions caused by AF.
- Miazzo *et al.* (2005) supplemented sodium bentonite (SB; 0.3%) to AF-CT (2.5 ppm) broiler diet and SB provided significant improvements in liver histopatholgy and biochemistry.
- Magnoli *et al.* (2008) incorporated natural bentonite (0.3%) to AF-CT (30-135 ppb) broiler diet and bentonite reduced severity of hepatic histopathology changes associated with aflatoxicosis.
- Magnoli *et al.* (2011) added SB (0.3%) and monensin (55 ppm) into AF-CT (100 ppb) broiler diet. Histopathology indicated that SB was effective in reducing the severity of hepatic changes associated with aflatoxicosis. Also the decrease of its capacity in the presence of monensin was observed.
- Mosca and Marichal (2011) supplemented hydrated sodium calcium aluminosilicate (HSCAS), esterified glucomannan (EGM) and multi modular additive (MM) to AF-CT (4.5 ppm) broiler diet and MM appeared to be the most effective to counteract the adverse effect produced by these mycotoxin combinations (AF plus fumonisin).

Australia

- Bryden (2012) recently reviewed mycotoxin contamination in the feed supply chain, with implications for animal productivity and feed security; numerous (260) related references.

Belgium

- Schwarzer and Baecke (2009) reviewed inactivators for mycotoxins (based on botanicals, yeast and clay-minerals) on animal performance.

Brazil

- Santurio *et al.* (1999) supplemented SB (0.25 and 0.5%) to AF-CT (3 ppm) broiler diet and SB partially neutralized the effects AF on broiler chickens when included at 0.5% in the diet.
- Rosa *et al.* (2001) added SB (0.3%) to AF-CT (5 ppm) broiler diet and SB in the diets significantly improved the adverse effects of AF on performance, biochemistry and gross and histopathology of liver.
- Santin *et al.* (2003) added Saccharomyces cerevisiae (SCE; 0.2%) to the broiler diet and SCE did not improve the suppressive effects of AF on performance and immunity.
- Batina *et al.* (2005) added sodic montmorillonite (MNT; 0.25 and 0.5%) to AF-CT (5 ppm) broiler diet and addition of 0.5% level MNT provided partial improvements in biochemical changes associated with AF.
- Franciscato *et al.* (2006) added sodic MNT (0.25 and 0.5%) to AF-CT (3 ppm) broiler diet, addition of 0.5% sodic MNT provided significant improvements in biochemistry.
- Santin *et al.* (2006) incorporated yeast cell wall (0.1%) into AF-CT (250 and 500 ppb) broiler diet, and yeast cell wall was found to be effective in preventing the detrimental effects of AF on performance.
- Siloto *et al.* (2011) incorporated glucan derived from yeast cell wall (0.2%) into AF-CT (1 ppm) layer hen's diet, and yeast cell wall partially ameliorated the detrimental effects of AF on performance and egg quality.
- Uttpatel *et al.* (2011) supplemented EGM (0.1%) into AF-CT (500 and 750 ppb) broiler breeders diet. Body weight of the breeders, egg weight, specific weight of eggs, hatchability and chick quality were not affected by the levels of AF and adsorbent present in the diet.

- Rosa *et al.* (2012) added EGM (0.1%) to AF-CT (500, 750 and 1000 ppb) broiler diet; the addition of up to 750 ppb AF and adsorbent in the breeder diets during eight weeks did not affect the performance or blood parameters of their progeny.

Cameroon

- Kana *et al.* (2009) added plant charcoal from Canarium schweinfurthii (charcoal A) and maize cob (charcoal B) at doses of 0.2; 0.4 and 0.6 % to AF-CT (22 ppb) broiler diet. The addition of 0.20% of charcoal A and 0.60% of maize charcoal was effective in absorbing AF and promoting growth performance of broilers.

China

- Shi *et al.* (2009) added MNT (0.3%) and MNT nanocomposite (0.3%) to AF-CT (110 ppb) broiler diet; MNT nanocomposite significantly diminished the effects of AF on performance and biochemistry.
- Juan-juan *et al.* (2010) incorporated yeast cell extracts, HSCAS and a mixture of yeast product; HSCAS at the levels of 1.5% into AF-CT (100 ppb) broiler diet and HSCAS effectively prevented the toxic effects of AF on performance and biochemistry.
- Che *et al.* (2011) added EGM (0.05%), HSCAS (0.2%) and a kind of adsorbent (CMA) into AF-CT broiler. Addition of 0.05% EGM and 0.2% HSCAS partially alleviated the adverse effects of AF; 0.1% CMA ameliorated the adverse effects.
- Guan *et al.* (2011) reviewed the microbial strategies to control AF in food and feed with 111 related references.
- Liu *et al.* (2011) supplemented EGM (0.05%), HSCAS (0.2%) and compound mycotoxin adsorbent (CMA; 0.1%) to AF-CT (450 ppb) broiler diet. the addition of EGM, HSCAS or CMA prevented some adverse effects of mycotoxins to varying extents, with CMA being the most effective adsorbent treatment.
- Liu *et al.* (2012) recently reviewed the advanced research on the mycotoxin removing with related references.

Colombia

- Diaz *et al.* (2009) added some feed additives (containing aluminosilicate and phytogenic substances) to AF-CT (250 and 500 ppb) turkey diet and used feed supplements partially diminished the negative effects of AF on performance and immunology by the supplements.

Croatia

- Peraica *et al.* (2002) reviewed prevention of mycotoxin production and methods of decontamination including adsorbents, with related 68 references.

Cuba

- Rivera and Farias (2005) reviewed clinoptilolite (CLI)-surfactant composites as a drug support and their mechanism, with related 52 references.

Czech Republic

- Trckova *et al.* (2004) reviewed kaolin, bentonite and zeolites, their binding properties and their usage as feed supplements for animals, with related 108 references.

Denmark

- Shetty and Jespersen (2006) reviewed SCE and lactic acid bacteria for decontamination of mycotoxins. The authors also noted the binding mechanism of the them, with related 84 references.

Egypt

- Matari (2001) incorporated SB (0.5 and 1%) into AF-CT broiler diet and SB significantly restored the adverse effects of AF.
- Eshak *et al.* (2010) added SCE (0.5, 1, 2, 2.5%) to AF-CT (0.5 ppm) quail diet and addition of SCE to quail diets suppressed the aflatoxicosis in quail tissues leading to improvement of growth performances and enhancement of expression levels of neural and gonadal genes.
- Ellakany *et al.* (2011) supplemented HSCAS (0.50%), SCE (0.25%) and EGM (0.25%) into AF-CT broiler diet. While HSCAS significantly improved performance, biochemical and immunological parameters when compared with AF group; EGM significantly improved performance, but there was no effect on other parameters. SCE had no effect on any of the parameters tested when compared with broilers fed AF.

France

- Guerre (2000) reviewed the physical and chemical methods used for inactivation of mycotoxins. The adsorbents including aluminosilicates were also explained in detail, with the results of related 128 references.
- Jouany (2007) reviewed the methods for preventing, decontaminating and minimizing the toxicity of mycotoxins including aluminosilicates and yeast derivatives, with related 165 references.

Germany

- Dänicke (2002) reviewed prevention and/or control of mycotoxins in poultry feed; results of the researches in detail, with related 128 references.

Hungary

- Bata and Laztity (1999) reviewed physical and chemical methods and biolgical adsorbents recommended for detoxification of mycotoxin-contaminated feed. The present state of research in this field and the perspectives of such procedures were also discussed, with 42 related references.

India

- Jindal *et al.* (1994) added activated charcoal (200 ppm) to AF-CT (0.5 ppm) broiler diet; the results showed that activated charcoal provided protection of broilers against harmful effects of AF on performance and biocemistry.
- Raju and Devegowda (2000) incorporated EGM (0.1%) into AF-CT (300 ppb) broiler diet; addition of EGM significantly decreased the detrimental effects of AF on performance parameters, biochemistry and organ morphology.
- Girish and Devegowda (2004) added EGM (0.1%) and HSCAS(1%) to AF-CT (2 ppm) broiler diet and both adsorbents provided significant improvements in performance and relative organ weights associated with aflatoxicosis.
- Gowda *et al.* (2008) added turmeric powder (0.5%) and HSCAS (0.5%) to AF-CT (1 ppm) broiler diet and the adsorbents demonstrated protective action in the deleterious effect of AF on performance, biochemistry, antioxidant functions and histopathology.
- Sawarkar *et al.* (2011) supplemented Toxiroak Gold (0.1%) to AF-CT (100 ppb) broiler diet; herbomineral toxin binder feed supplement provided amelioration of aflatoxicosis in broilers.
- Srikanth *et al.* (2011) added activated charcoal (0.4%) and yeast culture (0.1%) into AF-CT (1 ppm) broiler diet; the combination of activated charcoal and yeast culture was more effective in counteracting the combined toxicity of AF and T-2 toxin compared to the activated charcoal alone.

Indonesia

- Sjamsul *et al.* (1990) supplemented activated charcoal (1.5 and 3%) to AF-CT (150 ppb) duck diet and addition of charcoal alleviated the detrimental effects of AF on gross and histopathology of the livers of ducks. 3% activated charcoal was found to be more effective.

Iran

- Modirsanei *et al.* (2004) added SCE (0.5%) and natural zeolite (0.75%) to AF-CT (1 ppm) broiler diet; addition of 0.75% zeolite did not reduce any of the adverse effects, whereas supplemention of SC moderately ameliorated the effects in respect of performance and biochemistry.
- Safameher *et al.* (2004) administrated ammonia to AF-CT (1 ppm) broiler diet and they provided significant improvements in performance and hematology by treating ammonia in contaminated feed.
- Abousadi *et al.* (2007) incorporated SB (0.5%), SCE (0.2%), HSCAS (0.5%), ammonia (0.5%), formycine (0.1%), and toxiban (0.1%) into AF-CT (125 ppb) broiler diet. Generally addition of the compounds made an improvement against negative effects of AFB1 on performance and biochemistry in broiler chickens. Formycine was recognized to be the best additive in this respect.
- Modirsanei *et al.* (2008) added diatomaceous earth (30 ppm) to AF-CT (1 ppm) broiler diet; the added adsorbent alleviated the negative effects of AF in performance and biochemistry associated with aflatoxicosis.
- Safameher (2008) supplemented CLI (2%) to AF-CT broiler diet to ameliorate the toxic effect of AF (0.5 ppm) and CLI provided significant improvements against AF toxicity in performance, biochemistry and liver histopathology.
- Ghahri *et al.* (2009) added EGM (0.1%), SB (0.5%) and humic acid (0.2-1%) to AF-CT broiler diet to ameliorate the toxic effect of AF (254 ppb) against humoral immunity. The addition of EGM, SB and humic acid to the AF-CT diet ameliorated the negative effects of AF on ND antibody titers, but humic acid proved to be more effective in the amelioration of the detrimental effect of AF on humoral immunity against ND.
- Kamalzadeh *et al.* (2009) added yeast glucomannan (0.5, 1 and 1.5%) to AF-CT (184 ppb) broiler diet and yeast glucomannan significantly decreased the negative effects of AF on performance. 1% glucomannan was found more effective than other concentrations.
- Kermanshahi *et al.* (2009) supplemented SB (0.5 and 1%) to AF-CT (0.5 and 1 ppm) broiler diet and SB significantly improved the effects of AF on performance and biochemistry.
- Manafi *et al.* (2009) added high-grade SB (1%) to AF-CT (500 ppb) broiler diet and SB reduced the toxicity of AF on some parameters.
- Shabani *et al.* (2010) incorporated nanozeolite (0.25-1%) into AF-CT (500 ppb) broiler diet; nanozeolite significantly reduced the toxic effects of AF in performance and biochemistry.
- Manafi (2011; 2012) added bentonite (0.5; 0.75 and 1%), Spirulina platensis (0.1%) and EG (0.2%) to AF-CT (300, 400 and 500 ppb) broiler breeders diet. Among the binders, EG showed better protection against AF in terms of biochemical and immunological parameters, fertility and hatchability.
- Mogadam and Azizpour (2011) added yeast glucomannan (0.05 and 0.1%) and SB (1.5 and 3%) to AF-CT (250 ppb) broiler diet. The addition of yeast glucomannan and SB, individually and in combination to the AF-containing diet, ameliorated the adverse effects of AF. But 0.1% yeast glucomannan supplementation to the contaminated diet with AF proved to be much more effective in the amelioration of the adverse effect of AF on performance and humeral immunity against ND.
- Rangsaz and Ahangaran (2011) incorporated ethanolic turmeric extract (0.05%) to AF-CT (3 ppm) broiler diet. The results suggested that turmeric extract (Curcuma longa) provided protection against the negative effects of AF on performance of broiler chickens.

- Khadem *et al.* (2012) supplemented yeast (0.5%), zeolite (1.5%) and active charcoal (1.5%), alone or in combination into AF-CT (200 ppb) broiler diet. Results indicated that the mixtures of the tested absorbents were more effective in reducing symptoms of AF toxicity in growing broilers.

Iraq

- Ibrahim *et al.* (2000) added SB (0.2, 0.4 and 0.6%) to AF-CT (2.5 ppm) broiler diet and the addition of SB was significantly effective in ameliorating deleterious effect of AF on humoral immunity. SB also improved the adverse effects of AF on performance and hematology (Ibrahim et al. 1998) and carry-over of AF from feed to eggs (Ibrahim and Al-Jubory 2001).

Italy

- Rizzi *et al.* (1998) supplemented EGM (0.11%) to the layer diet and EGM provided significant improvements in the detrimental effects of AF.
- Galvano *et al.* (2001) reviewed dietary strategies to counteract the toxic effects of mycotoxins; feed additives and binding agents were discussed in detail, with the results of 113 related references.
- Rizzi *et al.* (2003) added CLI (2%) to AF-CT (2.5 ppm) layer diet and CLI provided no improvements in egg quality.
- Tedesco *et al.* (2005) added silymarin-phospholipid complex (600 mg/kg BW) to AF-CT (800 ppb) broiler diet; they provided significant improvements in performance parameters by adding feed additive.
- Zaghini *et al.* (2005) added mannanoligosaccharide (MOS; 0.11%) to AF-CT (2.5 pmm) layer diet and MOS decreased the gastrointestinal absorption of AF and its level in tissues.

Korea

- Kim *et al.* (2003) incorporated soybean paste (doen-jang; 0.5, 1 and 5%) into AF-CT (500 ppb) layer diet and the addition of 5% soybean paste significantly reduced the effects of AF on performance, biochemistry, gross and histopathology of liver, egg production and accumulation of AF in hens' eggs.

Mexico

- Mendez-Albores *et al.* (2007) treated AF-CT (110 ppb) duck feed with citric acid (1N for 15 min, 3 ml/g feed) and citric acid significantly ameliorated negative effects of AF on mutagenity, carcinogenity and toxicity in respect of performance, biochemistry and pathology.

Pakistan

- Musaddeq *et al.* (2000) added Myco-Ad, Sorbatox and Mycofix-Plus to AF-CT (8 and 60 ppb) broiler diet and the adsorbents recovered the negative effects of AF on performance of chicks.
- Hashmi *et al.* (2006) supplemented yeast sludge (1%; 0.26% mannan oligosaccharide) to AF-CT (100, 200 and 300 ppb) broiler diet and 1% yeast sludge act as toxin binder effectively at 100 and 200 ppb AF, but its efficiency was reduced at 300 ppb AF level; higher levels of yeast sludge effectively improved the aflatoxicosis condition.
- Pasha *et al.* (2007) added SB (0.5 and 1%), SB+gention violet, SB+acetic acid, Sorbatox and Klinofeed to AF-CT (100 ppb) broiler diet. Addition of indigenous 0.5% SB gave overall better results than the market products and provided significant improvements in performance, organ weight and immunology.

Poland

- Kolacz *et al.* (2004) reviewed the use of synthetic aluminosilicates in decontamination of mycotoxins including AF. They also noted the characteristics of aluminosilicate and its decontaminating effect, with 43 related references.

Saudi Arabia

- Teleb *et al.* (2004) added kaolin and activated charcoal (0.5%) to AF-CT (30 ppb) broiler diet and two adsorbents ameliorated the toxic effects of AF on performance but did not reduce the histopathological changes associated with aflatoxicosis.

Serbia

- Zekovic *et al.* (2005) reviewed the use of natural and modified glucans to promote health and control diseases including their immunomodulator effects and mycotoxin adsorption ability, with 245 related references.

Slovak Republic

- Iveta *et al.* (2000) added CLI and cephalite (0.5%) to AF-treated (0.5 mg/kg BW) broilers; long term oral administration of two sorbents caused an increase in CD3+ cells in lamina of duodenum. AF did not change the number of CD3+ lymphocytes significantly.

South Africa

- Rensburg (2005) incorporated humic acid (0.35%) into AF-CT (1 and 2 ppm) broiler diet; partial improvements in performance, hematology and biochemistry were found.
- Rensburg *et al.* (2006) also added humic acid (0.35%) and dried brewer yeast (0.35%) to AF-CT (1 and 2 ppm) broiler diet; they provided significant improvements by humic acid in performance, biochemistry and hematology. Humic acid was found to be much more effective than brewer yeast.

Spain

- Marquez and Hernandez (1995) added two Mexican aluminosilicates (Atapulgita and Füller earth) at the levels of 0.5 and 1% to AF-CT (200 ppb) broiler diet and the results showed that both aluminosilicates were as efficient as the commercial material in protecting chicks against AF toxicity on performance and gross and histopathology.
- Ramos *et al.* (1997) reviewed nonnutritive adsorbent compounds used for prevention of toxic effects of mycotoxins, with 111 related references.
- Denli *et al.* (2009) added AflaDetox (1, 2 and 5%) AF-CT (1 ppm) broiler diet; the addition of AflaDetox prevented all toxic effects on performance and serum biochemistry and reduced the accumulation of AFB1 residues in the livers.

Switzerland

- Huwig *et al.* (2001) reviewed nonnutritive clay-based adsorbents used in poultry feed and their respective mechanism of adsorption. They also listed the adsorption capacity of compounds commonly used, with 73 related references.

Thailand

- Banlunara *et al.* (2005) supplemented EGM (0.05 and 0.1%) to AF-CT (100 ppb) duck diet; supplementation of EGM effectively reduced AFB1-induced hepatic injury in ducklings.
- Bintvihok and Kositcharoenkul (2006) added Ca propionate (0.25 and 0.5%) to AF-CT (100 ppb) broiler diet; addition of Ca propionate appeared to be effective in reducing toxicity of AF on performance and hepatic enzyme activities in broilers.
- Bintvihok (2010) reported that using EGM (0.05% and 0.1%) to AF-CT (60 and 120 ppb) duck diet and EGM provided significant improvements in performance, histopathology and leg deformity caused by AF. The addition of 0.05% EGM also recovered the adverse effects of AF (100 ppb) on serum biochemistry and in ducklings.

Turkey

- Oguz (1994,1997) produced AF on rice for feeding trials by using Aspergillus parasiticus culture with minor modification of Shotwell's method (1966). After production of AF, fermented rice was then steamed to kill the fungus, dried and ground to a fine powder. The rice powder was then analyzed for AF content. Then it became useful rice powder which was possible to be incorporated into the basal diet to provide desired amounts of AF levels in animal experiments.
- Kececi *et al.* (1998) incorporated synthetic zeolite (0.5%) into AF-CT (2.5 ppm) broiler diet and synthetic zeolite provided significant improvements in the adverse effects of AF on performance, hematology and biochemistry.
- Oguz and Kurtoglu (2000) added CLI (1.5 and 2.5%) to AF-CT (2.5 ppm) broiler diet and CLI provided significant improvements in performance. Addition of 1.5% CLI also ameliorated the toxic effects of AF (2.5 ppm) on hematology-biochemistry (Oguz et al. 2000a) and reduced the number of affected broilers and the severity of gross and histopathological lesions caused by AF (Ortatatli and Oguz 2001).
- Oguz *et al.* (2000b) also incorporated CLI (1.5%) into lower levels AF-CT (50 and 100 ppb) broiler diet and CLI significantly recovered the negative effect of AF on performance of broilers. Adding 1.5% CLI also improved the changes in gross and histopathology of target organs (Ortatatli et al. 2005) and humoral immunity (Oguz et al. 2003) associated with aflatoxicosis.
- Parlat *et al.* (2001) added SCE (0.1%) to AF-CT (2 ppm) quail diet and SCE provided significant improvements the effect of AF on performance. SCE (0.2%) was also added to AF-CT (5 ppb) quail diet and the negative changes in the performance, egg production and egg quality were significantly ameliorated by adding of SCE (Acay 2006).
- Celik *et al.* (2001) added SCE (0.1%) to AF-CT (100 ppb) quail diet and SCE partially neutralized some toxic effects of AF.
- Denli *et al.* (2003) supplemented vitamin A (15.000 IU) to AF-CT (100 ppb) quail diet and vitamin A partially decreased the negative effects of AF on performance, biochemistry and pathology.
- Denli *et al.* (2004, 2005) added conjugated linoleic acid (CLA; 0.2 and 0.4%) to AF-CT (200 and 300 ppb) broiler diet and CLA provided a partial improvement in performance and biochemistry parameters. CLA also decreased the detrimental effects of AF on liver pathology.
- Eraslan *et al.* (2004a) incorporated SB (0.25 and 0.5%) into AF-CT (1 ppm) broiler diet and SB provided a partial improvement in lipid peroxidation in the liver and kidneys of broilers.
- Eraslan *et al.* (2004b) also added HSCAS (0.5 and 1%) to AF-CT (2.5 ppm) quail diet and HSCAS provided a moderate amelioration the negative effects of AF on performance and biochemistry.
- Oguz and Parlat (2004) added MOS (0.1%) to AF-CT (2 ppm) quail diet and MOS significantly improved the adverse effects of AF on performance of quail.
- Yildiz *et al.* (2004) added SCE (0.2%) to AF-CT (2 ppm) quail diet and the addition of SCE significantly recovered the deleterious effects of AF on performance, egg production and egg weight. The addition of 0.2% SCE also provided significant improvements in hatchability and fertility of quails (Yildirim and Parlat 2003).
- Basmacioglu *et al.* (2005) supplemented EGM (0.1%) to AF-CT (2 ppm) broiler diet and EGM significantly ameliorated the toxic effects of AF on hematology and biochemistry. Addition of 0.1% EGM also reduced the rate of affected broilers and the severity of lesions in the target organs caused by AF (Karaman et al. 2005).
- Celik *et al.* (2005) added tribasic copper chloride (200 ppm) to AF-CT (1 ppm) broiler diet and tribasic copper chloride significantly improved the effects of AF on performance and biochemistry.
- Sehu *et al.* (2005) incorporated Mycotox (0.5%) into AF-CT (2.5 ppm) quail diet; the adsorbent did not reduce the toxic effects of AF.

- Denli and Okan (2006) added HSCAS, diatomite and activated charcoal (0.25%) to the AF-CT (40 and 80 ppb) broiler diet. HSCAS was the most effective adsorbents among them to ameliorate the toxic effects of AF in performance and biochemistry.
- Essiz *et al.* (2006) supplemented HSCAS (0.5%) and yeast wall (0.5%) and to AF-CT (2.5 ppm) quail diet and they restored plasma malondialdehyde levels altered by AF. The addition of 0.5% HSCAS also moderately decreased the toxic effects of AF (2.5 ppm) in quail in terms of performance, histopathology and immunology parameters (Sehu et al. 2007).
- Kabak *et al.* (2006) reviewed strategies to prevent contamination of animal feed and listed all detoxification methods which have been studied in vivo and in vitro and used for mycotoxin decontamination; results with 276 related references.
- Cinar *et al.* (2008) added yeast glucomannan (0.075%) to AF-CT (2 ppm) broiler diet; yeast glucomannan at this level was not sufficient to ameliorate the oxidative damage caused by AF in broilers.
- Keser and Kutay (2009) reviewed chemical methods including adsorbents and biological methods for preventing of mycotoxins, with 40 related references.
- Ozen *et al.* (2009) added melatonin (10 mg/kg/bwt) to AF-CT (150 and 300 ppb) broiler diet; melatonin supplementation greatly reduced the nitrosative tissue degeneration caused by AF.
- Demirel *et al.* (2010) reviewed the usage of natural zeolites in animal production including poultry, with 49 related references.
- Karaman *et al.* (2010) added lipoic acid (60 mg/kg/bw) to AF-CT (150-300 ppb) broiler diet they; lipoic acid provided moderate improvements in lipid peroxidation and histopathology of target organs.
- Matur *et al.* (2010) supplemented SCE extract (0.1%) to AF-CT (100 ppb) hen diet; addition of SCE extract reduced the toxic effects of AF on pancreatic lipase and chymotrypsin activity.
- Yildirim *et al.* (2011) added yeast glucomannan (0.075%) to AF-CT (2 ppm) broiler diet; the deleterious effects were partially alleviated, but the treatment did not prevent tissue damage.

United States

- AF was produced on rice by using Aspergillus flavus culture (Shotwell et al. 1966) for using in feeding trials with poultry and other animals. This method has become a preferential method in the experiments for investigating AF toxicity and/or evaluation of preventive efficacy of feed additives against AF.
- Kubena *et al.* (1990) supplemented HSCAS (0.2%) and activated charcoal (0.5%) to AF-CT (5 and 7.5 ppm) Leghorn chicks' diet and HSCAS significantly diminished the adverse effects of AF on performance, organ weights and biochemistry, whereas adding activated charcoal had no effect.
- Araba and Wyatt (1991) added SB, HSCAS and ethacal (0.5 and 1%) to AF-CT (5 ppm) broiler diet. Addition of 0.5% SB and HSCAS significantly reduced the deleterious effects of AF on performance, liver weights and liver lipids.
- Kubena et al. (1991) added HSCAS (0.5%) to AF-CT (0.5 and 1 ppm) turkey diet and HSCAS neutralized the effects of AF performance, relative organ weights, hematological and biochemical values associated with 0.5 ppm AF.
- Huff *et al.* (1992) incorporated HSCAS (0.5%) into AF-CT (3.5 ppm) broiler diet and HSCAS effectively recovered the detrimental effects of AF on serum biochemistry.
- Harvey *et al.* (1993) added zeolites (CLI, zeomite and mordenite) (0.5%) to AF-CT (3.5 ppm) broiler diet; zeomite and mordenite decreased the toxicity of AF to growing chicks as indicated by weight gains, liver weight, and serum biochemical values.
- Kubena *et al.* (1993) added HSCAS (0.5%) to AF-CT (2.5 and 5 ppm) broiler diet. The addition of 0.5% of the HSCAS compounds significantly recovered the growth inhibitory effects caused by AF. The increases in relative organ weights and the decreases in serum biochemical values caused

by AF were significantly alleviated to differing degrees by HSCAS compounds and HSCAS was found to be protective against the effects of AF in young growing broilers.

- Scheideler (1993) incorporated Ethacal, Novasil, zeobrite and perlite (1%) into AF-CT (2.5 ppm) broiler diet. Initial three adsorbents provided significant improvements in performance and liver lipid, and partial improvements in mineral status.
- Abo-Norag *et al.* (1995) added HSCAS (0.5%) to AF-CT (3.5 ppm) broiler diet; HSCAS effectively restored the negative effects of AF on performance and serum biochemistry.
- Edrington *et al.* (1997) supplemented super activated charcoal (0.5%) to AF-CT (4 ppm) broiler diet; active charcoal moderately alleviated the toxic effects of AF on performance, hematology and biochemistry.
- Bailey *et al.* (1998) added three different adsorbents (0.5%) to AF-CT (5 ppm) broiler diet; the adsorbents offered some protection against AF toxicity in chickens.
- Kubena *et al.* (1998) added HSCAS (0.25%) to AF-CT (5 ppm) broiler diet and significantly reduced negative effects of AF on performance and serum biochemistry.
- Ledoux *et al.* (1999) added HSCAS (Milbond-TX; 1%) to AF-CT (4 ppm) broiler diet and HSCAS completely improved in AF-dependent changes in organ weights, serum chemistry changes, and gross pathology observed in chicks fed AF. HSCAS also effectively reduced the incidence and severity of the hepatic and renal histopathology changes associated with aflatoxicosis.
- Phillips (1999) reviewed dietary clay used in the prevention of aflatoxicosis. In this review AF prevention strategies, chemoprevention, HSCAS and possible nutrient interaction with adsorbents were expressed, with 70 related references.
- Stanley *et al.* (2003) added SCE (0.05 and 0.1%) to AF-CT (5 ppm) broiler diet and the addition of 0.1% SCE significantly improved the changes in performance, relative organ weights and serum biochemistry associated with aflatoxicosis.
- Stanley *et al.* (2004) also added yeast culture residue (2 lb/ton) to AF-CT (3 ppm) breeder hen diet; the inclusion of yeast culture in the AF-treated diet improved hatchability and egg production, and lowered embryonic mortality significantly. Serum globulin and albumin were partially restored with the addition of yeast.
- Bailey *et al.* (2006) incorporated MNT clay (0.5%) into AF-CT (4 ppm) broiler; they reported that MNT clay in broiler diets provided significant protection on growth performance, serum biochemistry, and relative organ weight associated with aflatoxicosis.
- Fairchild *et al.* (2008) added bentonite based Astra-Ben (1 and 2%) to AF-CT (4 ppm) broiler diet; the adsorbent provided significant improvements in performance and liver lipid content.
- Rawal *et al.* (2010) reviewed toxicology, metabolism and prevention of AF; clay-based inorganic adsorbents and their effects were also discussed, with 121 related references.
- Zhao *et al.* (2010) supplemented HSCAS and yeast cell wall component with two doses (0.1 and 0.2%) to AF-CT (1 and 2 ppm) broiler diet and they provided significant improvements by adding of HSCAS and less improvements by yeast cell wall components in performance, biochemistry and histopathology changes associated with aflatoxicosis.
- Jaynes and Zartman (2011) reviewed the AF toxicity reduction in feed by enhanced binding to surface-modified clay additives, with 45 related references.

Venezuela

- Marin *et al.* (2003) added SCE (0.1%) and selenium (2.5 ppm) to AF-CT (70 ppb) broiler diet; no improvements in biochemistry and hematology by adding the supplements were found.
- Arrieta *et al.* (2006) incorporated SCE (0.1%) and selenium (2 ppm) into AF-CT (70 ppb) broiler diet; no improvements were seen in biochemical parameters. Also no significant changes were seen by adding low levels of AF in parameters.

- Gomez *et al.* (2009) supplemented SCE (0.1%) and Se (2 ppm) to AF-CT (70 ppb) broiler diet and the results suggested that the ingestion during 42 days period with 70 ppb AFB1 on diet of broiler may have some effects on production parameters.

Vietnam

- Kinh et al. (2010) added Mtox (0.25%) to AF-CT (31-44 ppb) broiler diet; Mtox improved growth rate and feed efficiency of broiler chickens significantly.

Conclusion

The evaluation of the preventive efficacy of protective agents is possible by determining significant statistical differences between parameters of AF and AF plus additive groups in the target organs and key parameters in favor of AF plus feed additive groups. In my opinion, the best way to assess the performance of feed supplements against AF toxication for producers and scientists is to evaluate the results "as total" in terms of performance, biochemical-hematological, immunological and gross pathologic and histopathological parameters by comparing the AF groups with AF plus feed additive groups.

Evaluation of experiments "as total" is not always easy, because authors from different departments sharing responsibility for designing the experiment and interpreting the results tend to publish special aspects of experimental results in different scientific journals, with focus on their own special field of interest. To assess the "total" preventive efficacy and practical benefit of toxin binders used in experiments, nutritionists in the feed industry may invest some of their time following the titles of articles and/or associate authors and/or materials and methods of articles – unless they rely on recent reviews.

As the present review shows, experiments to reduce negative effects of AF in poultry feed have been mainly performed with zeolites and bentonites such as HSCAS, CLI and SB or biological matters such as yeast (SCE) and yeast derivates (EGM). Nutritionists in the feed industry and scientists can examine the results and decide which protective agent to use, taking into account the AF dose in feed, levels of protective agent, the experimental period and the species/variety of poultry species. Feed supplements must be inert and non-toxic and have no pharmacological and toxicological effects themselves in the organisms of animals. Possible nutrient interaction and dioxin contamination should also be regarded for using of natural clays.

Summary

In this meta-analytic review in vivo experimental trials on inactivation of aflatoxins by using adsorbents and biological products as a feed additive in poultry feed are briefly summarized. For this purpose, 155 researches performed in 35 different countries were examined and listed by country of first author, with main results presented in their summary. The aim of this review is to present the results of the experiments for nutritionists in the feed industry and scientists and to provide a basis for total evaluation on the basis of regional results.

For research on AF in poultry feed, it is preferable to evaluate the preventive efficacy of feed additives "as total" in terms of performance, biochemical-hematological, immunological and gross and histopathologic parameters, comparing AF treated control diets with AF plus feed additive diets. Scientists can assess the preventive efficacy and practical usability of feed additives in more detail by following the titles of articles, associate authors and/or materials and methods of related articles. For application in practice, focus on limiting AF contamination by optimizing harvesting and storage conditions should be stressed instead of expecting miracles from feed additives which have shown positive effects under experimental conditions.

Zusammenfassung

Entgiftung von Aflatoxin im Geflügelfutter: eine aktuelle Literaturübersicht

In dieser kurzen Übersicht werden Ergebnisse von Fütterungsversuchen zur Inaktivierung von Aflatoxinen durch Futterzusätze mit Adsorbentien und biologischen Produkten aus 155 Veröffentlichungen zusammengestellt Die zitierten Arbeiten sind mit den wichtigsten Ergebnissen nach Ländern des Erstautors aufgeführt, um Lesern einen schnellen Zugang zu regionalen Lösungsversuchen zu geben.

Leistungsmerkmale, biochemisch-hämatologische, immunologische und histopathologische Parameter sollten im Zusammenhang betrachtet werden, um die Effizienz spezifischer Futteradditiva in der jeweiligen Dosierung zu bewerten.

References

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