



## INVITED REVIEW

### Meta analytic study on detoxification of aflatoxin in poultry feed: An update

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### Kanatlı yemlerindeki aflatoksinlerin etkisizleştirilmesine yönelik meta analitik çalışma: Bir güncelleme

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#### Öz

Bu meta-analitik derlemede kanatlı yemlerindeki aflatoksinlerin etkisizleştirilmesi ile ilgili yem katkısı şeklinde kullanılan adsorbanlar ve biyolojik ürünlerle yapılan in vivo deneysel çalışmalar özetler halinde sunuldu. Bu amaçla 39 farklı ülkede gerçekleştirilen toplam 206 araştıma tarandı ve ulaşılan sonuçlar ana hatlarıyla verildi. Bu derleme ile ilgili konuda yapılan tüm çalışmalar ve sonuçlarının konu ile ilgilenen sektör ve bilim temsilcilerine ülkeler bazında toplu halde sunulması ve onların bütüncül bir değerlendirme yapmalarına imkan sağlanması amaçlandı. Üreticiler ve araştırmacılar için yeme aflatoksin bağlayıcı olarak katılan yem katkısının etkinliğini belirlemede en iyi yol, aflatoksin ve aflatoksin + bağlayıcı madde grubunu karşılaştırılarak elde edilen sonuçların performans, biyokimyasal-hematolojik, immunolojik ve makroskobik-histopatolojik verilerin hepsinin "bir bütün olarak" ele alınması ve değerlendirilmesidir. Üreticiler ve araştırmacılar denemelerin bütününe ulaşip koruyucu maddenin pratikte kullanılabilirliğini değerlendirmek için makale başlıklarını, ortak yazarları ve/veya makalenin materyal ve metodunu takip edebilirler. Pratikteki uygulamalar için aslında, deneysel koşullar altında olumlu etkiler gösteren yem katkılarından mucizeler beklemek yerine hasat ve depolama koşullarını optimize ederek aflatoksin kontaminasyonunu sınırlandırılmasına odaklanmak gerekir.

**Anahtar kelimeler:** Aflatoksin, etkisizleştirme, kanatlı, yem

#### Abstract

In this meta-analytical review in vivo experimental trials on inactivation of aflatoxin (AF) by using adsorbents and biological products as a feed additive in poultry feed are briefly summarized. For this purpose, 206 researches performed in 39 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 histo-pathological 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. In fact, 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.

**Keywords:** Aflatoxin, detoxification, poultry, feed





## 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 (Oguz and Kurtoglu 2000, Ortatlatli et al 2002). Aflatoxicosis in poultry also causes listlessness, anorexia with lowered growth rate, poor feed utilization, decreased egg production and increased mortality (Miazzo et al 2000). Additionally, anaemia (Oguz et al 2000), reduction of immune function (Gabal and Azzam 1998, Oguz et al 2003), hepatotoxicosis, hemorrhage (Ortatlatli and Oguz 2001), teratogenesis, carcinogenesis and mutagenesis are associated with aflatoxicosis. The toxicity of AF in poultry has been widely investigated by determining their teratogenic (Sur and Celik 2003), carcinogenic, mutagenic and growth inhibitory (Oguz and Kurtoglu 2000) effects. The biochemical-hematological (Basmacioglu et al 2005), immunological (Qureshi et al 1998), gross and histopathological (Ortatlatli and Oguz 2001) toxic effects of AF have also been well described.

The problem of aflatoxicosis 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 AF-contaminated (AF-CT) raw materials presents a major problem. Detoxification as well as routine AF analysis of feed ingredients is an important step in a control program at field level.

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.

Physical, chemical and biological methods are essential to counteract the level of contamination of AF 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 (Patil 2014).

Practical and cost-effective methods of detoxifying AF-CT feed are in great demand. Besides of the 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 (Dwyer et al 1997, Phillips 1999, Rosa et al 2001). Also, possible dioxin contamination may be a risk factor for using of natural clays in case of forest and trash fire near their source (Abad et al 2002, Feidler 2002, Trckova et al 2004, Arikani et al 2009).

## 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 (Bata and Lasztity 1999). 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 (Bailey et al 1998, Kubena et al 1998, Parlat et al 1999). As a result, researchers have directed efforts towards finding effective means of biological degradation of AF.

Many pellet binding products and flowing agents (clay minerals) or feed materials (yeasts and their derivatives) with the claim of mycotoxin binding and or detoxification have been used in animal feeds worldwide. However, regulations for mycotoxin binders and deactivators have not been implemented in many parts of the world for various reasons. This negates the guarantee on the safety and efficacy of the product to the user. Therefore it is important to have guidelines in place which prove safety and efficacy of such additives under different *in vitro* and *in vivo* conditions (Murugesan et al 2015).

The European Commission established a new group of technological feed additives for the reduction of mycotoxins in feed to overcome this unsatisfactory legal situation. In 2010, the European Food Safety Authority (EFSA) published guidelines with stringent requirements, e.g. the binding capacity must be demonstrated; mycotoxin degradation products must be safe for target animals and consumers; minimum three *in vivo* studies with significant efficacy at the lowest recommended dose; relevant biomarkers of each individual mycotoxin have to be used to demonstrate the efficacy of the product, for the evaluation of mycotoxin deactivating products (EFSA 2010, Murugesan et al 2015).

Most studies have used greater concentrations of AF than are likely to be found under field conditions. The AF concentra-



tions in these experiments ranged from 2 to 5 ppm (Kubena et al 1990, 1993, 1998, Kiran et al 1998, Ibrahim et al 2000, Oguz et al 2000a, Miazzo et al 2000, Rosa et al 2001), 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 feed additive in poultry are briefly given below. A total of 206 studies (in *in vivo* and in poultry species only) were examined and are listed for 39 countries according to the first author's institute.

### 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 adverse effects 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 histopathology 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.
- Pizzolitto et al. (2013) added SCE to AF-CT (1.2 ppm) broiler diet and drinking water for 28 d. The addition of SCE to drinking water and to the diets contaminated with AFB1, showed a positive protection effect on the relative weight of the liver, histopathology, performance and biochemical parameters.

#### Australia

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

#### Austria

- Lee et al. (2012) added mycofix select (2.27 g/kg) into AF-CT (1, 1.5, 2 ppm) laying hens' feed for 6 weeks. Results indicate that AF deactivating compound can ameliorate some of the negative effects of mycotoxin consumption.
- Murugesan et al. (2015) reviewed prevalence and effects of

mycotoxins on poultry health and performance, and recent development in mycotoxin counteracting strategies, with related 174 references.

- Vekiru et al. (2015) added different bentonites and zeolites (0.5%) into AF-CT (2 ppm) broiler feed for 21 d. Our results demonstrated that the tested zeolite was ineffective in AFB1 binding, while most of the tested Ca- or Na-bentonites were effective. Moreover, *cis*-bentonites were more effective than the tested *trans*-bentonite. Even among the good binders there were differences in *in vivo* efficacy indicating that *in vitro* testing alone is not adequate for evaluation of adsorbents.

#### Belgium

- Schwarzer and Baecke (2009) reviewed inactivators for mycotoxins (based on botanicals, yeast and clay-minerals) on animal performance.
- Kolosova and Stroka (2011) reviewed the substances for reduction of the contamination of feed by mycotoxins with related articles.

#### 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 hens' 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.
- Neff et al. (2013) added hydrated sodium calcium aluminosilicate (HSCAS; 0.5%) to AF-CT (2.5 ppm) broiler diet for 21 d. AF residues were lower in livers and kidneys of birds fed AFB1 plus HSCAS when compared with birds fed AFB1 alone. The decrease in the bioavailability of AFB1 caused by the HSCAS reduced AF residues in liver and kidney, but not enough to completely prevent the toxic effects of AFB1 in broilers.
- Carao et al. (2014) reviewed the physical and chemical methods of detoxification of AF and reduction of fungal contamination on poultry productive chain, with 38 references.
- Eckhardt et al. (2014) supplemented Brazilian Ca-MNT (2.5 and 5 g/kg) into AF-CT (3 ppm) broiler diet for 42 d. Dietary Ca-MNT positively affected parameters such as weight of liver, heart and gizzard and partially reduced the toxic effects of AF in broilers when included at levels of 2.5 and 5 g/kg in the diet.
- Bovo et al. (2015) added fermentation residue containing SCE (1%) into AF-CT (2 ppm) broiler diet for 42 d. Feed additives reduced the adverse effects of AF on performance parameters; and severity of histological changes in liver and kidney caused by AF while partially ameliorated the changes on relative liver and kidney weights.
- Oliveira et al. (2015) added anti-mycotoxin additives based on SCE (0.2%) to AFB1-CT (1 ppm) broiler diet for 21 d. The addition of two different kinds of SCE (0.2%) could reverse such effects. These are the first data reported from Brazil anti-mycotoxin additives with preliminary isothermal analysis. Since beneficial characteristics of SCE cell wall in animal industry are strain dependent, this study suggests two new promising alternatives to ameliorate AF problem.

#### 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 effec-

tively 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) reviewed the advanced research on the mycotoxin removing with related references.
- Fan et al. (2013) added *Bacillus subtilis* ANSB060 to AF-CT (90 ppb) broiler diet for 42 d. The addition of *Bacillus subtilis* provided protective effects on growth performance and meat quality while reducing the amount of AF residues in the livers of broilers fed naturally moldy peanut meal.
- Zhu et al. (2013) incorporated wood vinegar (0.5, 1 and 2%) into AF-CT (40 ppb) broiler feed for 42 d. Wood vinegar could reduce or substantially eliminate the adverse effects from AFB1 on growth performance and tissue damage.
- Zou et al. (2013) added probiotic (0.5%) into AF-CT (400 ppb) broiler diet for 30 d. The results showed that adding 0.15% feed additive in broiler diets could significantly relieve the negative effect of AFB1 on chicken's production performance and nutrient metabolic rates. It could be concluded that the probiotic was able to degrade AFB1 and improve animal production.
- Chen et al. (2014a) supplemented Na-selenite (0.2, 0.4, 0.6 ppm) to AFB1-CT (0.3 ppm) broiler feed for 21 d. The results indicate that sodium selenite in diet can protect chicken from AFB1-induced impairment of humoral immune function by reducing bursal histopathological lesions and percentages of apoptotic bursal cells.
- Yu et al. (2015) added Na-selenite (0.4 ppm) into AF-CT (300 ppb) broiler diet for 21 d. These results suggested that Na-selenite supplied in the diet could effectively inhibit AFB1-induced apoptosis and cell cycle blockage in renal cells of broiler.

#### Colombia

- Diaz et al. (2009) added some feed additives (containing aluminosilicate and phytochemical 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 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.
- Attia et al. (2013) added mannanoligosaccharide (MOS), HSCAS and *L. acidophilus* (2 g/kg) to AF-CT (200 ppb) broiler diet for 21 d. *Lactobacillus* was most effective in reversing the adverse effects of AF on growth and FCR and on the percentage, functions and morphology of the liver. HSCAS also improved the economic traits of broilers but was less effective than *Lactobacillus* and more effective than MOS.
- El-Ghany et al. (2013) incorporated HSCAS (0.5%), turmeric powder (80 mg/kg) into AF-CT (2.5 ppm) broiler diet for 5 weeks. Both HSCAS and turmeric powder treatment induced significant amelioration of the measured organs body weights ratio, humoral immune response to Newcastle Disease and biochemical parameters in aflatoxicated chickens. In conclusion, addition of HSCAS and or turmeric powder can be considered an integrated approach for the control of aflatoxicosis in broiler chickens.

#### *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.
- Jard et al. (2011) reviewed mycotoxin reduction methods in food and feed: from prevention in the field to detoxification by adsorption or transformation; with related 241 references.

#### *Germany*

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

#### *Greece*

- Pappas et al. (2014) added bentonite (1%) into AF-CT (20 ppb) broiler diet for 42 days. The study revealed that the examined bentonites may maintain optimum broiler performance when AF levels present in the diet do not exceed EU limits.

#### *Hungary*

- Bata and Laztity (1999) reviewed physical and chemical methods and biological 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 biochemistry.
- 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 func-





ons 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.
- Gowda et al. (2013) reviewed recent advances for control, counteraction and amelioration of potential AF in animal feeds with the results of 38 related references.
- Kumar et al. (2013) incorporated citrus fruit oil (2.5 g/kg) into AF-CT (1 ppm) broiler diet for 35 d. The addition of citrus oil to AF-CT diet moderately decreased the magnitude and severity of lesions (hydropic degeneration and bile duct hyperplasia) in the liver.
- Dhanpal et al. (2014) also added citrus fruit oil (2.5 g/kg) into AF-CT (1 ppm) broiler diet for 35 d. The results showed that supplementation had a moderate effect on post treatment growth performance, relative organ weight, and biochemical parameters. It is suggested that citrus fruit oil as a feed additive causes partial amelioration of aflatoxicosis.
- Patil et al. (2014) reviewed mycotoxicosis and its control in poultry with the results of 86 related references.
- Aravind and Churchill. (2015) supplemented EGM (0.1%) to AF-CT (1 ppm) broiler diet for 6 weeks. The addition of EGM significantly counteracted the ill effects of AF on weight gain and feed consumption. The reduction in feed efficiency due to AF was restored to normal by EGM supplementation.
- Mamta et al. (2015) added methionine (0.05 and 0.1%) into AF-CT (250 ppb) broiler feed for 42 d. Supplementation of 0.1% methionine to the AF-CT diet had pronounced ameliorative effect on performance of the birds.
- Tingting et al. (2015) Na-selenite (0.2, 0, and 0.6 ppm) to AF-CT (300 ppb) broiler diet for 21 d. It was indicated that Na-selenite in the diets could exert protective effects against AFB1-induced damage on the red blood cells, and the transport capacity and immune adherence function of erythrocyte could be maintained.

#### 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

supplementation 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 to-xiban (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.
- Ahangaran and Jahromi (2011) added nanosilver (2500 ppm) to AF-CT (3 ppm) broiler feed for 28 d. Feed additive completely restored the adverse effects of AF on performance parameters. These improvements showed the ability of nanocid to diminish the inhibitory effects of AF.
- 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.

- Rangszaz 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.
- Kaki et al. (2012) added zeolite (3 g/kg) and mycosorb (1 g/kg) to AF-CT (0.5 and 1 ppm) broiler feed for 6 weeks. The addition of mycosorb and zeolite to the AF-CT diet significantly recovered the adverse effect of AF on performance and biochemical-hematological values of broilers. The protective effect of mycosorb was higher than that of zeolite against the toxic effects of AF.
- Kasmani et al. (2012) incorporated *Bacillus* probiotic (108 CFU/ml) and mill-bound-TX (2.5 g/kg) to AF-CT (2.5 ppm) Japanese quail diet for 49 d. The results verified its AFB1-binding activity in quails with regard to performance, serum biochemistry, and immune responses.
- 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.
- Sherefat et al. (2013) added SB (0.5%) into AF-CT (1 ppm) broiler cockerel's diet for 42 d. The results showed that SB partially diminished the adverse effects of dietary AFB1 on performance and organ weights in broiler cockerels.
- Manafi et al. (2014a) supplemented rosemary (500 ppm) into AFB1-CT (600 ppb) broiler feed for 6 weeks d. The rosemary could essence have partially restored the negative impacts of AF on performance and antibody titers in broilers.
- Manafi et al. (2014b) added thyme essence (500 ppm) to AFB1-CT (600 ppb) broiler feed for 42 d. The inclusion of thyme essence have showed an improved data and addition of Thyme essence to AF-fed groups could partially alleviate the adverse effects of AF in the diet. The antibody titers of broilers fed AF were significantly increased and incorporation of thyme essence could partially restore the negative impact of AF in commercial broilers.
- Sadeghi et al. (2014) incorporated savory essential oil (500 mg/kg/dry matter) into AF-CT (0.5 ppm) broiler diet for 42 d. The addition of savory reduced the adverse effects of AF on growth performance and provided slight positive effect on serum biochemistry and humoral immune responses in broilers exposed AF.
- Azizpour and Mogadam (2015) supplemented EGM (0.05 and 0.1%) and SB (1.5 and 3%) into AF-CT (250 ppb) broiler diet for 42 d. The addition of YG and SB to the AF-CT diet partially reduced the negative effects of AF. The 0.1% EGM

supplementation to the AF-CT feed significantly prevented the pathological effect of AF on serum biochemical parameters and liver, and was found to be more effective than other treatments.

#### *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).
- Al-Daraji (2012) incorporated licorice extract (LE; 150 mg/kg) into AF-CT (2 ppm) broiler diet for 7 weeks. The simultaneous addition of LE to the AF-CT diet improved the adverse effects of AF on carcass traits and provided great improvement in AF toxicity on broiler performance.
- Shareef and Omar (2012) added synertox (0.5 ml/L) to AF-CT (2.5 ppm) broiler feed for 42 d. Synertox was effective in counteracting the negative effect of AF on relative bursal weight, thymus and spleen relative weights. A significant restoring of ND antibody titre to those of control group was recorded by addition of Synertox to the drinking water of broilers in compared with the AF fed group. It could be concluded that Synertox could be used in counteracting the negative effects of AF on health and performance of broiler chicks.
- Ali (2014) added vitamin E, poultry star, levamesole, acetic acid into drinking water of broilers with AF-CT (8 ppb) for 25 d. Using vitamin E with selenium and poultry star were reduced the effect of AF on immune response and protect the lymphoid organs. Whereas, levamesole and acetic acid were act in less degree as compared with vitamin E and poultry star.

#### *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 MOS (0.11%) to AF-CT (2.5 ppm) 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 mutagenicity, carcinogenicity and toxicity in respect of performance, biochemistry and pathology.

### *Nepal*

- Karna (2013) incorporated *N. sativa* seed (2%) to AF-CT (30 µg/kg/d) duckling feed for 2 weeks. From the obtained results, it can be concluded that the addition of *N. sativa* as a feed additive in poultry diet products the hepatotoxicity induced by AF on biochemical and histopathological parameters.

### *Nigeria*

- Lala et al. (2015) added nano-clay adsorbent (2.5 g/kg) into AF-CT (60, 110 ppb) turkey diet for 84 d. Dietary supplementation with clay adsorbents regardless of contamination levels of AF showed improved packed cell volume and hemoglobin count when compared with turkeys fed AF-CT diet containing no adsorbent.
- Ologhobo et al. (2015) supplemented MNT, HSCAS and SB (2 g/kg) into AF-CT (2 ppm) broiler feed for 8 weeks. No significant preventive effects were observed. AF binding agents should be rigorously tested paying particular attention to their effectiveness and safety.

### *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.

- Mahmood et al. (2011) reviewed the comparative evaluation of different techniques for AF detoxification in poultry feed and its effect on broiler performance, with 93 related references.

- Khan and Zahoor (2014) added magnetic carbon at five levels (0.2-0.5%), into AF-CT (200 ppb) broiler diet for 42 d. The prepared adsorbent was efficient for the detoxification of AFB1 in gastrointestinal tract in terms of biochemical, organ lesions and performance.

### *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.
- Dos Anjos et al. (2015) supplemented bentonite (0.75%), diatomaceous earth (0.75%) and turmeric (0.37%) into AF-CT (2 ppm) broiler diet for 21 d. Feed additives partially





ameliorated the adverse effects of AF on performance, organ weights and biochemical parameters.

#### *Spain*

- Marquez and Hernandez (1995) added two Mexican aluminosilicates (Atapulgita and Fuller 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.
- Suksombat et al. (2011) supplemented SCE (2x10<sup>7</sup> CFU/g) into AF-CT (250 ppb) broiler feed for 42 d. It is indicated in the present study that supplementation of either commercial or bovine yeasts had beneficial effects on performance of broiler chickens intoxicated with AF in terms of performance and biochemical parameters.

#### *Turkey*

- Oguz (1997) produced AF on rice for feeding trials by using *Aspergillus parasiticus* culture in October 1994 with minor modification of Shotwell's method (1966). After production of AF, fermented rice was then steamed to kill the fungus, dri-

ed 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 signifi-





cant 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.

- Oguz (2011, 2012) reviewed meta-analytically the in vivo experimental trials on inactivation of AF by using adsorbents and biological products as a feed additive in poultry feed, with 155 related references.
- Mizrak et al. (2014) supplemented sepiolite (1.5 and 3%) and MOS (0.1%) into AF-CT (120 ppb) laying hens' feed for 12 weeks. The addition of MOS and sepiolite to the feed reduced the degree of digestion of AF by 6-12%. Sepiolite supplementation to AF-CT diet had the beneficial effects on hen performance, egg quality, blood and digestion characteristics.
- Yenice et al. (2015) added SB (0.5 and 1%) and MOS (0.1%) into AF-CT (120 ppb) laying hens' feed for 12 weeks. SB appears to be more effective than MOS as a toxin-binding agent in counteracting the adverse effects of AF on performance, egg quality, blood and digestion characteristic in laying hens.

#### *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 improve-

ments 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.
- Wan et al. (2013) added clay adsorbent (0.1%) to AFB1-CT (25, 50 and 100 ppb) duckling feed for 21 d. The addition of 0.1% clay adsorbent can protect against the detrimental effects caused by AF on performance and organ weights in ducks.
- Chen et al. (2014b) supplemented HSCAS (0.5%) to AF-CT (0.5, 1, and 2 ppm) to broiler diet for 21 d. Results from this study indicate that dietary supplementation with HSCAS can effectively improve body weight gain and partially ameliorate aflatoxicosis for broiler chicks fed AF-CT feeds.
- Womack et al. (2014) reviewed non-biological remediation of AF-CT crops, with 72 related references.
- Fowler et al. (2015) added Ca bentonite (0.2%) into AF-CT (600, 1200 and 1800 ppb) into broiler feed for 21 d. Results also showed that 0.2% Ca bentonite was effective at reducing the accumulation of AFB1 residues in the liver and improving livability in birds fed AF.

#### *Uruguay*

- Mosca and Marichal (2011) supplemented 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).

#### *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.





## Conclusions

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 histo-pathological 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 derivatives (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.

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.

## Acknowledgement

This meta-analytical review is an updated version of invited papers published at the beginning of 2011 and 2012 (Oguz, 2011, 2012). Since then, 51 new articles in different countries related to detoxification of AF in poultry feed were published and are included here.

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