Chapter 8

# Control of Aflatoxicosis in Poultry Using Probiotics and Polymers

Bruno Solis-Cruz, Daniel Hernandez-Patlan, Billy M. Hargis and Guillermo Tellez

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**Abstract**

An important approach to prevent aflatoxicosis in poultry is the addition of non-nutritional adsorbents in the diet to bind aflatoxin B1 (AFB1) in the gastrointestinal tract. These adsorbents are large molecular weight compounds that are able to bind the mycotoxin, forming a stable complex adsorbent-mycotoxin, which can pass through the gastrointestinal tract. In this chapter, we evaluate the use of polymers and probiotics to reduce AFB1 toxic effects in poultry. Our results on the efficacy of polymers and probiotics in sequestering mycotoxins are highly promising, although this field is still in its infancy and further research is needed. Furthermore, *in vivo* studies are needed to confirm the effectiveness of these materials against AFB1 toxic effects, since results in the past have indicated that there is great variability in the efficacy of adsorbing materials *in vivo*, even though the compounds may show potential adsorption capacity of the mycotoxin *in vitro*.

**Keywords:** aflatoxins, chickens, polymers, adsorption, probiotics

## 1. Introduction

Mycotoxins are low molecular weight compounds produced as secondary metabolites by filamentous fungi contaminating crops in the field or warehouses when environmental conditions of temperature and humidity are adequate. These metabolites have no biochemical relevance to fungal growth or development, and they constitute a chemically and toxicologically heterogeneous group, which are together only because they can cause diseases, including death, to human beings and other animals even at low concentrations [1].

Currently, more than 400 different mycotoxins are known, but only six are currently considered to be of worldwide importance, and aflatoxins are the most toxigenic and investigated mycotoxins worldwide because their natural occurrence can cause serious economic losses and health problems [2, 3]. In terms of toxicity and occurrence, aflatoxin B1 (AFB1) is the most important mycotoxin due to its hepatotoxic and hepatocarcinogenic effects, which can result in immunosuppression, anorexia with reduced growth rate, decreased egg production, reduced reproductivity, poor feed utilization, anemia, hemorrhage, and increased mortality [4, 5]. Furthermore, intoxication with AFB1 has been linked to other severe effects such as teratogenesis, carcinogenesis, and mutagenesis [6].

Due to the severe and harmful effects of AFB1, many methods to reduce its toxic effects have been proposed. The first and best attempt to prevent the effects of AFB1 is to minimize its production through good agricultural practices (GAP), including cultivating practices in fields as well as harvest, transport, and storage conditions [7, 8], all these steps are under GAP. However, since prevention is not always possible, decontaminating and/or detoxifying methods have been gaining attention as an alternative to reducing AFB1 contamination of feed and grains. Methods of detoxification can be physical, chemical, or biological treatments of contaminated feed or grains, and they can be as simple as the physical separation through screening, classification, and selection of damaged grains or as complex as gamma irradiation or chemical methods using ammonia, ozone, hydrogen peroxide, or some acids and alkalis [9–14]. Nevertheless, many of these methods to detoxify aflatoxin-contaminated feed are not currently available because they cannot be applied on a large scale and in a cost-effective manner or because many of them are impractical, ineffective, or potentially unsafe.

Another approach to prevent aflatoxicosis in animals is the addition of adsorbents in the diet for binding aflatoxin in the gastrointestinal tract so that these compounds impede its adsorption in the intestine [15]. Adsorbents have been recurrently used because of their economic feasibility and suitability for nutritional perspective [16]. Many studies have demonstrated that aluminosilicates, mainly zeolites, hydrated sodium calcium aluminosilicate (HSCAS), and aluminosilicate-containing clays, can effectively reduce aflatoxins toxicity to animals; being these inorganic materials, the most thoroughly studied adsorbents [17–21]. Alternatively, both carbon-based organic polymers and synthetic polymers have been tested, and some of them are currently on the market [17, 22]. Even though the cost of these polymers could be the limiting factor for practical applications, their use can help to solve the problems related with the use of aluminosilicates and clay adsorbents, such as binding preferly just to aflatoxins, the possibility to adsorb important micronutrients, and the risk of natural clays to be contaminated with dioxins [7, 23]. Nowadays, there are some highly promising research on the effectiveness of synthetic and organic polymers in adsorbing aflatoxins, although this field is still under developing and it needs more *in vitro* and *in vivo* research [24].

On the other hand, biological methods to prevent aflatoxicosis have also been evaluated showing promising results [25–28]. Many microorganisms, including bacteria, yeasts, molds, actinomycetes, and algae, have been tested for their ability in the control of aflatoxin contamination, mainly through adsorption and degradation [29, 30]. Among the bacteria tested, probiotics have been identified as a good option to reduce the availability of aflatoxins *in vitro*. Additionally,

probiotic bacteria have shown numerous beneficial health effects, which make them even more suitable additives to food and feed [25, 31–33].

## 2. Biological importance of AFB1 in poultry

Poultry species are probably the most sensitive food-producing animals to AFB1 toxic effects, and small amounts of it severely damage animal health and the profitability of the productive system, which results in substantial annual economic losses to producers [6, 34–39].

However, there are also differences in terms of susceptibility to AFB1 among poultry species, which could be due to differences in hepatic metabolism of AFB1 in these species. According to comparative toxicological studies, ducklings and turkey poults are the most sensitive species to AFB1, followed by goslings and young pheasants with intermediate sensitivity, and finally, the chicks showed to have relative resistance to AFB1 injury [40]. Toxicity and carcinogenicity of AFB1 occur after its bioactivation by the cytochrome P450 (CYP450) mixed function oxidase system, resulting in a highly reactive AFB1 8,9-epoxide (AFBO), which forms covalent adducts with cellular macromolecules such as DNA, RNA, protein constituents, and some enzymes [41–44]. Since metabolic activation of AFB1 to AFBO by CYP450 is especially efficient in poultry species [45], they are extreme sensitivity to the toxic effects of AFB1. Another possible reason which may also explain the differences in susceptibility of poultry species is the variation in phase II biotransformation enzymes, such as glutathione S-transferase (GST), that catalyze a conjugation reaction of AFBO with endogenous glutathione (GSH). Although avian species are highly efficient in producing AFBO, they are not able to conjugate it effectively with GSH, which indicates that they have low GST activity [46, 47].

The most noticeable effect of AFB1 on poultry is the impair of all important productive parameters, including body weight gain, feed intake, feed conversion efficiency, pigmentation, processing yield, egg production, male and female reproductive performance, and an increased mortality [35, 48, 49]. These alterations in the productive parameters are the result of the physiological effects of AFB1 consumption, of which liver damage is the most notorious, characterized by its enlargement, pale yellow coloration, petechial hemorrhages and hematomas on the surface, usually accompanied with proliferation of biliary ducts and depletion of lymphoid organs [50–52]. However, for poultry industry AFB1 contamination and consumption are important because of its ability to decrease resistance to common infectious diseases, including parasitic, bacterial, and viral infections, due to depression of the humoral and cellular immune responses [53–57].

## 3. Microbiological control of AFB1

To date, many physical and chemical methods have been used to detoxify AFB1; however, only a few of these methods are in practical use, probably due to difficulties in complying with the FAO requirements: reduction of AFB1 without residual toxicity, guarantee of nutritional

values, and no modification of food or feed properties [58, 59]. Since cost-effective methods to detoxify mycotoxin-contaminated grains and foods are urgently needed to minimize potential losses to the farmer and toxicological hazards to the consumer [60], finding of new and suitable methods for AFB1 decontamination has become a primary need.

In this sense, microbiological control approach has taken strength in the field of research to control AFB1. Researchers have focused on biological treatments for detoxification mainly through two mechanisms: adsorption and degradation, both of which can be achieved by biological systems such as bacteria, yeasts, molds, actinomycetes, and algae [61].

Biological adsorption can occur either by attaching the AFB1 to the cell wall components of the microorganisms or by active internalization and accumulation. Also, dead microorganisms can absorb AFB1, and this phenomenon can be exploited in the creation of biofilters for fluid decontamination or probiotics to bind and remove the AFB1 from the intestine [62]. However, biological adsorption mechanism is naturally reversible, and AFB1 may be easily released, so that it is necessary to search for novel approaches to overcome these drawbacks, as for example the combination of mineral and biological adsorbents to improve their effectiveness [63].

On the other hand, microbiological biodegradation is performed by either extracellular or intracellular enzymes, so the degradation is generally permanent and irreversible which can alter, reduce, or completely eradicate AFB1 toxicity [30]. Nevertheless, modification of AFB1 structure can result in other molecules, such as aflatoxicol (AFL), also with potential toxic effects [64]. Thus, further knowledge is needed on the identification, quantity, and toxicity of degradation metabolites prior to the potential applications of biological treatments [59].

Microbiological control seems to be becoming one of the most promising approaches for AFB1 control; since the last four decades, the use of microorganisms is one of the well-known strategies for the management of AFB1 in foods and feeds. These methods of bioadsorption and biodegradation are being actively studied and can be a highly promising choice because they are efficient, specific, and environmentally friendly [65–68].

## 4. Use of probiotics to prevent AFB1 toxic effects in poultry

Microbiological control of AFB1 is still considered as a promising area in research; so recently, these methods have attracted researcher's attention due to their easy usage and affordable processes [69]. However, since the use of microorganisms is expected to be safe both for animal health and for the production of innocuous livestock products, there are still many microorganisms that cannot be directly employed in the food or feed directly. In the last decades, research to find microorganisms for AFB1 control has focused on testing, screening, and choosing those strains that have demonstrated their effectiveness not only to reduce or even suppress AFB1 toxicity but also to be Generally Regarded as Safe (GRAS) [70, 71].

There are several microorganisms that have been shown to be effective in preventing and controlling the toxic effects of AFB1; among them, probiotic bacterial strains are some of the

most studied, due largely to their GRAS character and because they have shown to have several potential applications against AFB1 both *in vitro* and *in vivo* [72–75]. Probiotics are living microorganisms that when administered in adequate amounts confer a health benefit to the host directly or indirectly through the maintenance of the microbial balance in their digestive tract [65, 76]. Several bacterial genera have been used as probiotics in livestock, including many species of *Bacillus*, *Bifidobacterium*, *Enterococcus*, *E. coli*, *Lactobacillus*, *Lactococcus*, and *Streptococcus*, although some species of molds and yeasts, such as *Aspergillus*, *Candida*, and *Saccharomyces*, have also been used [77, 78].

In poultry industry, probiotics have been reported to have a beneficial effect on performance, modulation of intestinal microflora and pathogen inhibition, intestinal histological changes, immunomodulation, certain hematobiochemical parameters, improving sensory characteristics of dressed meat, and promoting microbiological meat quality [79, 80]. In addition, probiotic bacteria may possess antimutagenic and anticarcinogenic activity. The mechanisms of these activities remain unclear; however, alteration of fecal bacterial enzyme activities associated with conversion of promutagens and procarcinogens to ultimate carcinogens and binding of dietary mutagens and carcinogens has been proposed [81].

Three possible mechanisms have been proposed by which probiotics can counteract the toxic effects of AFB1: (1) competing with aflatoxigenic mold strains for space, occupying the same ecological niche or using nutrients, and thus reducing AFB1 biosynthesis; (2) encouraging AFB1 metabolic degradation by enzymes, or (3) impeding its intestinal absorption by AFB1 binding onto the cell walls of the probiotics strains.

It has been suggested by *in vitro* studies that probiotics can inhibit AFB1 production through releasing metabolites to the media, such as organic acids, bacteriocins, and even hydrogen peroxide, which may interfere with AFB1 biosynthesis [82, 83]. Other alternative could be the reduction or inhibition in the growth of aflatoxigenic mold strains caused by a decrease in pH of the media and/or a nutrient competition of the culture media, which could also have contributed to the removal of AFB1 [84–87]. In **Figure 1**, it is shown how some probiotics from the lactobacilli strains can decrease both AFB1 production and the growth rate of an aflatoxigenic mold strain.

Although several bacterial strains have been used as biocompetitive agents of aflatoxigenic mold strains, some of them become inactive under extreme conditions of humidity and temperature, so that not all probiotic strains are ideal for this application. In this sense, studies on the prevention of AFB1 contamination using highly competitive non-toxigenic strains of *A. parasiticus* and *A. flavus* have shown certain advantages, which implies that these mold strains may be potentially useful as agents directed at competitively excluding toxigenic strains [88].

The other mechanism that the probiotics have to counteract the toxic effects of AFB1 is through its metabolic degradation or biodegradation, which can be defined as the degradation or enzymatic transformation of the mycotoxin to less or non-toxic compounds. Biodegradation using microorganisms or their enzymes is one of the most studied strategies for AFB1 management; this method has been actively studied and can be a highly promising choice, since it is efficient, specific, and environmentally friendly to reduce or eliminate the possible contaminations of

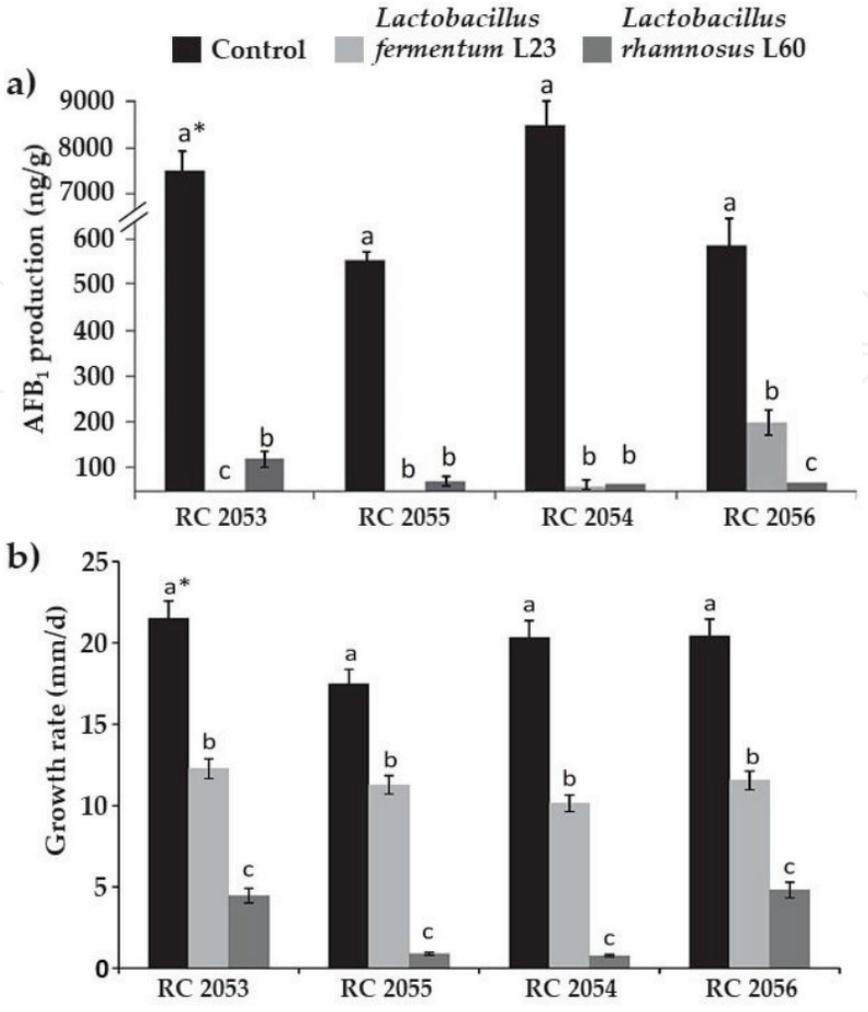


**Figure 1.** Effect of lactobacilli strains on: (a) the production of AFB1 and (b) the rate growth by *Aspergillus* section *Flavi*. Mean values based on quadruplicate data. * Mean with a letter in common is not significantly different according to Tukey's test ($p < 0.05$) (modified from [83]).

AFB1 under mild conditions, without using harmful chemicals and without significant impairment of the nutritive value or palatability of the detoxified food or feed [68].

Studies on microbial degradation of AFB1 involve the use of microbial catabolic pathways, which act on one of the two key sites influencing its toxicity and potency, shown in **Figure 2**. The first site is the double bond in position 1,2 of the furofuran ring [41], and the second reactive group is the lactone ring in the coumarin moiety [89]. AFB1 is usually detoxified to a less toxic compound by opening the lactone ring, altering the coumarin structure, but it can also occur by removing the double bond from furan ring when there is a scission on it [2, 90, 91]. It is known that opening the lactone ring abolishes or decreases the fluorescence spectrum of AFB1; however, the cleavage of the furofuran ring does not change its fluorescence properties [92].

For AFB1 metabolic degradation, several microbial isolates have been studied and reported with different levels of degradation capacities, including bacteria and fungi strains [94–101];

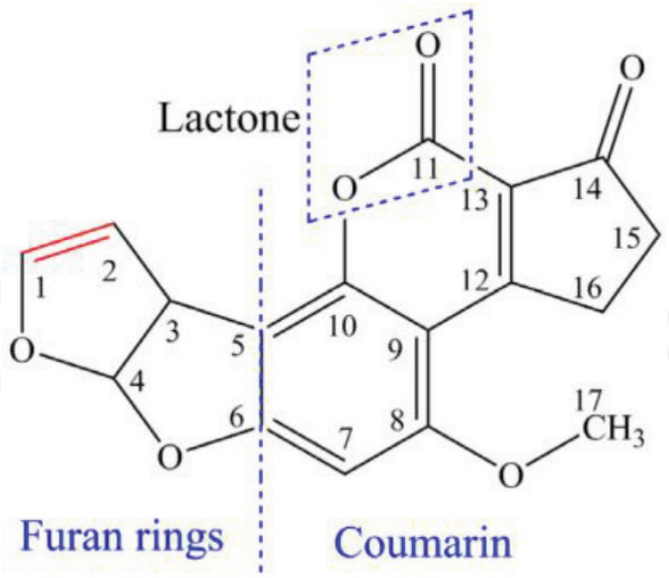


**Figure 2.** Chemical molecular structure of AFB1, showing the two key sites responsible of its toxicity (taken from [93]).

however, for the fungi species, limitations such as long degradation time, non-adaptability to typical food fermentations, and culture pigmentation reduced their potential application in AFB1 detoxification [97], besides the use of fungi species is not economical because of the extraction process and lengthy incubation time [102]. Moreover, some of these fungi strains with degradation potential may also produce AFB1 under varying conditions [103].

One of the first studies in this area was carried out in the 1960s, when it was evaluated the ability of about 1000 types of microorganisms to degrade aflatoxins [61]. Since then, many other studies have been done with several bacterial genera and strains; being the lactic acid bacteria (LAB), the most studied to detoxify AFB1; nevertheless, the ability of LABs to detoxify AFB1 has been attributed to their strong affinity and capacity to adsorb the toxin rather than for their degradation abilities [75, 81, 104–106].

AFB1 degrading activity has been found in other bacteria genera, such as *Mycobacterium fluoranthenivoran*, *Nocardia corynebacterioides* (formerly *Flavobacterium aurantiacum*), *Rhodococcus erythropolis*, *Stenotrophomonas maltophilia*, *Pseudomonas*, as well as *Bacillus licheniformis* and *B. subtilis* [70, 71, 97, 107–110], which have demonstrated that their biodegradation activity is from enzymatic nature. For example, *B. subtilis* JSW-1, a bacterium isolated from soil samples, is able to degrade almost 70% of AFB1 within 72 h, as shown in **Figure 3**, and its degradation activity was likely due to the extracellular enzymes [26]. In other study, biological degradation of AFB1 by *Rhodococcus erythropolis* was evaluated in liquid cultures, in which dramatic reduction of AFB1 was observed after 48 and 72 h of incubation with just 17 and 3–6% of residual AFB1, respectively [97]. The ability to effectively biotransform AFB1 by *Myxococcus fulvus* has also been demonstrated. This bacterial isolate from deer feces was able to biotransform AFB1 by 80.7% after 72 h [111].

Although probiotic bacterial strains are more desirable for AFB1 degradation, the use of whole cultures has less potential for large-scale utilization in the industry, so the use of fractions (cells

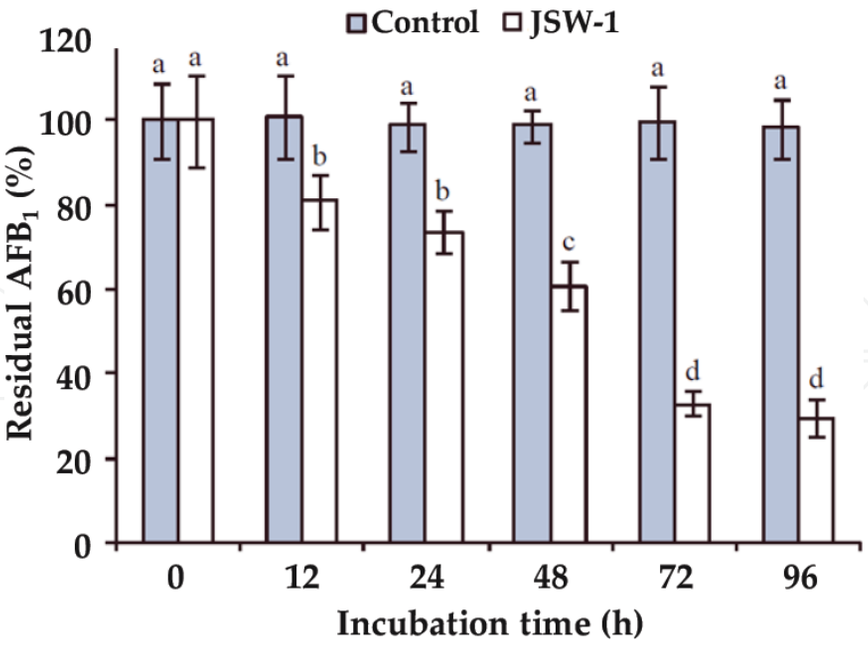


**Figure 3.** Time course of *in vitro* AFB1 degradation by *B. subtilis* JSW-1 at 30°C for 12, 24, 48, 72, and 96 h in the dark. The initial concentration of AFB1 was 2.5 mg/mL. Values represent the mean ± SD (n = 3). Values with different letters indicate significant differences ($p < 0.05$) among them (modified from [26]).

or lysates) may be convenient, since they are substrate specific, effective, environmentally friendly, and possess better utilization in the food and feed industry [112].

In literature, there are many studies of AFB1 biodegradation carried out in laboratory conditions with many probiotic strains; however, the information in livestock and poultry about the effect of probiotics on AFB1 detoxification is very limited, especially in poultry science. This is important because *in vitro* studies are not always good indicators of the *in vivo* responses, since there are physiological parameters, such as pH, peristaltic movements, and gastric and intestinal secretions affecting their *in vivo* behavior. This can be observed in studies carried out with the genus *Bacillus* spp., of which some strains have been identified as GRAS organisms with probiotic properties in humans and animals as direct fed microbials (DFM). In the *in vitro* study, 3 of 69 *Bacillus* spp. candidates, which were evaluated, showed ability to biodegrade AFB1, based on growth as well as reduction of fluorescence and area of clearance around each colony [70]. However, when the biodegradation potential of these selected *Bacillus* spp. was tested in broiler chickens, no beneficial performance effects were showed. In addition, no significant performance differences were observed when compared with their respective control diets [113]. Therefore, there is still missing research to evaluate the effect of AFB1 degrading probiotics on growth performance, digestibility, immune function, and toxic residues in tissues and excreta in livestock production animals.

The other mechanism that the probiotics have to counteract the toxic effects of AFB1 is through its physical adsorption, which is in fact the most commonly used technique for reducing exposure to AFB1 [114]. It has been demonstrated that AFB1 is absorbed into the enterocytes by passive diffusion so, after its oral ingestion, AFB1 is efficiently absorbed in the intestinal

tract, being the duodenum the major site of absorption [115]. If the AFB1 is physically linked to the probiotic microorganism, its bioavailability is decreased, and therefore AFB1 uptake and its access to systemic circulation are also diminished. Adsorption is a physical process, in which the cell wall of microorganism binds the toxin by non-covalent weak bonds and some electrostatic attraction. This interaction appears to occur predominantly with polysaccharides, peptidoglycan, and teichoic or lipoteichoic acids in the cell wall [116–118].

*In vitro* adsorption of AFB1 by probiotics has been described as a fast and reversible process, which is affected for many factors such as strain, toxin dose, temperature, pH, and microorganism concentration [72, 104, 118–120]. It has also been demonstrated that viability of some probiotic strain does not affect their absorption ability; thus, viable, heat-killed, and acid-killed cells respond in a similar manner [118, 121].

Several studies have been done in optimal laboratory conditions with several strains of probiotic microorganisms tested for their capacity to adsorb AFB1 and have been reported a wide range of genus, species, and strain-specific binding capacities [75, 81, 104, 116, 122–125], being the LABs and yeasts such as *Saccharomyces cerevisiae* those that have demonstrated the greatest ability to remove AFB1 by its adsorption [126]. Such is the case of *Lactobacillus rhamnosus* GG and *Lb. rhamnosus* LC-705, which have demonstrated to be very effective for removing AFB1, being able to remove up to 80% of the toxin instantly [104, 127]. On the other hand, yeasts have been reported to have similar mechanism as LAB in binding to AFB1 as a means of detoxification [68, 126], with studies that have shown that some strains of *S. cerevisiae* can adsorb up to 90% of AFB1 [123, 128].

There is strong evidence in literature that some specific probiotics can adsorb AFB1 *in vitro*, but only limited information is available on adsorption in poultry *in vivo*. These *in vivo* studies are really important since *in vitro* studies have shown that there are relevant physiological conditions that the microorganisms encounter during their passage through the gastrointestinal tract, such as pH, intestinal mucus, and presence of bile, which modify the AFB1 adsorption and the stability of the AFB1-microorganism complex, either positively or negatively [122]. Although not many probiotic strains have been tested *in vivo*, the studies that have been conducted in poultry showed good results, such as in the *in vivo* study using the chicken duodenum loop technique, in which probiotic strain GG of *L. rhamnosus* removed as high as 54% of the added AFB1 and reduced its intestinal adsorption by 73% [73]. In this study, there was a difference in adsorption capacity when these strains were incubated *in vitro*, being the reduction of AFB1 even higher *in vivo* when compared to its adsorption *in vitro*. *Bacillus* probiotics have also been proved to remove or reduce AFB1 adsorption in the gastrointestinal tract at *in vivo* and *in vitro* conditions, showing the positive impact of these bacteria in preventing the harmful effects of aflatoxin in poultry with regard to performance, serum biochemistry, and immune responses [69]. However, when the capacity of *Bacillus* and *Lactobacilli* strains to control the stressful effects caused for AFB1 on chickens was compared, the *Lactobacilli* abilities resulted to be higher. This study shows that these probiotics can control the toxicity of AFB on poultry by improving humoral and cellular immune function, serum biochemical parameters, the process of protein synthesis, and reducing the anti-nutritional effects of AFB1 [65]. In a recent study, the effect of lactic acid bacteria and HSCAS on

detoxification of AFB was evaluated in broiler chickens. The results showed that LAB or HSCAS supplementation improved the growth performance, digestibility, and immune function of birds, reducing deleterious effects and tissue residues of AFB1; however, the effect of LAB resulted to be more effective than HSCAS, which indicates a possible mechanism of biodegradation of the toxin by the probiotics [129].

## 5. Use of polymers to prevent AFB1 toxic effects in poultry

As it was mentioned in Section 1, an important approach to prevent aflatoxicosis in livestock and poultry is the addition of non-nutritional adsorbents in the diet to bind AFB1 in the gastrointestinal tract, reducing its bioavailability, which leads to a reduction of mycotoxin uptake as well as distribution to the blood and the target organs. These adsorbents are large molecular weight compounds that are able to bind the mycotoxin, forming a stable complex adsorbent-mycotoxin, which can pass through the gastrointestinal tract of the animals without dissociating the AFB1, to be eliminated via the feces [22].

The efficacy of adsorption appears to depend on the chemical structure of both the adsorbent, the mycotoxin, and the feed components. The physicochemical properties of the adsorbents such as total charge, charge distribution, size of the pores on the surface, surface area, iodine number, methylene blue index, and pH take on an important function in binding effectively. On the other hand, the properties of the adsorbed mycotoxins, like polarity, solubility, size, shape, charge distribution, and dissociation constants, also play a significant role. It has also been mentioned that the high fiber content of the feed substrate increased the mycotoxin affinity to adsorbent [17, 18].

Even though clay minerals and aluminosilicate materials have been tested and recognized for their ability to bind AFB1 successfully [130, 131], the main risk of using them in animal feed is that they can also adsorb some feed vitamins and minerals, decreasing their utilization by animals [132, 133]. Another risk is that clays can release toxic components or elements bound to them, as heavy metals or dioxins, which can be released in the intestine of animals and accumulated in animal organs [134, 135].

Facing the problems of the use of clay and aluminosilicate adsorbents, other types of binders have been investigated in the search for new adsorbent materials such as organic binders or biopolymers and synthetic polymers [17, 112]. Both kind of polymers are large molecules that are composed of many monomers, whose large molecular mass relative to a small molecule produces unique physical properties playing important roles in our society [24]. Just a few synthetic polymers have been evaluated and demonstrated to bind mycotoxins *in vitro* and *in vivo*, such as cholestyramine, divinylbenzene-styrene, polyvinylpyrrolidone (PVP), and its modification polyvinylpolypyrrolidone (PVPP) [7, 17, 18, 112]; nevertheless, from these polymers, only PVP and PVPP have been tested against AFB1 in poultry. *In vitro* studies indicate that PVPP can bind up to 50 mg/kg of AFB1 from feed. On the other hand, *in vivo* studies carried out in broiler chickens demonstrated that PVPP could have ameliorated some serum biochemical and hematological parameters, it might have meliorated the detrimental effects of AFB1 on the immune system, and that the pathological changes were markedly inhibited by

the administration of PVPP in the diet [136–139]. However, the cost of those polymers would be a limiting factor for practical applications.

Biopolymers are generally complex indigestible carbohydrates, non-toxic, biocompatible, and biodegradable, such as cellulose, cellulose, lignin, hemicellulose, glucomannans, peptidoglycans, and chitosan. They have been widely used as a promising biosorbents for the removal of various heavy metal ions and dyes [140], but recently cellulosic polymers and chitosan have been demonstrated to have ability to adsorb AFB1 [24, 141]. According to the *in vitro* results, both cellulosic polymers and chitosan were able to bind other important mycotoxins for poultry industry besides AFB1, which is a clear advantage over inorganic adsorbents since they are very effective in preventing aflatoxicosis, but their efficacy against mycotoxins such as zearalenone, ochratoxin, and trichothecenes is limited [17]. These biopolymers also pose multilayer porous structure filled with openings and channels that provide huge volume per sorbent surface unit, which is favorable in the adsorption process. Concerning to chitosan, different molecular weights, deacetylation degree, and cross-linked degree have to be tested for their AFB1 adsorption properties, because these characteristics might show different adsorptive capacity against this mycotoxin [24].

The results on the efficacy of polymers in sequestering mycotoxins are highly promising, although this field is still in its infancy and further research is needed. Furthermore, *in vivo* studies are needed to confirm the effectiveness of these materials against AFB1 toxic effects, since results in the past have indicated that there is great variability in the efficacy of adsorbing materials *in vivo*, even though the compounds may show potential adsorption capacity of the mycotoxin *in vitro* [22].

## Author details

Bruno Solis-Cruz[1], Daniel Hernandez-Patlan[1], Billy M. Hargis[2] and Guillermo Tellez[2]*

*Address all correspondence to: gtellez@uark.edu

1 National Autonomous University of Mexico-Superior Studies Faculty at Cuautitlan (UNAM-FESC), Multidisciplinary Research Unit L5 (Pharmaceutical Development Testing Laboratory), Cuautitlan Izcalli, Mexico

2 Department of Poultry Science, University of Arkansas, Fayetteville, AR, USA

## References

[1] Hussein HS, Brasel JM. Toxicity, metabolism, and impact of mycotoxins on humans and animals. Toxicology. 2001;**167**(2):101-134

[2] Adebo O, Njobeh P, Gbashi S, Nwinyi O, Mavumengwana V. Review on microbial degradation of aflatoxins. Critical Reviews in Food Science and Nutrition. 2017;**57**(15): 3208-3217

[3] Kabak B, Dobson ADW, Var I. Strategies to prevent mycotoxin contamination of food and animal feed: A review. Critical Reviews in Food Science and Nutrition. 2006;**46**(8): 593-619

[4] Bondy GS, Pestka JJ. Immunomodulation by fungal toxins. Journal of Toxicology and Environmental Health Part B: Critical Reviews. 2000;**3**(2):109-143

[5] Coulombe RA Jr. Biological action of mycotoxins. Journal of Dairy Science. 1993;**76**(3): 880-891

[6] Rawal S, Kim JE, Coulombe R. Aflatoxin B1 in poultry: Toxicology, metabolism and prevention. Research in Veterinary Science. 2010;**89**(3):325-331

[7] Jouany JP. Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. Animal Feed Science and Technology. 2007;**137**(3–4):342-362

[8] Commission CA, Commission CA, et al. Code of practice for the prevention and reduction of mycotoxin contamination of cereals, including annexes on ochratoxin a, zearalenone, fumonisins and trichothecenes. CAC/RCP. 2003;51-2003

[9] McKenzie KS, Sarr AB, Mayura K, Bailey RH, Miller DR, Rogers TD, et al. Oxidative degradation and detoxification of mycotoxins using a novel source of ozone. Food and Chemical Toxicology. 1997;**35**(8):807-820

[10] Goldblatt L, Dollear F. Review of prevention, elimination, and detoxification of aflatoxins. Pure and Applied Chemistry. 1977;**49**(11):1759-1764

[11] Ghosh M, Chhabra A, Atreja P, Chopra R. Effect of treating with propionic acid, sodium bisulfite and sodium hydroxide on the biosynthesis of aflatoxin on groundnut cake. Animal Feed Science and Technology. 1996;**60**(1):43-49

[12] Aziz NH, El-Zeany SA, LAA M. Influence of gamma-irradiation and maize lipids on the production of aflatoxin B1 by *Aspergillus flavus*. Die Nahrung. 2002;**46**(5):327-331

[13] Samarajeewa U, Sen A, Cohen M, Wei C. Detoxification of aflatoxins in foods and feeds by physical and chemical methods. Journal of Food Protection. International Association for Food Protection. 1990;**53**(6):489-501

[14] Pankaj S, Shi H, Keener KM. A review of novel physical and chemical decontamination technologies for aflatoxin in food. Trends in Food Science & Technology. 2017;**71**:73-83

[15] Kubena L, Harvey R, Bailey R, Buckley S, Rottinghaus G. Effects of a hydrated sodium calcium aluminosilicate (T-bind) on mycotoxicosis in young broiler chickens. Poultry Science. 1998;**77**(10):1502-1509

[16] Kong C, Shin SY, Kim BG. Evaluation of mycotoxin sequestering agents for aflatoxin and deoxynivalenol: An in vitro approach. SpringerPlus. 2014;**3**(1):346

[17] Huwig A, Freimund S, Käppeli O, Dutler H. Mycotoxin detoxification of animal feed by different adsorbents. Toxicology Letters. 2001;**122**(2):179-188

[18] Avantaggiato G, Solfrizzo M, Visconti A. Recent advances on the use of adsorbent materials for detoxification of *Fusarium mycotoxins*. Food Additives and Contaminants. 2005;**22**(4):379-388

[19] Dixon J, Kannewischer I, Arvide MT, Velazquez AB. Aflatoxin sequestration in animal feeds by quality-labeled smectite clays: An introductory plan. Applied Clay Science. 2008;**40**(1–4):201-208

[20] Jaynes W, Zartman R, Hudnall W. Aflatoxin B1 adsorption by clays from water and corn meal. Applied Clay Science. 2007;**36**(1–3):197-205

[21] Papaioannou D, Katsoulos P, Panousis N, Karatzias H. The role of natural and synthetic zeolites as feed additives on the prevention and/or the treatment of certain farm animal diseases: A review. Microporous and Mesoporous Materials. 2005;**84**(1–3):161-170

[22] Boudergue C, Burel C, Dragacci S, Favrot M-C, Fremy J-M, Massimi C, et al. Review of mycotoxin-detoxifying agents used as feed additives: Mode of action, efficacy and feed/food safety. EFSA Supporting Publications. 2009;**6**(9):1-192

[23] Kolosova A, Stroka J. Evaluation of the effect of mycotoxin binders in animal feed on the analytical performance of standardised methods for the determination of mycotoxins in feed. Food Additives & Contaminants: Part A. 2012;**29**(12):1959-1971

[24] Solis-Cruz B, Hernández-Patlán D, Beyssac E, Latorre JD, Hernandez-Velasco X, Merino-Guzman R, et al. Evaluation of chitosan and cellulosic polymers as binding adsorbent materials to prevent aflatoxin B1, fumonisin B1, ochratoxin, trichothecene, deoxynivalenol, and zearalenone mycotoxicoses through an in vitro gastrointestinal model for poultry. Polymers. 2017;**9**(10):529

[25] Zuo R, Chang J, Yin Q, Wang P, Yang Y, Wang X, et al. Effect of the combined probiotics with aflatoxin B1-degrading enzyme on aflatoxin detoxification, broiler production performance and hepatic enzyme gene expression. Food and Chemical Toxicology. 2013;**59**: 470-475

[26] Xia X, Zhang Y, Li M, Garba B, Zhang Q, Wang Y, et al. Isolation and characterization of a *Bacillus subtilis* strain with aflatoxin B1 biodegradation capability. Food Control. 2017; **75**:92-98

[27] Slizewska K, Smulikowska S. Detoxification of aflatoxin B1 and change in microflora pattern by probiotic in vitro fermentation of broiler feed. Journal of Animal and Feed Sciences. 2011;**20**:300-309

[28] Rawal S, Bauer MM, Mendoza KM, El-Nezami H, Hall JR, Kim JE, et al. Aflatoxicosis chemoprevention by probiotic Lactobacillus and lack of effect on the major histocompatibility complex. Research in veterinary science. 2014;**97**(2):274-281

[29] Halasz A, Lásztity R, Abonyi T, Bata Á. Decontamination of mycotoxin-containing food and feed by biodegradation. Food Reviews International. 2009;**25**(4):284-298

[30] Aliabadi MA, Alikhani FE, Mohammadi M, Darsanaki RK. Biological control of aflatoxins. European Journal of Experimental Biology. 2013;**3**(2):162-166

[31] Vinderola G, Ritieni A. Role of probiotics against mycotoxins and their deleterious effects. Journal of Food Research. 2014;**4**(1):10

[32] Tipu M, Saleem U, Rehman T, Aslam M, Muhammad K, Hussain K, et al. Protective role of *Lactobacillus acidophilus* against aflatoxin B1 induced immunosuppression. JAPS. Journal of Animal and Plant Sciences. 2015;**25**(6):1566-1571

[33] Kurhan S, Çakir I. DNA-bioprotective effects of lactic acid bacteria against aflatoxin B1. Current Research in Nutrition and Food Science Journal. 2016;**4**(Special Issue Nutrition in Conference October 2016):87-91

[34] Coulombe RA, Guarisco JA, Klein PJ, Hall JO. Chemoprevention of aflatoxicosis in poultry by dietary butylated hydroxytoluene. Animal Feed Science and Technology. 2005;**121**(1–2):217-225

[35] Dalvi R. An overview of aflatoxicosis of poultry: Its characteristics, prevention and reduction. Veterinary Research Communications. 1986;**10**(1):429-443

[36] Greco MV, Franchi ML, Rico Golba SL, Pardo AG, Pose GN. Mycotoxins and mycotoxigenic fungi in poultry feed for food-producing animals. The Scientific World Journal. 2014;**2014**:1-9

[37] Huff W, Kubena L, Harvey R, Corrier D, Mollenhauer H. Progression of aflatoxicosis in broiler chickens. Poultry Science. 1986;**65**(10):1891-1899

[38] Smith J, Hamilton P. Aflatoxicosis in the broiler chicken. Poultry science. 1970;**49**(1):207-215

[39] Mottet A, Tempio G. Global poultry production: Current state and future outlook and challenges. World's Poultry Science Journal. 2017;**73**(2):245-256

[40] Muller R, Carlson C, Semeniuk G, Harshfield G. The response of chicks, ducklings, goslings, pheasants and poults to graded levels of aflatoxins. Poultry Science. 1970; **49**(5):1346-1350

[41] Mishra HN, Das C. A review on biological control and metabolism of aflatoxin. Critical Reviews in Food Science and Nutrition. 2003;**43**(3):245-264

[42] Smela ME, Currier SS, Bailey EA, Essigmann JM. The chemistry and biology of aflatoxin B(1): From mutational spectrometry to carcinogenesis. Carcinogenesis. 2001;**22**(4):535-545

[43] Bbosa GS, Kitya D, Lubega A, Ogwal-Okeng J, Anokbonggo WW, Kyegombe DB. Review of the biological and health effects of aflatoxins on body organs and body systems. Aflatoxins-Recent Advances and Future Prospects. 2013;**12**:239-265

[44] McKean C, Tang L, Tang M, Billam M, Wang Z, Theodorakis CW, et al. Comparative acute and combinative toxicity of aflatoxin B1 and fumonisin B1 in animals and human cells. Food and Chemical Toxicology. 2006;**44**(6):868-876

[45] Lozano M, Diaz G. Microsomal and cytosolic biotransformation of aflatoxin B1 in four poultry species. British Poultry Science. 2006;**47**(6):734-41

[46] Gregorio MCD, Bordin K, Souto PCM de C, Corassin CH, CAF O. Comparative biotransformation of aflatoxin B1 in swine, domestic fowls, and humans. Toxin Reviews. 2015; **34**(3):142-150

[47] Diaz GJ, Murcia HW. Biotransformation of aflatoxin B1 and its relationship with the differential toxicological response to aflatoxin in commercial poultry species. Aflatoxins-Biochemistry and Molecular Biology. 2011;**1**:3-20

[48] Jones F, Hagler W, Hamilton P. Association of low levels of aflatoxin in feed with productivity losses in commercial broiler operations. Poultry Science. 1982;**61**(5):861-868

[49] Khlangwiset P, Shephard GS, Wu F. Aflatoxins and growth impairment: A review. Critical Reviews in Toxicology. 2011;**41**(9):740-755

[50] Moorthy A, Mahendar M, Rao P. Hepatopathology in experimental aflatoxicosis in chickens. Indian Journal of Animal Sciences (India). 1985;**55**:629-632

[51] Hussain Z, Khan MZ, Hassan Z. Production of aflatoxins from *Aspergillus flavus* and acute aflatoxicosis in young broiler chicks. Pakistan Journal of Agricultural Sciences. 2008;**45**(1):95-102

[52] Quezada T, Cuellar H, Jaramillo-Juarez F, Valdivia A, Reyes J. Effects of aflatoxin B1 on the liver and kidney of broiler chickens during development. Comparative Biochemistry and Physiology Part C: Pharmacology, Toxicology and Endocrinology. 2000;**125**(3):265-272

[53] Qureshi M, Brake J, Hamilton P, Hagler W Jr, Nesheim S. Dietary exposure of broiler breeders to aflatoxin results in immune dysfunction in progeny chicks. Poultry Science. 1998;**77**(6):812-819

[54] Ghosh R, Chauhan H, Jha G. Suppression of cell-mediated immunity by purified aflatoxin B1 in broiler chicks. Veterinary Immunology and Immunopathology. 1991;**28**(2): 165-172

[55] Azzam A, Gabal M. Interaction of aflatoxin in the feed and immunization against selected infectious diseases. I. Infectious bursal disease. Avian Pathology. 1997;**26**(2):317-325

[56] Gabal M, Azzam A. Interaction of aflatoxin in the feed and immunization against selected infectious diseases in poultry. II. Effect on one-day-old layer chicks simultaneously vaccinated against Newcastle disease, infectious bronchitis and infectious bursal disease. Avian Pathology. 1998;**27**(3):290-295

[57] Bryden WL. Mycotoxin contamination of the feed supply chain: Implications for animal productivity and feed security. Animal Feed Science and Technology. 2012;**173**(1–2):134-158

[58] Grenier B, Loureiro-Bracarense A-P, Leslie JF, Oswald IP. Physical and chemical methods for mycotoxin decontamination in maize. Mycotoxin Reduct Grain Chains. 2014;**9**:116-129

[59] Verheecke C, Liboz T, Mathieu F. Microbial degradation of aflatoxin B1: Current status and future advances. International Journal of Food Microbiology. 2016;**237**:1-9

[60] Young JC, Zhou T, Yu H, Zhu H, Gong J. Degradation of trichothecene mycotoxins by chicken intestinal microbes. Food and Chemical Toxicology. 2007;**45**(1):136-143

[61] Ciegler A, Lillehoj E, Peterson R, Hall H. Microbial detoxification of aflatoxin. Applied Microbiology. 1966;**14**(6):934-939

[62] Magan N, Olsen M. Mycotoxins in Food: Detection and Control. Cambridge, UK: Woodhead Publishing Ltd; 2004

[63] Poloni V, Dogi C, Pereyra CM, Fernández Juri MG, Köhler P, Rosa CA, et al. Potentiation of the effect of a commercial animal feed additive mixed with different probiotic yeast strains on the adsorption of aflatoxin B1. Food Additives & Contaminants: Part A. 2015; **32**(6):970-976

[64] Karabulut S, Paytakov G, Leszczynski J. Reduction of aflatoxin B1 to aflatoxicol: A comprehensive DFT study provides clues to its toxicity. Journal of the Science of Food and Agriculture. 2014;**94**(15):3134-3140

[65] Barati M, Chamani M, Mousavi SN, Hoseini SA, Taj Abadi Ebrahimi M. Effects of biological and mineral compounds in aflatoxin-contaminated diets on blood parameters and immune response of broiler chickens. Journal of Applied Animal Research. 2018; **46**(1):707-713

[66] Gacem MA, El Hadj-Khelil AO. Toxicology, biosynthesis, bio-control of aflatoxin and new methods of detection. Asian Pacific Journal of Tropical Biomedicine. 2016;**6**(9):808-814

[67] Ji C, Fan Y, Zhao L. Review on biological degradation of mycotoxins. Animal Nutrition. 2016;**2**(3):127-133

[68] Wu Q, Jezkova A, Yuan Z, Pavlikova L, Dohnal V, Kuca K. Biological degradation of aflatoxins. Drug Metabolism Reviews. 2009;**41**(1):1-7

[69] Bagherzadeh KF, Karimi TM, Allameh A, Shariatmadari F. A novel aflatoxin-binding Bacillus probiotic: Performance, serum biochemistry, and immunological parameters in Japanese quail. Poultry Science. 2012;**91**(8):1846

[70] Galarza-Seeber R, Latorre JD, Hernandez-Velasco X, Wolfenden AD, Bielke LR, Menconi A, et al. Isolation, screening and identification of Bacillus spp. as direct-fed microbial candidates for aflatoxin B1 biodegradation. Asian Pacific. Journal of Tropical Biomedicine. 2015;**5**(9):702-706

[71] Gao X, Ma Q, Zhao L, Lei Y, Shan Y, Ji C. Isolation of *Bacillus subtilis*: Screening for aflatoxins B1, M1, and G1 detoxification. European Food Research and Technology. 2011; **232**(6):957

[72] Bueno DJ, Casale CH, Pizzolitto RP, Salvano MA, Oliver G. Physical adsorption of aflatoxin B1 by lactic acid bacteria and *Saccharomyces cerevisiae*: A theoretical model. Journal of Food Protection. International Association for Food Protection. 2007;**70**(9):2148-2154

[73] El-Nezami H, Mykkänen H, Kankaanpää P, Salminen S, Ahokas J. Ability of Lactobacillus and Propionibacterium strains to remove aflatoxin B, from the chicken duodenum. Journal of Food Protection. 2000;**63**(4):549

[74] Hamidi A, Mirnejad R, Yahaghi E, Behnod V, Mirhosseini A, Amani S, et al. The aflatoxin B1 isolating potential of two lactic acid bacteria. Asian Pacific Journal of Tropical Biomedicine. 2013;**3**(9):732-736

[75] Haskard CA, El-Nezami HS, Kankaanpää PE, Salminen S, Ahokas JT. Surface binding of aflatoxin B1 by lactic acid bacteria. Applied and Environmental Microbiology. 2001;**67**(7): 3086-3091

[76] Nada S, Amra H, Deabes M, Omara E. *Saccharomyces cerevisiae* and probiotic bacteria potentially inhibit aflatoxins production in vitro and in vivo studies. International Journal of Toxicology. 2010;**8**(1):32

[77] Fijan S. Microorganisms with claimed probiotic properties: An overview of recent literature. International Journal of Environmental Research and Public Health. 2014;**11**(5):4745-4767

[78] Patterson J, Burkholder K. Application of prebiotics and probiotics in poultry production. Poultry Science. 2003;**82**(4):627-631

[79] Park YH, Hamidon F, Rajangan C, Soh KP, Gan CY, Lim TS, et al. Application of probiotics for the production of safe and high-quality poultry meat. Korean Journal for Food Science of Animal Resources. 2016;**36**(5):567

[80] Kabir S. The role of probiotics in the poultry industry. International Journal of Molecular Sciences. 2009;**10**(8):3531-3546

[81] Peltonen KD, El-Nezami HS, Salminen SJ, Ahokas JT. Binding of aflatoxin B1 by probiotic bacteria. Journal of the Science of Food and Agriculture. 2000;**80**(13):1942-1945

[82] Gourama H, Bullerman LB. Inhibition of growth and aflatoxin production of *Aspergillus flavus* by Lactobacillus species. Journal of Food Protection. International Association for Food Protection. 1995;**58**(11):1249-1256

[83] Gerbaldo GA, Barberis C, Pascual L, Dalcero A, Barberis L. Antifungal activity of two Lactobacillus strains with potential probiotic properties. FEMS Microbiology Letters. 2012;**332**(1):27-33

[84] Bueno DJ, Silva JO, Oliver G, Gonzalez SN. *Lactobacillus casei* CRL 431 and *Lactobacillus rhamnosus* CRL 1224 as biological controls for *Aspergillus flavus* strains. Journal of Food Protection. 2006;**69**(10):2544-2548

[85] Onilude A, Fagade O, Bello M, Fadahunsi I. Inhibition of aflatoxin-producing aspergilli by lactic acid bacteria isolates from indigenously fermented cereal gruels. African Journal of Biotechnology. 2005;**4**(12):1404-1408

[86] Reddy K, Raghavender C, Reddy B, Salleh B. Biological control of *Aspergillus flavus* growth and subsequent aflatoxin B 1 production in sorghum grains. African Journal of Biotechnology. 2010;**9**(27):4247-4250

[87] Prathivadi Bayankaram P, Sellamuthu PS. Antifungal and anti-aflatoxigenic effect of probiotics against *Aspergillus flavus* and *Aspergillus parasiticus*. Toxin Reviews. 2016;**35** (1–2):10-15

[88] Cole RJ, Cotty PJ. Biocontrol of aflatoxin production by using biocompetitive agents. In: A Perspective on Aflatoxin in Field Crops and Animal Food Products in the United States: A Symposium. 1990. pp. 62-66

[89] Lee L, Dunn J, DeLucca A, Ciegler A. Role of lactone ring of aflatoxin B 1 in toxicity and mutagenicity. Experientia. 1981;**37**(1):16-17

[90] Samuel SM, Aiko V, Panda P, Mehta A. Aflatoxin B-1 occurrence, biosynthesis and its degradation. Journal of Pure and Applied Microbiology. 2013;**7**(2):965-971

[91] Mokoena M, Chelule P, Gqaleni N. The toxicity and decreased concentration of aflatoxin B1 in natural lactic acid fermented maize meal. Journal of Applied Microbiology. 2006; **100**(4):773-777

[92] Cao H, Liu D, Mo X, Xie C, Yao D. A fungal enzyme with the ability of aflatoxin B1 conversion: Purification and ESI-MS/MS identification. Microbiological Research. 2011; **166**(6):475-483

[93] Mao J, He B, Zhang L, Li P, Zhang Q, Ding X, et al. A structure identification and toxicity assessment of the degradation products of aflatoxin B1 in peanut oil under UV irradiation. Toxins. 2016;**8**(11):332

[94] Ghazvini RD, Kouhsari E, Zibafar E, Hashemi SJ, Amini A, Niknejad F. Antifungal activity and aflatoxin degradation of *Bifidobacterium bifidum* and *Lactobacillus fermentum* against toxigenic *Aspergillus parasiticus*. The Open Microbiology Journal. 2016;**10**:197

[95] Farzaneh M, Shi Z-Q, Ghassempour A, Sedaghat N, Ahmadzadeh M, Mirabolfathy M, et al. Aflatoxin B1 degradation by *Bacillus subtilis* UTBSP1 isolated from pistachio nuts of Iran. Food Control. 2012;**23**(1):100-106

[96] Taylor MC, Jackson CJ, Tattersall DB, French N, Peat TS, Newman J, et al. Identification and characterization of two families of F420H2-dependent reductases from Mycobacteria that catalyse aflatoxin degradation. Molecular Microbiology. 2010;**78**(3): 561-575

[97] Teniola O, Addo P, Brost I, Färber P, Jany K-D, Alberts J, et al. Degradation of aflatoxin B1 by cell-free extracts of *Rhodococcus erythropolis* and *Mycobacterium fluoranthenivorans* sp. nov. DSM44556T. International Journal of Food Microbiology. 2005;**105**(2):111-117

[98] Adebo OA, Njobeh PB, Mavumengwana V. Degradation and detoxification of AFB1 by *Staphylococcus warneri*, *Sporosarcina* sp. and *Lysinibacillus fusiformis*. Food Control. 2016; **68**:92-96

[99] Adebo OA, Njobeh PB, Sidu S, Tlou MG, Mavumengwana V. Aflatoxin B1 degradation by liquid cultures and lysates of three bacterial strains. International Journal of Food Microbiology. 2016;**233**:11-19

[100] Mann R, Rehm H-J. Degradation products from aflatoxin B1 by *Corynebacterium rubrum*, *Aspergillus niger*, *Trichoderma viride* and *Mucor ambiguus*. European Journal of applied Microbiology and Biotechnology. 1976;**2**(4):297-306

[101] Tsubouchi H, Yamamoto K, Hisada K, Sakabe Y. Degradation of aflatoxins by *Aspergillus niger* and aflatoxin non-producing *Aspergillus flavus*. Journal of the Food Hygienic Society of Japan (Japan). 1983;**24**(2):113-119

[102] Eshelli M, Harvey L, Edrada-Ebel R, McNeil B. Metabolomics of the bio-degradation process of aflatoxin B1 by actinomycetes at an initial pH of 6.0. Toxins. 2015;**7**(2):439-456

[103] Huynh V, Gerdes R, Lloyd A. Synthesis and degradation of aflatoxins by *Aspergillus parasiticus*. II. Comparative toxicity and mutagenicity of aflatoxin B1 and it autolytic breakdown products. Australian Journal of Biological Sciences. 1984;**37**(3):123-130

[104] El-Nezami H, Kankaanpaa P, Salminen S, Ahokas J. Ability of dairy strains of lactic acid bacteria to bind a common food carcinogen, aflatoxin B1. Food and Chemical Toxicology. 1998;**36**(4):321-326

[105] Oatley JT, Rarick MD, Ji GE, Linz JE. Binding of aflatoxin B1 to bifidobacteria in vitro. Journal of Food Protection. 2000;**63**(8):1133-1136

[106] Peltonen K, El-Nezami H, Haskard C, Ahokas J, Salminen S. Aflatoxin B1 binding by dairy strains of lactic acid bacteria and bifidobacteria. Journal of Dairy Science. 2001; **84**(10):2152-2156

[107] Guan S, Ji C, Zhou T, Li J, Ma Q, Niu T. Aflatoxin B1 degradation by *Stenotrophomonas maltophilia* and other microbes selected using coumarin medium, International Journal of Molecular Sciences. 2008;**9**(8):1489-1503

[108] Hormisch D, Brost I, Kohring G-W, Giffhorn F, Kroppenstedt R, Stackebradt E, et al. *Mycobacterium fluoranthenivorans* sp. nov., a fluoranthene and aflatoxin B1 degrading bacterium from contaminated soil of a former coal gas plant. Systematic and Applied Microbiology. 2004;**27**(6):653-660

[109] Smiley R, Draughon F. Preliminary evidence that degradation of aflatoxin B1 by *Flavobacterium aurantiacum* is enzymatic. Journal of Food Protection. 2000;**63**(3):415-418

[110] Tejada-Castaneda Z, Avila-Gonzalez E, Casaubon-Huguenin M, Cervantes-Olivares R, Vásquez-Peláez C, Hernandez-Baumgarten E, et al. Biodetoxification of aflatoxin-contaminated chick feed. Poultry Science. 2008;**87**(8):1569-1576

[111] Guan S, Zhao L, Ma Q, Zhou T, Wang N, Hu X, et al. In vitro efficacy of *Myxococcus fulvus* ANSM068 to biotransform aflatoxin B1. International Journal of Molecular Sciences. 2010;**11**(10):4063-4079

[112] Kolosova A, Stroka J. Substances for reduction of the contamination of feed by mycotoxins: A review. World Mycotoxin Journal. 2011;**4**(3):225-256

[113] Galarza-Seeber R, Latorre J, Wolfenden A, Hernandez-Velasco X, Merino-Guzman R, Ledoux D, et al. Evaluation of Bacillus spp. as direct fed microbial (DFM) candidates for

aflatoxin B1 biodegradation in broiler chickens. International Journal of Probiotics & Prebiotics. 2016;**11**(1):29

[114] Hathout AS, Aly SE. Biological detoxification of mycotoxins: A review. Annals of Microbiology. 2014;**64**(3):905-919

[115] Hsieh DP, Wong JJ. Pharmacokinetics and excretion of aflatoxins. In: The Toxicology of Aflatoxins: Human Health, Veterinary, and Agricultural Significance. San Diego, CA: Academic Press. pp. 73-88

[116] Damayanti E, Istiqomah L, Saragih J, Purwoko T, et al. Characterization of lactic acid bacteria as poultry probiotic candidates with aflatoxin B1 binding activities. IOP Conference Series: Earth and Environmental Science. 2017. p. 012030

[117] Gratz S, Mykkänen H, El-Nezami H. Aflatoxin B1 binding by a mixture of Lactobacillus and Propionibacterium: In vitro versus ex vivo. Journal of Food Protection. 2005;**68**(11): 2470-2474

[118] Haskard C, Binnion C, Ahokas J. Factors affecting the sequestration of aflatoxin by *Lactobacillus rhamnosus* strain GG. Chemico-biological Interactions. 2000;**128**(1):39-49

[119] Kankaanpää P, Tuomola E, El-Nezami H, Ahokas J, Salminen S, et al. Binding of aflatoxin B1 alters the adhesion properties of *Lactobacillus rhamnosus* strain GG in a Caco-2 model. Journal of Food Protection. 2000;**63**(3):412-414

[120] El Khoury A, Atoui A, Yaghi J. Analysis of aflatoxin M1 in milk and yogurt and AFM1 reduction by lactic acid bacteria used in Lebanese industry. Food Control. 2011;**22**(10): 1695-1699

[121] El-Nezami H, Kankaanpää P, Salminen S, Ahokas J. Physicochemical alterations enhance the ability of dairy strains of lactic acid bacteria to remove aflatoxin from contaminated media. Journal of Food Protection. 1998;**61**(4):466-468

[122] Hernandez-Mendoza A, Garcia H, Steele J. Screening of *Lactobacillus casei* strains for their ability to bind aflatoxin B1. Food and Chemical Toxicology. 2009;**47**(6):1064-1068

[123] Gonçalves BL, Rosim RE, de Oliveira CAF, Corassin CH. The in vitro ability of different *Saccharomyces cerevisiae*-based products to bind aflatoxin B1. Food Control. 2015;**47**:298-300

[124] Fazeli MR, Hajimohammadali M, Moshkani A, Samadi N, Jamalifar H, Khoshayand MR, et al. Aflatoxin B1 binding capacity of autochthonous strains of lactic acid bacteria. Journal of Food Protection. 2009;**72**(1):189-192

[125] Bagherzadeh Kasmani F, Torshizi K, Allameh A, Shariatmadari F. Aflatoxin detoxification potential of lactic acid bacteria isolated from Iranian poultry. Iranian Journal of Veterinary Research. 2012;**13**(2):152-155

[126] Shetty PH, Jespersen L. *Saccharomyces cerevisiae* and lactic acid bacteria as potential mycotoxin decontaminating agents. Trends in Food Science and Technology. 2006;**17**(2):48-55

[127] Turbic A, Ahokas J, Haskard C. Selective in vitro binding of dietary mutagens, individually or in combination, by lactic acid bacteria. Food Additives and Contaminants. 2002; **19**(2):144-152

[128] Shetty PH, Hald B, Jespersen L. Surface binding of aflatoxin B 1 by *Saccharomyces cerevisiae* strains with potential decontaminating abilities in indigenous fermented foods. International Journal of Food Microbiology. 2007;**113**(1):41-46

[129] Liu N, Wang J, Deng Q, Gu K, Wang J. Detoxification of aflatoxin B1 by lactic acid bacteria and hydrated sodium calcium aluminosilicate in broiler chickens. Livestock Science. 2018;**208**:28-32

[130] Pasha T, Farooq M, Khattak F, Jabbar M, Khan A. Effectiveness of sodium bentonite and two commercial products as aflatoxin absorbents in diets for broiler chickens. Animal Feed Science and Technology. 2007;**132**(1–2):103-110

[131] Phillips TD, Kubena LF, Harvey RB, Taylor DR, Heidelbaugh ND. Hydrated sodium calcium aluminosilicate: A high affinity sorbent for aflatoxin. Poultry Science. 1988;**67**(2): 243-247

[132] Chung T, Ekdman JR, Baker D. Hydrated sodium calcium aluminosilicate: Effects on zinc, manganese, vitamin A, and riboflavin utilization. Poultry Science. 1990;**69**(8):1364-1370

[133] Moshtaghian J, Parsons C, Leeper R, Harrison P, Koelkebeck K. Effect of sodium aluminosilicate on phosphorus utilization by chicks and laying hens. Poultry Science. 1991; **70**(4):955-962

[134] Abad E, Llerena JJ, Sauló J, Caixach J, Rivera J. Comprehensive study on dioxin contents in binder and anti-caking agent feed additives. Chemosphere. 2002;**46**(9–10):1417-1421

[135] Trckova M, Matlova L, Dvorska L, et al. Kaolin, bentonite, and zeolites as feed supplements for animals: Health advantages and risks. A review. Veterinarni Medicina-UZPI (Czech Republic). 2004;**49**:389-399

[136] Celik I, Oğuz H, Demet O, Dönmez HH, Boydak M, Sur E. Efficacy of polyvinylpolypyrrolidone in reducing the immunotoxicity of aflatoxin in growing broilers. British Poultry Science. 2000;**41**(4):430-439

[137] Kececi T, Oguz H, Kurtoglu V, Demet O. Effects of polyvinylpolypyrrolidone, synthetic zeolite and bentonite on serum biochemical and haematological characters of broiler chickens during aflatoxicosis. British Poultry Science. 1998;**39**(3):452-458

[138] Kiran M, Demet Ö, Ortatath M, Oğuz H. The preventive effect of polyvinylpolypyrrolidone on aflatoxicosis in broilers. Avian Pathology. 1998;**27**(3):250-255

[139] Thalib A. Detoxification of aflatoxin in feed with a binder of polyvinylpolypyrrolidone. Jurnal Ilmiah Penelitian Ternak Klepu (Indonesia). 1995;**1**:43-48

[140] Hokkanen S, Bhatnagar A, Sillanpää M. A review on modification methods to cellulose-based adsorbents to improve adsorption capacity. Water research. 2016;**91**:156-173

[141] Zhao Z, Liu N, Yang L, Wang J, Song S, Nie D, et al. Cross-linked chitosan polymers as generic adsorbents for simultaneous adsorption of multiple mycotoxins. Food Control. 2015;**57**:362-369

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