Chapter

Decontamination of Aflatoxin B1

Qian Yang

Abstract

Aflatoxins are a class of highly toxic carcinogenic mycotoxins by food contaminant *Aspergillus* fungi: *Aspergillus flavus* and *Aspergillus parasiticus*. Aflatoxins are classified into four compounds: aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1), and aflatoxin G2 (AFG2), while AFB1 is the most potent carcinogenic agent associated with hepatocellular carcinoma (HCC). *Aspergillus* fungi is ubiquitously found in the soil and contaminates the crops such as maize, groundnuts, rice, and so on. Prevention of aflatoxin contamination, detection and degradation of *Aspergillus* fungi contamination, and the concentration of AFB1 in the foodstuffs are of the primary task to prevent health problems from aflatoxin. Here, the different ways are summarized to degrade or decontaminate the aflatoxins available with the foods. Traditional decontamination of aflatoxin includes physical (heat and irradiation), biological, and chemical treatments. However, these traditional aflatoxin decontamination technologies are not enough to remove the aflatoxin from the foods. Recently, some novel processing approached have been explored to achieve full degradation of the aflatoxin available with the foodstuffs, like microwave heating, gamma and electron beam irradiation, pulsed light, electrolyzed water, cold plasma, and so on. Decontamination mechanism, degradation efficiency, advantages, and limitations of these new technologies shall be discussed herein.

Keywords: aflatoxin B1, detoxification, toxicity, decontamination, biological degradation

1. Introduction

Mycotoxins are low-molecular-weight nature products as secondary metabolites by filamentous fungi or mold, which display overlapping toxicities to invertebrates, plants, and microorganism. The term mycotoxin was coined in 1962 in the aftermath of unusual veterinary crisis close to London, England, where nearly 100,000 turkey poultry died. It came out that was linked to peanut meal contaminated by aflatoxins. Now, more than 300 mycotoxins are found; however, only very few mycotoxins caught scientists' eyeball, which have been proven to be carcinogenic and toxic.

Human food can be contaminated with mycotoxins during storage. One of the principal classes of highly toxic carcinogenic mycotoxins is the metabolite of *Aspergillus flavus* and *Aspergillus parasiticus* aflatoxins [1]. Aflatoxins are classified into such four compounds as aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1), and aflatoxin G2 (AFG2) based on their fluorescence under UV light (blue or green), and in the milk it was aflatoxin M1 (AFM1) and aflatoxin M2 (AFM2) which are the metabolites of AFB1 and AFB2, respectively [2–4]. The toxic effect

upon the living organisms of aflatoxin decreases in an order B1, G1, B2, and G2 [5]. AFB1 is the most potent carcinogenic agent associated with hepatocellular carcinoma (HCC), one of the most lethal and common cancers in the world, especially in Asia and Africa. The mycotoxin aflatoxin B1 (AFB1), the most notorious liver carcinogen, has been proven to be genotoxic. Epidemiological studies have shown that chronic exposure to aflatoxin B1 in the diet is one of the important factors in the etiology of liver cancer in experimental animal models, including rats and rainbow trouts [6].

Discovery of practical and economical procedure to prevent aflatoxin contamination, detect and degrade *Aspergillus* fungi contamination, and lower the concentration of AFB1 in the foodstuffs is of the primary task to prevent or eliminate the aflatoxin risk.

Aspergillus fungi is ubiquitously found in the soil and contaminates the crops in the field and during storage, such as maize, groundnuts, rice, and so on. Mycotoxins are the low-molecular weight nature products as the secondary metabolites of molds that make the industrial factories lose money resulting from condemnation of contaminated crops. They have been detected in various commodities such as maize, wheat, barley, oilseed, peanut, and beverages made from contaminated grains and other foods. Thus direct exposure to aflatoxin-contaminated commodities may impose a great risk to the consumers.

Unquestionably, prevention is the best method to control mycotoxin contamination. As the result of the high prevalence of AFB1 in the foods, many strategies are being developed to prevent or remove AFB1 contamination. In general, two ways are available to prevent AFB1 from contamination: pre- and postharvest treatment. Pre-harvest techniques are the first barrier to prevent mycotoxin contamination in all kinds of grains or feed. Pre-harvest techniques include the use of genetically altered crops that are resistant to *Aspergillus* infection and environmental stressors, pesticide usage, crop rotation, and timing of planting. Postharvest strategies include physical methods (proper drying, packaging, storage, preservative/pesticide usage). These strategies play the roles as the preventative measures to reduce the chance and the amount of contaminations that are introduced to the crops. However, these strategies fail to prevent the contaminations fully and effectively; thus some postharvest techniques are being developed to degrade or reduce AFB1 contamination. In this review, we aimed to investigate AFB1 decontamination methods, including several traditional strategies, and update some new methods.

2. Physical treatment of aflatoxin removal and detoxification

2.1 Cleaning and segregation of aflatoxins

The first option to reduce aflatoxin is to physically separate the mold-contaminated grains or feed (kernel, seeds, and nuts) from the intact and apparently uncontaminated product. The physical procedure is the safe way not to alter the products significantly, including cleaning, sorting, and handpicking [7]. In the developing countries or economically underdeveloped areas, the people have little or no access to do mycotoxin testing of their foods. Hand sorting is still the primary method to remove AFB1. As compared with other methods including flotation and dehulling of the grains, hand sorting of maize grains boasts <6% of AFB1 and <5% of fumonisin B1. Thus hand sorting of maize grains is being recommended as a last line of defense against mycotoxin exposure among subsistence consumers [8].

2.2 Heating treatment

Aflatoxins are well known to be stable at high temperature. In modern food/feed manufacturing technology, heating treatment is always used to degrade mycotoxins to a certain extent during the processing. Recent studies have shown that AFB1 could be significantly removed at high humidity [9–12]. However, several possible facts are associated with the prediction of the extent of mycotoxin reduction, such as initial mycotoxin concentration, the extent of binding between mycotoxin and food or feed products, heat penetration, moisture content, and processing conditions. Nonetheless, heat treatment to partially reduce the mycotoxin concentration in the food/feed stuffs is still the feasible physiological method because heating technique can be carried out easily at low cost. Extrusion cooking is broadly used in the field of food industry, which is an efficient process in food/feed process. High temperature with short-time extrusion is commonly used in the industry [5].

2.3 Microwave heat treatment

Perez-Flores et al. [13] found that aflatoxin content could be significantly reduced by microwave thermal-alkaline treatment in the traditional Mexico food tortillas. Using extract acidification methods to mimic human stomach digestion procedure to quantify AFB1 concentration, the results indicated that the aflatoxin reduction was almost permanent. However, this thermal-alkaline treatment for tortilla-making could only remove most of AFB; thus some AFB would be left in the food.

2.4 Irradiation treatment

Another most commonly reported physical decontamination technology is γ radiation. The use of γ radiation has been reported on some kinds of food substrates including groundnuts, grains, palm juice, soybean, and animal feed. Irradiating the food products with a γ-ray source is moderately effective with an average percent reduction of 65% at high irradiation dose [14–20]. Gamma irradiation is a promising method to improve the safety and economy of moderately fungi-damaged feedstuffs.

2.5 Electrolyzed water (EOW) treatment

Electrolyzed water treatment is a sort of newly developing skill to treat AFB1-contaminated foods or feeds. The AFB1 was markedly reduced when treated with EOW, particularly with neutral electrolyzed oxidizing water (NEW). The levels of OH that exist in EOW could be the important reason that leads to significant fungicidal efficiencies against *A. flavus*. After 15 min treatment with EOW, AFB1 was mostly degraded [21, 22]. Another study performed by Fan et al. [23] showed that alkaline electrolyzed water (AIEW) could remove AFB1, and its best working condition was at pH 12.2. When 10 ml AIEW with pH 12.2 was added into 5.0 g peanut oil or olive oil, followed by oscillation for 5 min at 20°C, AFB1 removal could reach nearly 100%.

2.6 Pulsed light technology to remove AFB1

Pulsed light has been demonstrated to be an effective decontamination technique capable of destroying bacteria, viruses, fungi, and spores at the surface of food and material [24]. The work of Moreau et al. [25] provides the first

demonstration of a nonthermal technology allowing mycotoxin destruction and inactivation of their mutagenic activity. They evaluated that the effectiveness of the pulsed light technology for the degradation of mycotoxins. AFB1 was destroyed around 98% by eight flashes of pulsed light.

3. Chemical treatment to degradation of aflatoxins

The use of chemical additives upon the contaminated foods has been one popular method, especially the additives themselves would be used in the foods.

3.1 Ammonia decontamination treatment

Ammonization of maize, rice, barley, peanuts, and cottonseeds to alter the toxic and carcinogenic effects of aflatoxin contamination has been intensely researched by the scientists from government agencies and universities in the world. Several studies have shown that aflatoxin B1 levels were reduced effectively and permanently by 1 hour ammonia treatment. Treatment with either NH_4OH at high temperature or gaseous NH_3 can effectively reduce aflatoxin B1 content sometimes reaching above 99%. But at lower temperature, for example, at 25°C, AF1B level could not be reduced very well. Their study revealed that the moisture level of the product and holding temperature were the crucial factors to have influence upon the efficacy of aflatoxin decontamination [26–29]. The degradation of AFB1 is ammonization of aflatoxin (AFD1), which has been shown to be far less mutagenic than AFB1.

3.2 Hydrochloric acid (HCl) treatment

Aly and Hathout [30] investigated the effect of hydrochloric acid on AFB1 degradation in contaminated corn gluten under different HCl concentrations. The effect of AFB1 degradation by HCl is in a temperature-, HCl concentration-, and time-dependent manner. During the wet milling process, treating with 1 mol/L HCl at 100°C resulted in degradation of AFB1 by 27.6% after 4 hours and reached to 42.5% after 8 hours. When concentration of HCl increased, the degradation of AFB1 increased, and it will completely degrade AFB in the presence of 5 mol/L HCl after 4 hour at 110°C.

3.3 Lactic acid and citric acid treatment

Previous studies have shown that some organic acids have detoxification ability in treatment of aflatoxin-contaminated foods [31]. Mendez-Albores et al. showed that citric acid and lactic acid have efficiency upon aflatoxin degradation. When the acid concentration increased, the amount of B-aflatoxins decreased, and citric acid has more notable effect upon AFB degradation. Lee et al. also found the reduction rates of AFB1 in 1.0 N citric acid and lactic acid treatment for 18 hour could reach 94.1 and 92.7%, respectively [11].

3.4 Ozonation treatment

Ozonation is another commonly used chemical control method. Ozonolysis at a concentration 6–90 mg/L is effective to degrade AFB1 in short-time treatment. As short as 15 min, all molds were inactivated, and *Aspergillus parasiticus* and *Aspergillus flavus* were isolated from dried figs, while AFB1 was degraded in

time-dependent manner in dried figs [32]. Aflatoxins in the peanuts at moisture content of 5% (w/w) were sensitive to ozone and easily degraded when treated with 6.0 mg/l of ozone for half hour at room temperature. The detoxification rates of the total aflatoxins and aflatoxin B1 (AFB1) were 65.8% and 65.9%, respectively [33]. Another study also showed that 89.4% AFB1 in the peanuts was decomposed by ozone with a concentration at 50 mg/L, flow rate 5 L/min for 60 hours [34].

4. Biological treatment to degrade aflatoxins

Using microorganisms or enzymes for biodegradation of aflatoxins is one of the well-known strategies to decrease the level of aflatoxins in the foods or feed products. The methods of biologically based interventions are being actively studied because they are efficient, specific, and environmentally friendly as compared with other non-biological degradation methods.

4.1 Soil bacteria

Many bacteria in the soil are able to degrade aflatoxins. *Flavobacterium aurantiacum* NRRL B-184, a kind of bacteria from the soils and water, showed that it can detoxify aflatoxins in high efficiency. The study from Ciegler et al. [35] showed that *F. aurantiacum* NRRL B-184 removed aflatoxin irreversibly from contaminated milk, oil, peanut butter, peanuts, and corns and partially removed from soybeans. The aflatoxins are not only removed away by *F. aurantiacum* NRRL B-184 but also failed to form any new toxic products. The bacteria was also reported that AFM1 could be removed by it from milk [35]. During monitoring the roles of such metal ions as Cu^{2+}, Mn^{2+}, Zn^{2+}, and other chemical materials on AFB1 degradation by the bacteria, they could increase AFB1 degradation by 10–15% [36–38], suggesting enzymatic system was involved in aflatoxin B1 degradation by *F. aurantiacum*. Except *F. aurantiacum*, other microorganisms, for example, *Nocardia asteroides* and *Corynebacterium rubrum*, are able to detoxify aflatoxin [5, 39]. *Mycobacterium fluoranthenivorans* sp. nov. DSM44556, as a single carbon source from soil of a former coal gas plant, could reduce AFB1 concentration to amounts of 70–80% of the initial concentration within 36–48 hours, and no AFB1 could be detected in 72 hours [40, 41], while the cell-free extracts of *M. fluoranthenivorans* sp. nov. DSM44556 degraded AFB1 more than 90% the initial amount of AFB1 at high temperature within 4 hours and fully degraded in 8 hours [41]. Teniola et al. showed that *N. corynebacterioides* DSM20 151 could degrade more than 90% of AF1B after 24 hours treated in cell-free extracts. Alberts et al. [42] examined that AFB1 was biodegraded by *Rhodococcus erythropolis* in liquid cultures. AFB1 was dramatically degraded to 32% of initial concentration by extracellular extracts from *R. erythropolis* liquid cultures. Thus *F. aurantiacum*, *M. fluoranthenivorans*, and *N. corynebacterioides* could be a potential and promising application because of their potent efficient degradation of AFB1 in the food and feed process.

4.2 Fungi

Fungi can not only produce aflatoxins but also degrade aflatoxin. Such four fungal strains *Aspergillus niger*, *Eurotium herbariorum*, a *Rhizopus* sp., and non-aflatoxin-producing *A. flavus* were able to convert AFB1 to aflatoxicol-A (AFL-A); then AFL-A was converted to aflatoxicol-B (AFL-B) by the actions of medium components or organic acids produced from the fungi. Fungi *Penicillium raistrickii* NRRL 2038 could transform AFB1 to a new compound which is similar to AFB2.

Kusumaningtyas et al. found *Rhizopus oligosporus* was able to inhibit synthesis or to degrade AFB1 when cultured together with AFB1-producing fungi *A. flavus* [43].

4.3 Yeasts and lactic acid bacteria

The mechanism of degradation AFB by yeasts and lactic acid bacteria is due to their adhesion to cell wall components. However the role of yeasts and lactic acid bacteria on AFB is controversial. A few study showed there was no effect of yeasts and lactic bacteria upon aflatoxin [44]. The results showed that high levels of aflatoxins in raw maize would not be degraded during the fermentations in the processing of the west African traditional food "kenkey." Other studies reported very efficient aflatoxin reductions after fermentation. Chu et al. [45] reported that AFB1 concentration dramatically decrease during brewing process, which suggested that *S. cerevisiae* yeasts sorb mycotoxin. AFB1 was detoxified into a nontoxic new fluorescing compound corresponding to AFB2a during yogurt-making and dairy product fermentation [46, 47]. Drinking water with *S. cerevisiae* strain showed a positive protection effect on the relative weight of the liver and histopathological and biochemical parameters when giving the diets contaminated with AFB1 [48].

Lactic acid bacteria have been previously reported to possess antimycotoxigenic activities both in vitro and in vivo. The specific strains of lactic acid bacteria will bind selected dietary aflatoxin contaminants. The ability of 12 *Lactobacillus*, 5 *Bifidobacterium*, and 3 *Lactococcus* bacteria strains to bind AFB1 was investigated by Peltonen et al. [49]. Two *Lactobacillus* amylovorus strains and one *Lactobacillus rhamnosus* strain removed more than 50% AFB1 rapidly after a 72-hour incubation period. Another two lactic acid bacteria *Lactobacillus rhamnosus* strain GG (LBGG) and *L. rhamnosus* strain LC-705 (LC705) can significantly and very quickly remove approximately 80% AFB1 from culture media in both temperature- and bacteria concentration-dependent manner [50]. Kankaanpaa et al. [51] found that the binding of AFB1 to *L. rhamnosus* GG decreased its subsequent adhesion capability to Caco-2 cells, thereupon which the bacteria may reduce the accumulation of aflatoxins in the intestine via increasing aflatoxin-bacteria complex excretion.

4.4 Aflatoxin degradation by enzymes

Some specific enzymes to degrade aflatoxins have been purified from microbial systems. Using enzyme to degrade aflatoxins have some merits, such as avoiding to change flavor or impairing the nutritional value. Motomura et al. [52] investigated the ability of degrading AFB1 in cultured supernatants from 19 fungi and purified 1 enzyme with aflatoxin degradation activity from *P. ostreatus* supernatant. The enzyme showed that AFB could make the best degradation of activity at 25°C with a pH of 4.0–5.0. The novel enzyme could cleave the lactone ring of aflatoxin. Another study showed that an intracellular enzyme, named aflatoxin-detoxifizyme, exhibited detoxification activity on aflatoxin B1 and the optimum activity for the enzyme was at 35°C with a pH of 6.8 [53]. Shcherbakova et al. [54] also proved AFB1 degradation by *Phoma glomerata* PG41 strain was stable and reproducible.

4.5 Cold plasma technology to remove AFB1

In the past cold plasma is used for sterilization of sensitive materials. Lately, much attention has been paid to cold plasma as a new microbial decontamination technology in the food industry. It has the advantages of high efficiency and short treatment time, no residue, and low impact on the quality of treated food products [55, 56]. Recently the degradation of mycotoxins by cold plasma was studied.

It was reported that AFB1 could be successfully removed by 5 s of treatment with microwave-induced argon plasma [57]. Nitrogen gas plasma could efficiently bw degraded to 10% of initial concentration within a 15-min treatment [58]. Low-temperature radio-frequency plasma degraded 88% of AFB1 within 10 min [59]. High-voltage atmospheric cold plasma (HVACP) is a novel nonthermal decontamination technology that has the potential to be used in the food industry. HVACP treatment of aflatoxin has been shown to degrade 70% of the total aflatoxin in 12 min [60, 61].

5. Sorbent additives for degradation of AFB1

There is one approach to solve AFB1 contamination is the addition of sorbents in the foods. This process is not the same as the degradation process, because it does not involve destroying or reducing the amount of AFB1 in the foods or feeds. They act as binding agents to prevent AFB1 absorbed from intestinal tract after ingestion. Chlorophyllin added to the contaminated feeds could reduce AFB1-DNA adduct by 37% in rainbow trout which led to a 77% reduction of tumor incidence [62]. Another study observed that chlorophyllin exhibited the reduction of AFB1-DNA adducts, boasting the reduction of AFB1-album adducts by 65% and urinary AFM1 by 90% in rats; chlorophyll also reduces AFB1-DNA adducts, AFB1-album adducts, and urinary AFM1 levels by 55, 51, and 92%, respectively [63].

Clay works similarly to chlorophyll and chlorophyllin. By addition of the clay into the animal feeds, AFM1 level in milk is reduced accordingly with the decrease of AFB1 absorption rate [64]. And no overt toxicities were observed after SD rats were fed with NovaSil clay (NS) for more than half year [65]. For human beings, NS was performed for clinical study, and the side effect were reported in 99.5% of the persons as compared to the control group. After 3 months, the level of AFB1-albumin adduct was significantly decreased in both low-dose group and high-dose group. The level of AFM1 in urine samples decreased 58% in the high-dose group in 3 months. And there was no liver and kidney function or hematological parameter change reported [66, 67]. From these studies, NS diet can be regarded as a safe and effective method to reduce AFB1 toxicity in the foods.

In addition, different types of mineral clays have been tested for their capabilities to bind AF in animal feeds. These absorbents, such as activated carbon (charcoal), zeolite, and saponite-rich bentonite, reduced AFB1 absorption in the gastrointestinal tract [68].

6. Other methods to degrade of AFB1

Recently, some inexpensive, new promising methods on top of conventional methods for decontamination of food and raw materials have been developed. In the beer or wine factories, some fermentation residues were observed to have the ability of degradation of AFB. A group in Italy have shown that biosorption of mycotoxins onto grape pomace may be a reasonably low-cost decontamination method. The theoretical maximum adsorption capacities (mmol/kg dried pomace) were calculated at pH 7 and 37°C; around 1 hour of contact, that pomace could adsorb almost half of initial AFB1 concentration, but it seems the adsorption rate was kept stable within pH ranges [69]. Similarly, Bovo et al. [70] also found AFB adsorption by beer fermentation residue (BFR) ranged from 45.5 to 69.4% at pH 3.0 and from 24.0 to 63.8% at pH 6.0.

7. Conclusion

Among all mycotoxins, the group of aflatoxins has received much attention due to their severe impact on human and animal health. AFB1 is the most potent carcinogenic agent associated with hepatocellular carcinoma. And AFB1 can negatively affect nutrition absorption, growth and development, and immune system function. AFB1 contamination in the food/feed supplies was found in various countries, particularly in Asia and Africa. A lot of methods to remove or prevent AFB1 contamination, degrade AFB1, or inhibit AFB1 absorption have been developed in the last several decades. The efficiency of aflatoxin decontamination is subject to such factors as food conditions (food constituents, moisture content, pH conditions) and decontamination technologies and conditions. The traditional physical methods for separation or dehulling of the contaminated grains are the simple and safe ways without expensive costs to reduce the dietary exposure to aflatoxins; they can be chosen by anyone or in any area, which makes them the best methods for poor or undeveloped area. Decontamination of aflatoxin is one of the significant challenges for the food industry. The treated food should keep their nutrition values or other important desired qualities, and no residues be left or new contaminates be produced. Either most of the physical and chemical approaches for aflatoxin detoxification might affect the nutritional properties of the foods or be unsafe for human consumption; however, gamma radiation, ozone applications, microwave heating, electron beam, pulsed light, electrolyzed water, and cold plasma showed great potentials for future applications. Recently some inexpensive methods showed good perspectives for reducing aflatoxins in beer and wine factory, which are good choice to be adopted in commercial factory. Biological approaches based on removal or degradation of aflatoxins by bacteria and yeasts are of the promising perspectives, although these practices cannot be currently adopted for foods commercially. While applying these new technologies to make decontamination of aflatoxin, it shall be vital to make clear of the mechanisms of aflatoxin detoxification to determine the practical applications of these approaches in food products, especially concerning their impacts upon the food constituents. Furthermore, combination with traditional and novel technologies shall be also considered to improve the efficiency of decontamination and break through the limitations for specific technologies.

Acknowledgements

This study was supported partly by the National Natural Science Foundation of China (Nos. 81860489, 81760502, 81572353,81372639,81472243,81660495, and 81460423), the Innovation Program of Guangxi Municipal Education Department (Nos. 201204LX674 and 201204LX324), Innovation Program of Guangxi Health Department (No. Z2013781), the Natural Science Foundation of Guangxi (Nos. 2018GXNSFAA281043, 2017GXNSFAA198002, 2017GXNSFGA198002, 2016GXNSFDA380003, 2015GXNSFAA139223, 2013GXNSFAA019251, 2014GXNSFDA118021, and 2014GXNSFAA118144), Research Program of Guangxi "Zhouyue Scholar" (No. 2017–2038), Research Program of Guangxi Specially-invited Expert (No. 2017-6th), the "12th Five-Year Plan" Planning Program of Guangxi Education Science (No. 2015C397), the Innovative Program of Guangxi Graduate Education (No. JGY2015139), Research Program of Guangxi Clinic Research Center of Hepatobiliary Diseases (No.AD17129025), and Open Research Program from Molecular Immunity Study Room Involving in Acute and Severe Diseases in Guangxi Colleges and Universities (Nos. kfkt20160062 and kfkt20160063).

Author details

Qian Yang[1,2]

1 Department of Pathology, The Affiliated Hospital of Youjiang Medical University for Nationalities, Baise, China

2 Department of Internal Medicine-Gerontology and Geriatric Medicine, Wake Forest University School of Medicine, Winston-Salem, North Carolina, USA

*Address all correspondence to: yangqian2003@126.com

References

[1] Zain ME. Impact of mycotoxins on humans and animals. Journal of Saudi Chemical Society. 2011;**15**(2):129-144

[2] Nesbitt BF et al. *Aspergillus flavus* and Turkey X disease. Toxic metabolites of *Aspergillus flavus*. Nature. 1962;**195**:1062-1063

[3] Dalvi RR. An overview of aflatoxicosis of poultry: Its characteristics, prevention and reduction. Veterinary Research Communications. 1986;**10**(6):429-443

[4] Carnaghan RB, Hartley RD, O'Kelly J. Toxicity and fluorescence properties of the Aflatoxins. Nature. 1963;**200**:1101

[5] Wu Q et al. Biological degradation of aflatoxins. Drug Metabolism Reviews. 2009;**41**(1):1-7

[6] Gorelick NJ. Risk assessment for aflatoxin: I. metabolism of aflatoxin B1 by different species. Risk Analysis. 1990;**10**(4):539-559

[7] Dickens JW, Whitaker TB. Efficacy of electronic color sorting and hand picking to remove aflatoxin contaminated kernels from commercial lots of shelled peanuts. Peanut Science. 1975;**2**(**2**):45-50

[8] Matumba L et al. Effectiveness of hand sorting, flotation/washing, dehulling and combinations thereof on the decontamination of mycotoxin-contaminated white maize. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment. 2015;**32**(6):960-969

[9] Arzandeh S, Jinap S. Effect of initial aflatoxin concentration, heating time and roasting temperature on aflatoxin reduction in contaminated peanuts and process optimisation using response surface modelling. International Journal of Food Science and Technology. 2011;**46**(3):485-491

[10] Raters M, Matissek R. Thermal stability of aflatoxin B1 and ochratoxin A. Mycotoxin Research. 2008;**24**(3):130-134

[11] Lee J, Her JY, Lee KG. Reduction of aflatoxins (B(1), B(2), G(1), and G(2)) in soybean-based model systems. Food Chemistry. 2015;**189**:45-51

[12] Park JW, Lee C, Kim YB. Fate of aflatoxin B1 during the cooking of Korean polished rice. Journal of Food Protection. 2005;**68**(7):1431-1434

[13] Perez-FloresGC,Moreno-MartinezE, Mendez-Albores A. Effect of microwave heating during alkaline-cooking of aflatoxin contaminated maize. Journal of Food Science. 2011;**76**(2):T48-T52

[14] Di Stefano V et al. Mycotoxin contamination of animal feedingstuff: Detoxification by gamma-irradiation and reduction of aflatoxins and ochratoxin A concentrations. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment. 2014;**31**(12):2034-2039

[15] Applegate KL, Chipley JR. Effects of 60Co gamma irradiation on aflatoxin B1 and B2 production by *Aspergillus flavus*. Mycologia. 1974;**66**(3):436-445

[16] Priyadarshini E, Tulpule PG. Effect of graded doses of gamma-irradiation on aflatoxin production by *Aspergillus parasiticus* in wheat. Food and Cosmetics Toxicology. 1979;**17**(5):505-507

[17] Ogbadu G. Influence of gamma irradiation of aflatoxin B1 production by *Aspergillus flavus* growing on

some Nigerian foodstuffs. Microbios. 1980;**27**(107):19-26

[18] Schindler AF, Abadie AN, Simpson RE. Enhanced aflatoxin production by *Aspergillus flavus* and *Aspergillus parasiticus* after gamma irradiation of the spore inoculum. Journal of Food Protection. 1980;**43**(1):7-9

[19] Zhang ZS, Xie QF, Che LM. Effects of gamma irradiation on aflatoxin B1 levels in soybean and on the properties of soybean and soybean oil. Applied Radiation and Isotopes. 2018;**139**:224-230

[20] Domijan AM et al. Cytotoxicity of gamma irradiated aflatoxin B1 and ochratoxin A. Journal of Environmental Science and Health. Part. B. 2019;**54**(3):155-162

[21] Xiong K, Liu H, Li L. Product identification and safety evaluation of aflatoxin B1 decontaminated by electrolyzed oxidizing water. Journal of Agricultural and Food Chemistry. 2012;**60**(38):9770-9778

[22] Xiong K et al. Differences in fungicidal efficiency against *Aspergillus flavus* for neutralized and acidic electrolyzed oxidizing waters. International Journal of Food Microbiology. 2010;**137**(1):67-75

[23] Fan S et al. Removal of aflatoxin B(1) in edible plant oils by oscillating treatment with alkaline electrolysed water. Food Chemistry. 2013;**141**(3):3118-3123

[24] Elmnasser N et al. Pulsed-light system as a novel food decontamination technology: A review. Canadian Journal of Microbiology. 2007;**53**(7):813-821

[25] Moreau M et al. Application of the pulsed light technology to mycotoxin degradation and inactivation. Journal of Applied Toxicology. 2013;**33**(5):357-363

[26] Martinez AJ, Weng CY, Park DL. Distribution of ammonia/aflatoxin reaction products in corn following exposure to ammonia decontamination procedure. Food Additives and Contaminants. 1994;**11**(6):659-667

[27] Weng CY, Martinez AJ, Park DL. Efficacy and permanency of ammonia treatment in reducing aflatoxin levels in corn. Food Additives and Contaminants. 1994;**11**(6):649-658

[28] Hoogenboom LA et al. Genotoxicity testing of extracts from aflatoxin-contaminated peanut meal, following chemical decontamination. Food Additives and Contaminants. 2001;**18**(4):329-341

[29] Jorgensen KV, Price RL. Atmospheric pressure-ambient temperature reduction of aflatoxin B1 in ammoniated cottonseed. Journal of Agricultural and Food Chemistry. 1981;**29**(3):555-558

[30] Aly SE, Hathout AS. Fate of aflatoxin B(1) in contaminated corn gluten during acid hydrolysis. Journal of the Science of Food and Agriculture. 2011;**91**(3):421-427

[31] Mendez-Albores A et al. Effect of lactic and citric acid on the stability of B-aflatoxins in extrusion-cooked sorghum. Letters in Applied Microbiology. 2008;**47**(1):1-7

[32] Zorlugenc B et al. The influence of gaseous ozone and ozonated water on microbial flora and degradation of aflatoxin B(1) in dried figs. Food and Chemical Toxicology. 2008;**46**(12):3593-3597

[33] Chen R et al. Effect of ozone on aflatoxins detoxification and nutritional quality of peanuts. Food Chemistry. 2014;**146**:284-288

[34] Diao E et al. Ozonolysis efficiency and safety evaluation of aflatoxin B1 in

peanuts. Food and Chemical Toxicology. 2013;**55**:519-525

[35] Ciegler A et al. Microbial detoxification of aflatoxin. Applied Microbiology. 1966;**14**(6):934-939

[36] D'Souza DH, Brackett RE. The role of trace metal ions in aflatoxin B1 degradation by *Flavobacterium aurantiacum*. Journal of Food Protection. 1998;**61**(12):1666-1669

[37] D'Souza DH, Brackett RE. The influence of divalent cations and chelators on aflatoxin B1 degradation by *Flavobacterium aurantiacum*. Journal of Food Protection. 2000;**63**(1):102-105

[38] D'Souza DH, Brackett RE. Aflatoxin B1 degradation by *Flavobacterium aurantiacum* in the presence of reducing conditions and seryl and sulfhydryl group inhibitors. Journal of Food Protection. 2001;**64**(2):268-271

[39] Arai T, Ito T, Koyama Y. Antimicrobial activity of aflatoxins. Journal of Bacteriology. 1967;**93**(1):59-64

[40] Hormisch D 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

[41] Teniola OD et al. Degradation of aflatoxin B(1) by cell-free extracts of *Rhodococcus erythropolis* and *Mycobacterium fluoranthenivorans* sp. nov. DSM44556(T). International Journal of Food Microbiology. 2005;**105**(2):111-117

[42] Alberts JF et al. Biological degradation of aflatoxin B1 by *Rhodococcus erythropolis* cultures. International Journal of Food Microbiology. 2006;**109**(1-2):121-126

[43] Kusumaningtyas E, Widiastuti R, Maryam R. Reduction of aflatoxin B1 in chicken feed by using *Saccharomyces cerevisiae*, *Rhizopus oligosporus* and their combination. Mycopathologia. 2006;**162**(4):307-311

[44] Jespersen L et al. Significance of yeasts and moulds occurring in maize dough fermentation for 'kenkey' production. International Journal of Food Microbiology. 1994;**24**(1-2):239-248

[45] Chu FS et al. Stability of aflatoxin B-1 and ochratoxin a in brewing. Applied Microbiology. 1975;**29**(3):313-316

[46] Megalla SE, Hafez AH. Detoxification of aflatoxin B1 by acidogenous yoghurt. Mycopathologia. 1982;**77**(2):89-91

[47] Megalla SE, Mohran MA. Fate of aflatoxin B-1 in fermented dairy products. Mycopathologia. 1984;**88**(1):27-29

[48] Pizzolitto RP et al. Evaluation of *Saccharomyces cerevisiae* as an antiaflatoxicogenic agent in broiler feedstuffs. Poultry Science. 2013;**92**(6):1655-1663

[49] Peltonen K et al. Aflatoxin B1 binding by dairy strains of lactic acid bacteria and bifidobacteria. Journal of Dairy Science. 2001;**84**(10):2152-2156

[50] El-Nezami H et al. 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

[51] Kankaanpaa P 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

[52] Motomura M et al. Purification and characterization of an aflatoxin degradation enzyme from *Pleurotus ostreatus*. Microbiological Research. 2003;**158**(3):237-242

[53] Liu DL et al. Production, purification, and characterization of an intracellular aflatoxin-detoxifizyme from *Armillariella tabescens* (E-20). Food and Chemical Toxicology. 2001;**39**(5):461-466

[54] Shcherbakova L et al. Aflatoxin B1 degradation by metabolites of *Phoma glomerata* PG41 isolated from natural substrate colonized by aflatoxigenic *Aspergillus flavus*. Jundishapur Journal of Microbiology. 2015;**8**(1):e24324

[55] Schluter O et al. Opinion on the use of plasma processes for treatment of foods. Molecular Nutrition & Food Research. 2013;**57**(5):920-927

[56] Thirumdas R, Sarangapani C, Annapure US. Cold plasma: A novel non-thermal technology for food processing. Food Biophysics. 2015;**10**(1):1-11

[57] Park BJ et al. Degradation of mycotoxins using microwave-induced argon plasma at atmospheric pressure. Surface & Coatings Technology. 2007;**201**(9-11):5733-5737

[58] Sakudo A et al. Degradation and detoxification of aflatoxin B-1 using nitrogen gas plasma generated by a static induction thyristor as a pulsed power supply. Food Control. 2017;**73**:619-626

[59] Wang SQ et al. Degradation of aflatoxin B-1 by low-temperature radio frequency plasma and degradation product elucidation. European Food Research and Technology. 2015;**241**(1):103-113

[60] Shi H et al. Structures of degradation products and degradation pathways of aflatoxin B1 by high-voltage atmospheric cold plasma (HVACP) treatment. Journal of Agricultural and Food Chemistry. 2017;**65**(30):6222-6230

[61] Siciliano I et al. Use of cold atmospheric plasma to detoxify hazelnuts from aflatoxins. Toxins (Basel). 2016;**8**(5):125

[62] Breinholt V et al. Dietary chlorophyllin is a potent inhibitor of aflatoxin B1 hepatocarcinogenesis in rainbow trout. Cancer Research. 1995;**55**(1):57-62

[63] Simonich MT et al. Natural chlorophyll inhibits aflatoxin B1-induced multi-organ carcinogenesis in the rat. Carcinogenesis. 2007;**28**(6):1294-1302

[64] Phillips TD et al. Reducing human exposure to aflatoxin through the use of clay: A review. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment. 2008;**25**(2):134-145

[65] Afriyie-Gyawu E et al. Chronic toxicological evaluation of dietary NovaSil clay in Sprague-Dawley rats. Food Additives and Contaminants. 2005;**22**(3):259-269

[66] Afriyie-Gyawu E et al. NovaSil clay intervention in Ghanaians at high risk for aflatoxicosis. I. study design and clinical outcomes. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment. 2008;**25**(1):76-87

[67] Wang P et al. NovaSil clay intervention in Ghanaians at high risk for aflatoxicosis: II. reduction in biomarkers of aflatoxin exposure in blood and urine. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment. 2008;**25**(5):622-634

[68] Giovati L et al. AFM(1) in milk: Physical, biological, and prophylactic methods to mitigate contamination. Toxins (Basel). 2015;**7**(10):4330-4349

[69] Avantaggiato G et al. Assessment of multi-mycotoxin adsorption efficacy of grape pomace. Journal of Agricultural and Food Chemistry. 2014;**62**(2):497-507

[70] Bovo F et al. In vitro ability of beer fermentation residue and yeast-based products to bind aflatoxin B1. Brazilian Journal of Microbiology. 2015;**46**(2):577-581