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Aflatoxin contamination in food crops: causes, detection, and management: a review

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Abstract

Mycotoxins are secondary metabolites produced by several fungal species and molds. Under favorable conditions like high temperature and moisture, they contaminate a large number of food commodities and regional crops during pre and post-harvesting. Aflatoxin is the main mycotoxin that harm animal and human health due to its carcinogenic nature. Aflatoxins are mainly released by *Aspergillus flavus* and *Aspergillus parasiticus*. AFB1 constitutes the most harmful type of aflatoxins and is a potent hepato-carcinogenic, mutagenic, teratogenic and it suppresses the immune system. To maintain food safety and to prevent aflatoxin contamination in food crops, combined approaches of using resistant varieties along with recommended farming practices should be followed. This review concentrates on various aspects of mycotoxin contamination in crops and recent methods to prevent or minimize the contamination.

Keywords: Mycotoxin, Aflatoxin contamination, *Aspergillus flavus*, *Aspergillus parasiticus*, Food crops

Introduction

Aflatoxin contamination in crops is a global threat that compromises the safety of food, feed, and also influences the agricultural economy and crop-dependent small scale industries. Crops can be contaminated during the process of harvesting, storing, and transporting by the fungi and leads to the productions of several mycotoxins. Mycotoxins are produced by certain fungi as secondary metabolites and aflatoxin is one of them. Aflatoxins are synthesized by many fungi spp. including *Aspergillus, Penicillium, Fusarium,* and *Alternaria* but *Aspergillus flavus* and *Aspergillus parasiticus* are known to produce the most toxigenic strains of aflatoxins. There are mainly six different types of aflatoxins-Aflatoxins-B1(AFB_1), Aflatoxins-B2(AFB_2), Aflatoxin G1(AFG_1), Aflatoxins G2 (AFG_2), Aflatoxin M1 (AFM_1), and Aflatoxin M2 (AFM_2) (Quadri et al. 2012). Out of these B1, B2, G1, G2 are found in food crops or their products, while M1 (Metabolite of B1) and M2 are found in the animals' by-products such as dairy products.

Aflatoxin B1 and B2 are produced by *A. flavus,* while Aflatoxin G1 and G2 are synthesized by *A. parasiticus* and largely contaminate a wide range of food commodities including cereals (maize, sorghum, pearl millet, rice, and wheat), oilseeds (peanut, soybean, sunflower, and cotton), spices (chilies, black pepper, turmeric, coriander, and ginger), nuts (almond, Brazil nut, pistachio, walnut, and coconut), yam and various milk products (Rajarajan et al. 2013). *A. flavus* fungus has a green appearance and has the potential to increase its population even under many stressful conditions. The injuries caused by insects and nematode also paved the way for the entry of these fungi (Jeyaramraja et al. 2018). The entry of fungus in crops not only compromises the self-defense of crop plants by the fungal attack but also contaminates the crop seeds which lead the aflatoxin production. The fungal infections affect the crop's growth, yield, and also result in loss of market value.

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Aflatoxin B_1 is the most harmful aflatoxin to humans and animals as it is carcinogenic due to its association with hepatocellular carcinoma which leads to liver cancer (Qureshi et al. 2015). Aflatoxins suppress the immune systems of humans and animals by interfering with the fickleness of those cells which are responsible to boost immunity. Large doses of aflatoxins lead to direct death and damage, while small longstanding doses lead to immunologic or nutritional effects, but both types of doses lead to liver cancer due to the accumulation of aflatoxin (Marroquín-Cardona et al. 2014). Children are more prone to the toxicity of Aflatoxin as it increases the risk of early infections by reduced immunization. The carcinogenic nature of aflatoxin is due to its ability to damage DNA either by lipid peroxidation or by oxidation (Zhang et al. 2015). The cytochrome p-450 present in the liver activates AFB_1 which is then converted into AFB_1 8,9-epoxide. The compound AFB_1 8,9-epoxide is responsible for various carcinogenic effects (Denissenko et al. 1999). Apart from being carcinogenic, aflatoxin also has negative effects on the kidney, heart, liver, testis, and brain. Aflatoxin was also responsible for the various outbreaks in India and various African countries. The condition of the outbreak is more severe in under-developed and developing countries due to fewer food regulation acts.

To curb the aflatoxins contamination in food crops, countries have imposed different laws regarding the level of these toxins in food crops. The United State Food and Drug Administration (USFDA) imposed strict laws for the aflatoxins level in affected food commodities at 20 ppb (parts per billion) in food and feeds, while 0.5 ppb in milk products European Union (EU) also interpolates the aflatoxin contents level in food commodities in the range of 2–4 ppb (Gurtler & Keller 2019). In India, a maximum limit of 30 μg/kg has been imposed for all food commodities under the Food Safety and Standards Regulations, 2011. However such laws on Aflatoxins contamination range in various crop plants/food commodities put an extra load of over US$932 million on the agricultural economy by a reduction in crops growth and yields. Several lakh tones of harvested product go waste every year due to aflatoxin contamination and not fulfilling the export norms.

To minimize the aflatoxins contamination in crop plants, various physical, chemical, and biological methods and various breeding and genetic engineering approach has been used to minimize the toxicity of aflatoxin and reduce its level below the recommended one. This review describes an overview of various aspects of aflatoxigenic fungi, favorable conditions for growth, control measures, detection techniques, and recent reports in various crops.

Favorable conditions for aflatoxin contamination

Mycotoxins production depends on the food source, enzymes, and various environmental factors. However, the conditions that are favorable for aflatoxigenic fungi are not always conducive for the production of aflatoxins (Mannaa & Kim 2017). The factors are summarized as:

Physical factors

Physical factors like pH, light, moisture, temperature, water, relative humidity, and atmospheric gases are responsible for aflatoxin contamination. Aflatoxin-producing molds/Fungi can grow in a wide range of pH (1.7–9.3), but the optimum range of pH is (3–7) (Yoshinari et al. 2010). The lower pH ($3 > pH > 1$) minimizes the fungal growth and a slightly higher pH ($6 > pH > 3$) promotes both fungal and aflatoxins production (Eshelli et al. 2015). Initial pH ($pH = 5$) promote AFB (Aflatoxin B) production while higher pH ($pH = 7$) promote AFG (Aflatoxin G) production, however, the composition of media in which fungi grow also influence pH (Dalié et al. 2010). Fungi growth and aflatoxin production are also affected by the presence of light. Darkness increases aflatoxin production while sunlight inhibits it (Rushing & Selim 2019). High moisture content always favors the aflatoxin contamination because moist conditions are favorable for fungal growth. Relative humidity (85%) is optimal for aflatoxins production, while 95% relative humidity increases aflatoxins production to a considerable level (Ding et al. 2015). However, the water level does not have any reported effect on aflatoxin contamination. *Aspergillus flavus* poses an excellent survival capability to grow on a wide range of temperatures ranging from 12 °C to 48 °C, but 28 °C to 37 °C is the optimum temperature range for its growth (Hawkins et al. 2005). Aflatoxins production can occur at a wide range of temperature; however, the optimal temperature for aflatoxin production is 25-35 °C (Siciliano et al. 2017). Normally at high temperatures, AFB production is high than AFG, but at low temperatures both AFB and AFG production is equal (Matumba et al. 2015). Availability of O_2 and CO_2 also influence the aflatoxins productions. Aflatoxins production and fungal growth are inhibited at a higher level of CO_2 and a lower level of O_2 (Mahbobinejhad et al. 2019).

Nutritional factors

Aflatoxin productions are also widely affected by the substrate and various nutritional factors such as carbon, amino acids, nitrogen, lipids, and few trace elements. Substrate rich in carbohydrates supports more production as compare to oil as carbohydrate easily provides carbon which is needed for good fungal growth (Ma et al. 2014). Among carbohydrates glucose, ribose, sucrose, xylose, and glycerol acts as excellent substrates, while peptone, lactose, and sorbose were unable to promote aflatoxins production (Liu et al. 2016). Nitrogen in the form of nitrite and nitrate also increases the aflatoxin production level by *A. flavus* in various ways (Wang, Han, et al. 2017). Lipids also play an important

role in aflatoxin production. Aflatoxins biosynthesis in toxigenic fungi leads by lipophilic epoxy fatty acids and fungal growth as well as aflatoxin production induced by ergo-sterol oxidation (Reverberi 2014). Consequently, lipids also act as a substrate to obtain an acyl-CoA starter as well as a signaling molecule. The aflatoxin production and accumulation increases in full-fat substrates as compared to the low-fat substrate. The addition of corn oil in defatted wheat, infected by *A. flavus* promotes aflatoxin production as compare to media without the addition of corn oil (Liu et al. 2016). Vitamins, amino acids, and metal ions also promote aflatoxin production in combination. Amino acids like glycine, glutamate, and alanine along with some bivalent metals like zinc and magnesium promote aflatoxin production (Bolu et al. 2014). The aflatoxin production increased by 4, 5, and 19 times with the 20, 50, and 100 (mg/L) concentration of zinc respectively (Liu et al., 2016). Amino acid such as tyrosine promotes aflatoxin production, while it is inhibited by tryptophan (Chang et al., 2015). AFB1 production was supported by arginine, glycine, glutamic acid, and aspartic acid at a concentration of 0.5%.

Biological factors

Biological factors include fungal species, weeds, and insect injuries. Weeds mostly grow as a competitor and cause plant stress which is associated with aflatoxin production. The amount of aflatoxin production mainly depends on types of fungi; insects wound in the plant cause stress and provide the site for aflatoxigenic fungi for contamination (Kinyungu 2019). Aflatoxin production also depends on the types of strains. *A. flavus* produces fewer aflatoxins as compare to *A. parasiticus* (Manjunath & Mohana 2018). Apart from the above-mentioned factors, *A. flavus* is the main species that is mainly responsible for aflatoxin production and crop contamination because it is the most copious molds found in soil and possesses the saprobe character that enables it to grow on many organic nutrient substrates including compost piles, plant debris, cotton, dead insects, stored grains, field crops, animal corpses and animal fodder (Kakde 2012). Pre-harvest contaminations of field crops are common because of the natural existence of *A. flavus* in soil, while post-harvest contamination also occurred by *A. flavus* during storage because it spoils the food grains. Due to the lacking of host specificity *A. flavus* contaminate both monocot and dicot seeds (Leger et al. 2000).

Aflatoxins contamination in crop plants

Aflatoxin contamination occurs in a wide range of regional crops and food commodities. Food and feed like corn, rice, spices, dried fruits, nuts, and figs are mostly contaminated by aflatoxins (Martinez-Miranda et al. 2019). The four major aflatoxins like AFB1, AFB2, AFG1, and AFG2 are commonly found in a wide range of food commodities, AFB1 and AFB.2 are produced by *A. flavus* while AFG1 and AFG2 are produced by *A. parasiticus*. The post-harvest crops are more likely to be contaminated if the storage conditions are optimum for fungus growth. It was found that about 67.9% of maize samples, 92.9% of millet samples, and 50% of sorghum samples that were obtained from a storage room are contaminated by aflatoxins (Sirma et al. 2015). A detailed list of various food crops that were found to be infected with aflatoxin contamination is given in Table 1.

Methods to detect aflatoxin contamination in crop plants

There are many official methods to detect Aflatoxin contamination in crop plants, which are featured by the Association of Official Analytical Chemists (AOAC) (Kumar et al. 2017). Amongst them, the most commonly used method is Enzyme-Linked Immunosorbent Assay (ELISA) followed by some chromatographic methods including High-Performance Liquid Chromatography (HPLC), Liquid Chromatography-Mass Spectroscopy (LCMS), and Thin Layer Chromatography (TLC) (Sulyok et al. 2015). Wang, Li, et al. 2017 developed a highly specific nanobody-polyclonal antibody sandwich ELISA for detecting both *A. flavus* and *A. parasiicus* with a minimum detection limit of 1 μg/mL. Unfortunately, there are some limitations associated with the above-mentioned techniques including their fulsomeness, required high technical skills, and time consumption. Hence, those methods that provide instant results are proved to be useful when considering a large sample. These methods include Polymerase Chain Reaction (PCR), Fluorescence/Near-Infrared Spectroscopy (FS/NIRS), and Hyper Spectral Imaging (HSI). PCR technique is mainly used for the detection of Aflatoxins producing fungi *A. flavus* at the molecular level (Tao et al. 2018). Consequently, genes detected during molecular screening of *A. flavus*, responsible for Aflatoxin biosynthesis were used as a target gene to find out Aflatoxin by using multiplex PCR. Visible/Near-Infrared technique (VNIR) is also used for the detection of toxin contamination. In many parts of North America, a considerable amount of AFB1 was found on the surface of maize kernels when detected through VNIR (Chu et al. 2017). However, due to the bad image quality of VNIR, some recent studies focused on the combined use of the HSI technique with chemometric data analysis that resulted in better identification of AFB1 on the surface of maize kernels (Kimuli et al. 2018). The advancement in analytical techniques also led to simultaneous detection of aflatoxins with other toxic compounds. Aflatoxins along with zearalenone were simultaneously detected through the use of Time-Resolved Fluorescence Immuno-

Table 1 List of recent studies showing the mycotoxin contamination in different food crops

S. No.	Food crop	Country	Fungus species	Type of Mycotoxin	Mycotoxin concentration (ppb)	References
1.	Corn	Serbia	*A.flavus*, *A. parasiticus*	Total AFs	1.01–86.10	Kos et al. 2013
2.	Wheat	Saudi Arabia	*A. flavus*, *A. parasiticus*	AFB1 AFB2 AFG1 AFG2	2.3 2.6 1.3 0.5	Al-Wadai et al. 2013
3.	Maize kernel	Hungary	*A. flavus* *A. parasiticus*	AFB1	72.6–73.3	Dobolyi et al. 2013
4.	Red chili	Turkey	*A. flavus*, *A. parasiticus*	AFB1 AFB2 AFG1	0.24–165 0.15–11.3 0.15–3.88	Golge et al. 2013
5.	Groundnut	Ethiopia	*A. flavus*, *A. parasiticus*	Total AFs	15–11,900	Chala et al. 2013
6.	Fonio millet	Nigeria	*A. flavus*	AFB1,2	233.2–692.0	Ezekiel et al. 2014
7.	Corn	India	*A. flavus*	AFB1	48–383	Mudili et al. 2014
8.	Sorghum	Ethiopia	*A. flavus*	AFB1 AFB2	29.5 2.56 ppb	Chala et al. 2014
9.	Rice	Nigeria	*A. flavus*	AFB1	37.26–113.20 ppb	Anthony et al. 2014
10.	Cashew nuts	Brazil	*A. flavus*, *A. parasiticus*	Total AFs	0.60–31.50	Milhome et al. 2014
11.	Madidi	Nigeria	*A. flavus* *A. parasiticus*	AFB1 AFB2	0.2–125.60 0.95–18.4	Anthony et al. 2014
12.	Rice	China	*A. flavus*	AFB1	0.03–20	Lai et al. 2015
13.	Maize	Africa	*A. flavus*	AFB1	0.17–5.3	Sirma et al. 2015
	Millet				0.14–6.4	
	Sorghum				0.15–210.1	
14.	Guava	Egypt	*A. parasiticus*	AFB1 AFG1	0.163 0.296	Embaby & Hassan 2015
15.	Dried Fruits	Pakistan	*A. flavus*	Aflatoxin B1	0.04–9.80	Masood et al. 2015.
16.	Coffee beans	Spain	*A. flavus*	Fumonisins Total AFs	58.62–537.45 0.25–13.12	García-Moraleja et al. 2015
17.	Soybean	Indonesia	*A. flavus*	AFB1 AFB2 AFG1 AFG2	1.50 0.88 0.18 0.43	Pratiwi et al. 2015
18.	Hazelnut	Italy	*A. flavus*	AFB1	56.00	Diella et al. 2018
	Almond				72.00	
	Apricot				56.3	
	Pistachios				48.0	
19.	Groundnut	Africa	*A. flavus*	Aflatoxin B1	72.97–195.17	Magembe et al. 2016
					132.7	Sserumaga et al. 2021
20.	Peanuts	Zambia	*A. flavus*	Aflatoxin B1	0.015–46.60	Bumbangi et al. 2016
21.	Figs	Turkey	*A. flavus* *A. parasiticus* *A. niger*	AFB1 AFB2 AFG1 AFG2	0.1–12.5 0.07–0.72 0.08–15.3 0.1–0.38	Kabak 2016
22.	Lentil	Turkey	*A. flavus*	Aflatoxin B1	0.57–1.74	Baydan et al. 2016
23.	Rice	Pakistan	*A. flavus*	Aflatoxin B1	0.04–21.30	Iqbal et al. 2016
24.	Quince	India	*A. flavus*, *A. parasiticus*	AFB1 AFB2	12.32–241.291 8.231–149.103	Bala et al. 2016
25.	Mango seeds	Nigeria	*A. flavus*, *A. parasiticus*	AFB1 Total AF	68.1 61.7	Ezekiel et al. 2016

Table 1 List of recent studies showing the mycotoxin contamination in different food crops *(Continued)*

S. No.	Food crop	Country	Fungus species	Type of Mycotoxin	Mycotoxin concentration (ppb)	References
			A. parviscleroti	Ochratoxin A	43.4	
	Melon			AFB1 Total AF Ochratoxin A	37.5 48.7 0.6	
26.	Sunflower	Tanzania	*A. flavus*	AFB1	2.8	Mmongoyo et al. 2017.
27.	Chilies.	United State (US)	*A. flavus*	Aflatoxin B1	< 2	Singh & Cotty 2017
28.	Sesame	Nigeria	*A. flavus* *A. parasiticus* *A. niger*	AFB1 AFB2 AFG1 AFG2	3.95–11.75 2.35 2.06 1.47	Matthew et al. 2021
29.	Ginger	Nigeria	*A.flavus,* *A. parasiticus*	Total AFs	0.11–9.52	Lippolis et al. 2017.
30.	Corn	Vietnam	*A. flavus*	Aflatoxin B1	1.0–34.80	Lee et al. 2017
31.	Strawberry	Egypt	*A. flavus,* *A. parasiticus* *A. niger*	AFB1 AFB2 AFG1 AFG2	24.7–51.8 25.8–58.9 33.0–75.2 31.2–71.1	Saleem 2017
32.	Lentil	India	*A. flavus*	AFB1	3.8–8.6	Nazir et al. 2019
	Black pepper			AFB1	39.7–65.9	
	Coriander			AFB1	33.4–67.9	
	Cumin			AFB1	24.9–63.9	
	Aniseed			AFB1	35.3–52.5	
	Black gram beans			AFB1	4.8–15.4	
33.	Flax	United States	*A. flavus* *A. parasiticus*	AFB1 AFG1 AFB1 AFG1 AFB2	247 51 324 34 6	Ting et al. 2020

Chromatographic Assay (TRFICA) (Tang et al. 2017) and anti-idiotypic nanobody-Phage Display-mediated Immune-Polymerase Chain Reaction (PD-IPCR) (Ren et al. 2019). TRFICA and PD-IPCR provides a detection limit of 0.05 ng/mL and 0.0.03 ng/mL respectively for aflatoxins. A recent method also detects aflatoxins and fumonisins (a group of mycotoxins derived from *Fusarium spp.*) through Color-encoded Lateral Flow Immuno-Assay (CLFIA) (Di Nardo et al. 2019).

Certain nanoparticles-based techniques that use quantum dots (QD), carbon (CBNs), Au/Ag are also used to detect different aflatoxins in crop plants (Xue et al. 2019). Furthermore, the use of biosensors for the detection of AFB1 in crop products instead of the chromatographic or spectrophotometric method also gets popularized. The biosensors also permit easy and rapid detection with fewer expenses, minimal sample pretreatment, portability, and on spot identification of aflatoxins by utilizing an electrochemical enzyme-linked oligonucleotide array (Rotariu et al. 2016; Selvolini et al. 2019). Aptamer-based molecular assays are also used for instant detection of aflatoxin in some beverages like wine and certain food crops (Wang et al. 2019).

Measures to control aflatoxin contamination

Aflatoxin contamination in crops caused a serious threat to production, the food market, health, and economics. Several approaches have been manifested to reduce the aflatoxin contamination in crops which include various physical, chemical, and biological methods.

Physical methods

Physical methods such as steam under pressure, dry roasting, and other cooking methods are found to be effective in the control or to reduce the aflatoxin contamination in many crops (Peng et al. 2018). About 40–73% reduction in aflatoxin level was also observed by heating the seed samples on 180 °C (Opoku 2013). When groundnut and corn seed was roasted with 30% moisture at 100 °C temperature for 2 h, there is a reduction of aflatoxin by 85% (Leong et al. 2010). Roasting also reduced the concentration of AFB1 and AFG1 by 70 and 79% when the seeds are roasted at 150 °C for 15 min (Jalili 2016). An effective reduction in aflatoxin concentration was also observed when the seeds were treated with various radiations such as UV and Infrared radiation (Surekha et al. 2015).

Sunlight also plays an important role in the detoxification of AFB1 in many crops. A reduction in AFB1 content was found in artificially infected maize (80%) and groundnut (17%) when the seeds are exposed to sunlight for a 10–12 h period (Rushing & Selim 2019). Consequently, gamma radiation exposure was also found to reduce the aflatoxin level (Aquino 2011). Moisture is a significant factor in fungal growth which leads to the production of aflatoxin in crops. Aflatoxigenic fungi growth and aflatoxin production inhibited by drying groundnut to 6.6% and maize to 15% or much lower moisture level within 24–48 h (Awuah & Ellis 2002; Eziah, & &Afreh-Nuamah, K. 2015). UV irradiation (220–400 nm) also degrades the aflatoxins particularly AFB_1, AFB_2, and AFM_1 in various crops with a degradation potential ranging from 77 to 99.12% (Diao et al. 2015).

Chemical methods

Several chemicals such as acids, alkalis, oxidizing agents, aldehydes, and several gasses are also proved to mitigate the aflatoxigenic fungal growth and aflatoxin production when used in appropriate quantity (Udomkun et al. 2017). Among gasses, ozone was found to be most effective in maximizing the aflatoxin degradation on legumes and cereals by an electrophilic attack on carbon bonds of furan ring (Jalili 2016). However, due to the high-cost factor, ozone treatment is of less use in the post-harvest treatment of crops. Aflatoxin production can also be inhibited by the ammoniation process in corn and other food commodities (Karlovsky et al. 2016). The positive aspect of the ammoniation process is that high-pressure ammoniation (0.25, 0.5, 1.5, and 2%) minimizes the time required to reduce the aflatoxin production in several crops and food commodities (Temba et al. 2016). Certain chemicals such as sodium bisulfite, calcium hydroxide, formaldehyde, sodium hypochlorite, sodium borate, and sorbents also reduce the aflatoxin in many food commodities at a significant level (Carvajal & Castillo 2009). The groundnut cake and poultry feed were detoxified from aflatoxin by treating them with sodium bisulfite (0.5%) and sodium hydroxide (1%) (Bedi & Agarwal 2014). Some food additives are also used for the inhibition of fungal growth and aflatoxin production in combination with some physical factors like temperature and moisture. Treatment of citric acid in conjunction with high temperature and pressure leads to the inhibition of fungal growth as well as aflatoxin production in sorghum (Méndez-Albores et al. 2009). Some scientists also observed that some food preservatives such as propionic acid, crystal violet, p-amino benzoic acid, benzoic acid, boric acid, and sodium acetate were also inhibited the *A. flavus* growth and aflatoxin production (Aiko & Mehta 2015). In peanut and maize, AFB1 production was also inhibited by the treatment of sodium chloride (10%), acetic acid (5%), and propionic acid (5%) (Brožková et al. 2015). Even under the favorable conditions for the growth of *A. flavus,* several salts of propionic acid-like calcium, sodium propionates were able to reduce the aflatoxin formation in maize (Hassan et al. 2015). In groundnut cake, aflatoxin production by *A. flavus* was also foreclosed by certain week acids such as citric acid, propionic acid, acetic acid, and sorbic acid at several concentrations like 0.25, 0.5, 0.75, and 1% (Verma et al. 2000). Azole fungicides are also used as a tool to control fungus growth and aflatoxin production with prochloraz being more effective than tebuconazole (Mateo et al. 2017).

Biological methods

The aflatoxin contamination in agricultural products and many other food commodities are also minimized by the use of various microorganisms. Biological agents such as bacteria, yeasts, molds, and algae exhibit the different potential to degrade the aflatoxin in the emulative environment. Detoxification of aflatoxins by using biological agents is divided into two procedures named absorption and enzymatic decadence (Jard et al. 2011). Aflatoxins can be absorbed by microorganisms directly either by concatenating to their cell wall contents through effectual internalization or congregation (Motawe et al. 2014). Aflatoxins can also be absorbed by dead microorganisms; this ability can be helpful for the fabrication of bio-filters in the form of probiotics and found application in fluid decontamination (Mwakinyali et al. 2019). Degradation of aflatoxins can also be done by intra or extracellular enzymes; the end products of such enzymatic degradation are mostly water and CO_2 (Aliabadi et al. 2013). In a study on testing the efficacy of different microbes strains, only *Flavobacterium aurantiacum* B-184 was found to be effective enough for aflatoxin degradation (Darsanaki & Miri 2013). However, different bacteria strains were also found to be effective against degrading the AFB_1. The cell-free supernatant of strain *Bacillus velezensis* DY3108 exhibits a strong AFB_1 degradation activity of 91.5% (Shu et al. 2018). The thermophilic bacterial strains (*Geobacillus* and *Tepidimicrobium*) also play a major role in AFB_1 degradation when used as a microbial consortium (Wang, Zhao, et al. 2017). Moreover, a significant reduction in *A. flavus* growth was observed in pre-harvest crops by inoculation of antagonistic strains of *Pseudomonas, Trichoderma, Ralstonia, Lactobacilli, Burkholderia,* and *Bacillus spp.* (Akocak et al. 2015; Yang et al. 2017). Surprisingly aflatoxin contamination was also found to be inhibited by using the non-toxigenic strains of *A. flavus* and other molds as a chief controlling agent (Udomkun et al. 2017).

Conclusion

Aflatoxins contamination in food crops and their derived products have become a serious threat to humans and animal's lives. The problem is severe in developing countries where apart from causing a health hazard, the toxin-contaminated products are also losing economic value in the global food market. Various physical, chemical, biological, and nano-particles based approaches are used for minimizing and management of aflatoxin in food crops. However, researchers are also progressing in the development of fungal resistant varieties through breeding and genetic engineering approaches but their outcome is still a major concern. Hence a combined approach of using resistant varieties along with recommended pre-and post-harvest practices should be followed by farmers and food industries to minimize and degrade the aflatoxin content in food crops and their derived products.

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