Samarajeewa U, J Food Sci Nutr 2024, 10: 192
DOI: 10.24966/FSN-1076/100192

HSOA Journal of Food Science and Nutrition

Review Article

Agronomic Prevention of Pre-Harvest Mycotoxin Contamination in Foods: A Review

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Abstract

Mycotoxins, the antinutrients contaminating foods, continue to be an unsolved food safety hazard originating from the field. There is much attention on detoxification of contaminated foods by a variety of methods, with little success in commercialization of the findings. Preventing mycotoxin contamination at pre-harvest crop production is the more rational way of avoiding food safety hazards. With improvements in analytical methods, new mycotoxins and known mycotoxins at low concentrations are identified in food crops requiring increased attention. Identification of plant varieties resistant to mycotoxin contamination and application of biocontrol methods to resist mycotoxin production has been a subject of continuous study with some success at commercial level. Pre-harvest control of mycotoxins requires introducing checks at cultivation. The agronomic protection of staples and oilseeds through preventive methods is a priority. It is necessary to implement mycotoxin management practices based on a food safety management approach commencing at agronomic controls through Good Agricultural Practices, aiming prevention of proliferation of mycotoxigenic fungi. This review examines the current knowledge on agronomic and biocontrol of mycotoxins in foods pre-harvest, their limitations, and successful applications.

Keywords: Agronomic; Biocontrol; Mycotoxin prevention; Pre-harvest; Varietal resistance

Introduction

Contamination of foods with the antinutrient mycotoxins is addressed continuously through research aiming safe food supply. Protection of foods and feeds from mycotoxins requires minimizing contaminations at crop production. This review examines the applicable agronomic control mechanisms to prevent contamination of maize, peanuts, and grains by carcinogenic *Aspergillus and Fusarium* metabolites.

More than 300 potentially toxic metabolites from fungi have been recorded since the detection of hepatocarcinogenic aflatoxins in 1960. Of them, less than 4% are of immediate concern to food safety. Complete control of the mycotoxigenic fungi and their activities in foods continues to be a challenge. Among the crops vulnerable to mycotoxin contamination, peanuts and maize (corn) stand high.

Mycotoxin contamination of foods begins at the crop production stage. Soil-borne fungi release their spores to soil and air that may colonize the edible components of grains, nuts, or fruits apart from penetration through the flowers. Given the appropriate humidity in the environment or moisture on the kernels of agricultural products, the fungi colonize on the surface and their hyphae penetrates soft kernels depositing mycotoxins inside. Mycotoxins may become chemically detectable within three days of fungal infection.

Multiple mycotoxins are a problem in food crops. Mycotoxins may co-occur in food crops, and in masked forms as sugar derivatives in plant cells [1-4]. Co-occurrence of aflatoxins with fumonisin at a frequency of 8.4% and fumonisin with zearalenones at a frequency of 2% is reported in maize [2,5], and in bee honey [6]. Up to 51 microbial metabolites, which includes combinations of mycotoxins have been reported from maize [3]. Additive effects of fumonisin and zearalenones on porcine granulosa cell proliferation and steroid production have been demonstrated [7]. Additive, synergistic, and antagonistic effects were observed in piglets fed with diets containing combinations of fumonisin B and deoxynivalenol [8]. In human and animal metabolism of masked mycotoxins, the parent molecules may be released reintroducing the hazards associated with original mycotoxins [9]. Mitigation of mycotoxin production should therefore start at the crop production stage through appropriate preventive methods. Mitigation may include a combination of Good Agricultural Practices (GAP) and biological control methods. Some of the more hazardous multiple crop-mycotoxin relationships affecting the food chain are summarized in table 1.

Mycotoxin	C*	Major Fungi	Main crops	Prominent Hazard	Ref
Aflatoxins	1	*Aspergillus flavus, A. parasiticus, A. nomius, A. pseudotamarii*	Peanut, maize, Cottonseed, rice, tree nuts.	Hepatotoxic.	[10]
Ochratoxins	2B	*A. ochraceous, Penicillium verrucosum*	Wheat, cassava, maize, cereals, peanuts, cocoa.	Nephrotoxic, Urinary tract carcinoma.	[11]
Fumonisins	2B	*Fusarium verticilloides, F. proliferatum*	Maize, Sorghum, rice.	Esophageal carcinoma.	[7]

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Citation: Samarajeewa U (2024) Agronomic Prevention of Pre-Harvest Mycotoxin Contamination in Foods: A Review. J Food Sci Nutr 10: 192.

Received: July 23, 2024; **Accepted:** August 05, 2024; **Published:** August 12, 2024

Trichothecenes T-2 toxin Deoxynivalenol	3	*F. sporotrichiodes, F. poae, F. graminearum*	Maize.	Inhibit protein & nucleic acid synthesis affecting many organs.	[12]
Zearalenone	3	*F. sporotrichiodes, F. poae, F. graminearum*	Maize, wheat, barley, oats.	Estrogenic to animals, affects immune system.	[13]
Patulin	3	*Penicillium expansum, Byssochlamys*	Apple, pears, peaches. Fruit juices.	Adverse effects on liver and kidney. Carcinogenic and immunosuppressive effects.	[14]

Table 1: Major multiple crop-mycotoxins relationships needing mitigation.

C*=Carcinogenicity classification of IARC: 1=highly carcinogenic, 2A=Probably carcinogenic, 2B=Possibly carcinogenic, 3=Not classifiable as carcinogenic to humans, 4=Probably not carcinogenic to humans [15].

The diversity of potential hazards on human health due to combinations of individual hazards identified in the table make antinutritional effects arising from mycotoxins complex diagnostically [5].

Agronomic Considerations and Mycotoxin Hazards

Growth of food crops and mycotoxigenic molds are environment dependent. The abiotic factors (soil moisture, high humidity, temperature, and mechanical damage to plant components) and biotic factors (host susceptibility, fungal virulence, insect attacks) contribute to mycotoxin production during the pre-harvest stages of crop growth. The entry of the mycotoxigenic fungal spores through silk, influenced partly by the environmental factors, is the main challenge associated with protection of corn (maize) [16]. The silk is water dense, soft, and nutrient rich, serving as a guided doorway for the fungal spores to penetrate corn seeds [17]. The entry of spores during growth of cobs is related to the physiological age of the silk, ambient temperature, and relative humidity of the environment [18]. In peanuts, the entry of mycotoxigenic fungi may occur at the tender pod stages with soft shells and accompanying parasitic attacks, especially under favorable moisture conditions [19]. The peanut pods grow in an environment of mycotoxigenic fungi in the soil. Weaknesses triggered by extreme environmental factors on the development of the shell, or inadequacies of the nutrients, make peanuts easy targets for *Aspergillus* infections [20]. Droughts weaken the resistance of peanut kernels against fungal infections, while exposure to excessive rain provides a more conducive environment for fungi to grow on peanuts.

At the early stages of development of peanut seed, anthocyanins, flavonoids, coumarins and phenolic acids present in the seed coat (testa) serve as chemical barriers against fungal invasions. However, with the maturation of the seeds and post-harvest drying, the resistance to *A. flavus* infections tends to fade [21]. The pre-harvest control of mycotoxins requires biotic and abiotic interactions through protective agronomic practices. As mycotoxin contamination is more prune to extremes of environmental conditions, maintaining the right environment including soil nutrients remains a challenge in crop production stages to minimize contaminations. Agronomic prevention of mycotoxins requires early attention based on predictive science.

Use of decontaminated seeds, biological control methods, and ploughing the fields immediately after harvest are reported to reduce mycotoxin contamination in wheat [22]. A knowledge-based approach of combining several pre-harvest interactions including use of seeds resistant to fungal infections, seems to be effective in reducing the mycotoxin contamination of wheat.

Studies on relationships of maize fungal microbiome at pre-harvest and mycotoxin contamination identified dry conditions as the key driver for proliferation of *Aspergillus*, whereas *Fusarium* proliferation was insensitive to weather patterns [23]. The study demonstrated alteration of pre-harvest microbial composition during dry spells, providing opportunities to predict probable mycotoxin contaminations. Irrigation to maintain plants vigorous may provide a preventive approach for aflatoxin controls in the field. However, the advantage of moisture for fungal growth makes identification of the right moisture balance throughout crop growth challenging unless plant houses are used.

Rising Mycotoxin Hazards

Ability of each individual toxigenic fungus to produce several mycotoxins of differing toxicity, make recognition of antinutrient effects on foods challenging. Aspergillus produces four aflatoxins designated B1, B2, G1 and G2 having different degrees of toxicities. The trichothecene mycotoxins of high relevance are classified into 4 groups depending on their functional moieties (Table 2). Of the four groups of trichothecenes, groups A and B are studied widely due to their toxicity and the associations with widely consumed cereals.

Type	Mycotoxin	Main Fusarium species responsible
A	T-2 and HT-2, Diacetoxyscirpenol (DAS), Harzianum A, Neosolaniol (NEO) and Trichodermin).	*Fusarium sporotrichioides, F. graminearum, F. moniliforme, F. myrothecium, F. acuminatum, F. culmorum, F. equiseti, Cephalosporium sp., Trichoderma sp.*
B	Deoxynivalenol (DON), Nivalenol (NIV), Trichothecin and Fusarenon X.	*F. graminearum, F. culmorum, F. sporotrichioides, F. cerealis, F. lunulosporum.*
C	Crotocin.	*F. graminearum, F. sporotrichioides, F. poae and F. equiseti.*
D	Satratoxin G & H , Roridin A and Verrucarin A.	*Stachybotrys chartarum, Myrothecium sp .*

Table 2: Classification of Fusarium toxins [12,24].

Table 2 indicates the complexity that may arise due to several species of *Fusarium* producing different types of mycotoxins, requiring intense research to recognize control mechanisms to suit all probable situations. Effects of a combination of mycotoxins from different fungi on a given crop create a more complex nutritionally hazardous situations [5].

The exposure of food crops to fungi is continuous, irrespective of their growth phases as spores of the mycotoxigenic fungi are vectored by insects invading the plant tissues and harvested foods at different maturities. The insects form an army that can chew through by penetrating natural physical and chemical resistances in plant tissues and depositing the spores on the fleshy endosperm tissues having supportive moisture concentrations. Growth specific moisture concentrations is a natural requirement during crop growth which cannot be changed pre-harvest to prevent mycotoxin contaminations and insect invasions.

Entomopathogenic fungi are examined now to control insects under pre-harvest conditions taking an integrated pest management approach [25]. Insect management should possess the advantages of non-interference with pollinator insects and other beneficial

organisms as against toxigenic spore carriers. There are formulations of entomopathogenic fungi applicable to soils, targeting specific insects associated with the crop types to be cultivated. The formulations may carry the potential to be used to prevent pre-harvest transfer of spores of mycotoxigenic fungi through insects in the field. Breeding and release of entomopathogenic fungi is time consuming, requiring monitoring of their performance to keep the control levels active throughout crop growth up to harvest. Though such an effort would minimize entry of mycotoxigenic spores to food crops through insect vectors, it may not totally eliminate contaminations.

Environmental Effects on Mycotoxin Production

The environment and the climate are factors beyond human control, except in greenhouse cultivation systems. However, there is a possibility of influencing the moisture availability to the crops through soil at least partly in irrigated crops. The moisture content in commodities is linked to the relative humidity and the availability of water in the soil at the crop production stages [26]. Rainfall makes a notable contribution in determining fungal growth by providing water excessively to crops and increasing the relative humidity of the environment. Soil moisture, as against drought makes crops more resistant to fungal invasions. On the other hand, high relative humidity leads to moisture absorption by the harvested commodities as visible with uprooted peanuts exposed to rain in the field. Striking the right moisture balance to control mycotoxins is a challenge.

Based on the models developed from a multilayer survey on the factors affecting fumonisin contamination of maize in France since 2003, the identified agroclimatic risk factors include the presence of boring insects distributing fungal propagules, the use of late maturing maize varieties, the elevated temperatures in July and October, and the water deficits during the maize cycle [27]. The findings are vital in designing preventive methods for the growers and maize handlers to manage fumonisin production in the field to minimize public health risks. It requires predictive knowledge on the environment for effective implementation of preventive methods.

Biocontrol of Mycotoxin Contaminations

In biological control, desirable organisms are introduced to suppress mycotoxigenic fungi by altering the balance of microorganisms in the crop ecosystems. Atoxigenic microbial strains are introduced to compete with their mycotoxigenic counterparts in managing mycotoxin problems in food crops. Competition by atoxigenic strains restricts the growth of mycotoxigenic fungi at an early stage in the food chain. Some of the atoxigenic microorganisms may outcompete the mycotoxigenic fungi [28]. The introduced microorganisms may also detoxify or adsorb mycotoxins already on the food commodities [29-31]. The atoxigenic microorganisms are selected from among those adapted to the same environment, showing clear inability to produce any mycotoxins, and the ability to outcompete the mycotoxigenic fungi. The microorganisms to be used in biocontrol may arise from the same or other genera, or species that could exhibit beneficial characteristics. Atoxigenic *A. flavus* is from the same genus and many microorganisms discussed here for biocontrol of aflatoxins are from other genera. The ability of selected strains or species to spread from the soil or air to the target locations of the cereals and peanuts (spikes, kernels) easily constitutes an added advantage.

The competing microorganisms may be applied to the soil, the host plants or the host seeds depending on the technological needs. Introduction of the biological agents into the seeds to be sown may prevent proliferation of mycotoxigenic fungi during seed germination. The applications on seeds may take the form of coatings of antagonistic and/or plant growth promoting microorganisms. The seeds to be sowed also may be primed with essential oils or bacterial species to prevent invasions by the mycotoxigenic fungi. Coatings provide the opportunity to minimize application of fungicides on the seeds and soils prior to, or at sowing, making it an environment-friendly approach. Technology for coating seeds with fungi to enhance growth, facilitate nutrient uptake, and retain grain quality in winter wheat has been successfully demonstrated under field conditions [32]. Extension of the technology to incorporate antifungals would form an important step. Reviewing the biocontrol methods to downsize mycotoxin contamination in food crops, Zadravec et al. [33], described its application to cereal crops, highlighting the importance in avoiding mold infestations in the seeds to be sown. Developing resistance in or on the seeds provides the first weapon in the food chain against mycotoxigenic fungi. The studies in this field need to move beyond laboratory work focusing on industrial application along with GAP (Figure 1).

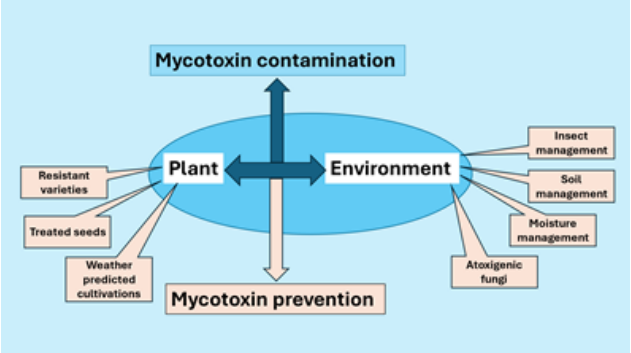

Figure 1: Interactive practices needed in preventing mycotoxin contaminations.

Aspergillus is mainly a saprophyte in the soil. Changing the soil microbiome to competitively eliminate mycotoxigenic fungi, provides another preventive approach to minimize mycotoxins in food crops. Several field studies have shown that *A. flavus* from soil tends to colonize the plant, maize, while *A. parasiticus* tends to stay mostly in the soils in the same environment. In the maize and peanut cultivated soils, comparatively higher populations of *A. parasiticus* than *A. flavus* were noted [34]. In a study where soil was inoculated with atoxigenic *A. flavus* and examined following the contamination patterns in maize, notable reductions in aflatoxin production in maize during the years 1994 to 1997 were reported [35]. The authors observed *A. flavus* as the more aggressive colonizer on the crop, though *A. parasiticus* was present in large populations in the soil. The initial focus thus needs to be on outcompeting the toxigenic *A. flavus* in the plant environment. Dorner et al. [36], describes 80-90% reduction of aflatoxins in peanuts by introducing atoxigenic *A. flavus* coated on hulled barley and applying in the field during middle of the growing period of peanuts. The technology received US-EPA section 3 registration, with registration number 100-1469, for use as a biopesticide under the commercial name afla-guard® [37]. Though use of biopesticides commercially is a major success, the problems that may arise due to genetic modifications in mycotoxigenic fungi to overcome the control mechanisms need to be followed continuously in the fields.

The atoxigenic microorganisms show a wide applicability in outcompeting the mycotoxigenic fungi in different situations and on different food crops serving as biopesticides. *In vitro* studies comparing colonization of atoxigenic and aflatoxigenic *A. flavus* on peanuts have shown significantly higher incidence and severity of colonization by atoxigenic *A. flavus* [28]. Biocontrol has been successful on maize, peanut, and cottonseeds in the USA [38] and on peanuts and cereals in Argentina [39]. There are at least two successful commercially available microbial cultures introduced in 2004 in the USA [36]. African countries have controlled the aflatoxigenic fungi in the field biologically [10]. The cultures they used have shown equal efficiency when applied on leaves of the host plants or the soil, serving as bio-fungicides too. The protection against mycotoxigenic fungi by the introduced atoxigenic cultures is reported to continue into post-harvest storage of the commodities providing an extended advantage [40]. A study in Argentina reports the use of formulations combining native bacteria, filamentous fungi, and yeasts capable of producing high biomasses for aflatoxin control. Another study in Argentina, reports the use of a bioformulation consisting of 2 native atoxigenic *A. flavus* cultures. The formulation has prevented aflatoxin accumulation in maize and continued protection for 6 months of storage in hermitically sealed bags [18]. Timing appears to be an important criterion for releasing the biocontrol formulations on the growing crops. The formulations have been more effective when applied during frequent rainfall or under heavy soil moisture conditions, favoring high biomass production outcompeting the mycotoxigenic fungi. Successful field control on aflatoxin production in the peanuts and continuation into post-harvest storage is reported in China, with atoxigenic *A. flavus* cultures [41]. The peanuts produced in soils with the biocontrol agents in this study showed low aflatoxin concentrations, even after 3 months of post-harvest storage under humid conditions. The carry over biocontrol effect is more important as peanuts tend to get contaminated with fungi post-harvest readily, compared to the grains. Incorporation of atoxigenic cultures in the field as a part of GAP could form a basis for early checks on mycotoxin contaminations, making downstream control steps more effective. However, the possibility of atoxigenic strains acquiring toxin producing capacity over many years of exposure needs continuous monitoring.

A variety of microbial fungicides for effective pre-harvest control of *A. flavus* are produced commercially. Most of them reduce conidiospore production and aflatoxin B1 production of *A. flavus in vitro*. Two of the commercial microbial fungicides have shown 49% and 80-90% reduction of aflatoxin B1 on the maize kernels with two delivery methods [40]. Microbial fungicides carry the advantage of low cost and acceptable safety, compared to synthetic pesticides. Yang et al. [42], describes identification of volatiles from *Saccharomyces cerevisiae* isolate NJ1, capable of inhibiting growth of *A. flavus* and aflatoxin production. The authors recognized 3-methyl-1-butanol as a key inhibitory compound, from among nine compounds in the yeast volatile fraction. Instead of a single compound from the yeast volatiles, a mixture may carry a high synergistic inhibitory potential. Microbial fungicides need recognition as a mixture of natural components effective against the mycotoxigenic fungi.

Aspergillus carbonarius produces ochratoxin A in wine, coffee, cocoa, and grapes. Llobregat et al. [43], demonstrated competitive exclusion of ochratoxin A production by infecting grapes with atoxigenic mutants, *A. carbonarius ΔotaA* and *ΔveA in vitro*. *In vitro* studies have shown *A. carbonarius* carrying the knockout mutant is not affected by osmolarity of the host and oxidative stresses from the environment. This preliminary finding possesses the potential in producing commercial cultures against ochratoxin A production in the same way as for aflatoxins. Yang et al. [11], discussed the ability of biocontrol microorganisms to cleave the molecular structure of ochratoxin A, by hydrolysing the amide bond. The inhibitory effect of yeast *Yarrawia lipolitica* GZPX-3Y-1 on ochratoxin biosynthetic pathway in *Aspergillus niger* A-8 in ham is reported recently [44]. With ochratoxin A identified as a probable carcinogen present in wheat, research to eliminate ochratoxin A from the human food chains tend to increase with time.

Interactions among mycotoxins themselves may tilt the balances between accumulation of different mycotoxins on crops [5]. A field study on *A. flavus* resistant maize in the USA showed increased Corn-Ear-Worm damage and increased fumonisin concentrations in seeds parallel to suppressed aflatoxin production [45]. The study also projects linkages in fumonisin formation with weather patterns that delay flowering, and increased worm attacks. It appears that a more meaningful control could be achieved only after recognizing the climatic patterns, insect infestations and competition among mycotoxigenic fungi on a time scale related to growth phase of maize. In contrary to the USA field observations, a study examining 200 samples of atoxigenic *A. flavus* treated maize from fields in Nigeria and Ghana have failed to show an increase of fumonisin content [46]. Multiple control approach linking climatic effects with inherent resistance of crops to fungi, and competition among fungi are important, in working out mechanisms to prevent pre-harvest mycotoxin hazards. There is research at molecular level to understand the interactions among biosynthetic pathways of mycotoxin in production with multiple toxigenic fungi on grains [5].

Czembor et al. [47], comparing varieties of maize resistant to Fusarium-Ear-Rot (FER) under natural and experimental field conditions, observed a significant positive correlation between the severity of FER and the presence of fumonisin but not the quantity of fumonisin. Reduced FER means reduced opportunities for fumonisin production in maize. However, the quantitative production of fumonisin would depend on host and climatic factors too. The results also indicate reduction of fumonisin through use of selected varieties of maize resistant to visible FER. Varietal resistance to fungal growth invariably reduces fumonisin production.

Transfer of atoxigenic fungal species to soils requires appropriate vehicles. Rice grains serve as a good vehicle to transfer atoxigenic *A. flavus* into the soil [48]. However, rice possesses the disadvantage of being consumed by predators, nullifying the effort to disperse atoxigenic *A. flavus* among plantations. In pistachio orchids, inoculation of fallen male inflorescences and the inflorescences in the plants has resulted in increased appearance of commercially recommended atoxigenic *A. flavus* in the plant canopy, especially under high humidity conditions [49]. While biocontrol has shown success in minimizing the growth of mycotoxigenic fungi at pre-harvest, probable risk on quality loss of the produce caused by atoxigenic fungi need examination. Aflatoxigenic fungi have already been reported to affect the nutritional quality of red pepper by reducing the fat and ascorbic acid concentrations [50]. The atoxigenic fungi may be producers of exolites [51], that could add new toxicities to foods. Possible mutations of atoxigenic fungal isolates to toxigenic forms too need to be monitored continuously. Preventing unforeseen toxic effects and quality deteriorations from competitive atoxigenic microorganisms needs further studies.

Varietal Resistance in Food Crops to Mycotoxin Production

Early research on mycotoxin prevention in food crops focused on recognition of plant varieties resistant to fungal growth or mycotoxin accumulation. Resistance of infection or mycotoxin accumulation may be achieved by preventing fungal infections, preventing fungal growth after infection, or inhibiting the biosynthesis of mycotoxins. Food crops may carry the capacity to prevent any of the three activities biotically. In several food crops, features resisting mycotoxin production have been observed among their varieties and cultivars. Capitalizing on the host resistance and understanding the behavior of the mycotoxigenic fungi against host resistance helps in initial mitigation of mycotoxin contamination at crop production.

The maize varieties resistant to aflatoxin formation have been used in eliminating infection by the aflatoxigenic fungi. The first line of maize resistant to aflatoxin formation, *Mp313E* was released by The Corn Host Plant Research Unit of Mississippi in 1990. This was followed by releasing more effective resistant lines to reach the same objective [51]. Six inbred maize lines resistant to *A. flavus* and aflatoxin production released by the USA were field tested in African and Asian countries. Three of the resistant inbred lines evaluated in Illinois have shown the ability to suppress aflatoxin biosynthesis, rather than fungal growth. Differential resistance to aflatoxin production at pericarp level and sub-pericarp level have been demonstrated in maize seeds [52]. The observation suggests the interference on aflatoxin production by the constituents in the kernels, with pericarp waxes playing a significant role. The transfer of resistance to aflatoxin accumulation to hybrids and through inbred lines by conventional methods has been proven difficult [53]. Combining the resistance to aflatoxin accumulation with high yielding characters of maize cultivars appears to be even more challenging.

The resistance of 67 genotypes of peanuts to aflatoxin production was examined in Senegal by laboratory inoculation experiments. Of them, 33 genotypes exhibiting reduced incidences of contamination were identified. Among them, the genotype *12CS_104* was reported to cause low aflatoxin production below 4µg/kg, making the genotype acceptable from a regulatory point of view [53]. Examining 99 accessions of peanuts in China, the researchers recognized two resistant accessions, and molecular markers that could deploy resistance to aflatoxin production through cross breeding [54]. In peanuts, the secondary metabolites anthocyanins, flavonoids, coumarins, and phenolic acids inhibiting infections by *A. flavus* are reported [21]. Studies on factors responsible in eliciting resistance to mycotoxins for their chemical capacity, or biochemical interactions and the ability to transfer these characters to the next generations of peanuts need deep examinations [55].

The conventional breeding methods with peanuts and maize had limited success in protecting the field crops against fungal infections and mycotoxin contamination. Efforts to propagate mycotoxin resistant crops through genomic and transgenic interactions would perhaps bring in long lasting changes of host-fungi equilibrium under focus. However, this approach may weaken genes providing protection against other agents. This aspect needs new orientations in research.

Conclusion

Notable success has been achieved in use of atoxigenic *Aspergillus* species in checking aflatoxin production commercially under different agroclimatic regions. However, the success is linked to the ability of the farmers to predict the environmental changes to time the cultivations together with introduction of competing atoxigenic microorganisms to prevent formation of *Aspergillus* and *Fusarium* toxins. Research to recognize crop varieties resistance to mycotoxin production has yielded poor and inconsistent results over the years. However, there is emerging evidence to recognize the possibility of influencing the biosynthesis of mycotoxins at the crop-fungi interphase. The potential use of the current knowledge biological control combined with GAP is expected in the future to pave way for pre-harvest control of mycotoxins in food crops ensuring food safety.

Acknowledgement

The author acknowledges the facilities provided by the University of Peradeniya for the work.

Conflict of Interest

The author has no conflicts of interest arising from financial or non-financial benefits.

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