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Aflatoxins in cereal crops and their integrated management: A review

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Abstract
Cereals and cereal-based products are the most common foods consumed by humans globally. Among cereals, rice, maize and sorghum are mostly contaminated by aflatoxins in natural conditions due to changes in agricultural practices. During the early phase of crop development and the second phase of crop maturation, aflatoxins are contaminated. Warm, humid, and even hot deserts and drought conditions increase contamination. The aflatoxins are produced both in pre-harvest and post-harvest conditions. Cereal crops like rice is more prone to aflatoxins contamination as compared to other cereals. The poor drying of rice grains results in greater moisture content (>14%) and the growth of the fungus *Aspergillus flavus*. Hence, these fungus result in grain and/or husk discoloration, which lowers grain quality. The extent of fungal growth and aflatoxins production in cereals depends on temperature, moisture, soil type, and storage conditions. The current review provides insight into the sources of integrated management practices of aflatoxins to ensure food safety and security.

Keywords: Aflatoxins, *Aspergillus flavus*, cereals, integrated management

Introduction
Aflatoxins are highly toxic and carcinogenic mycotoxins that frequently contaminate several cereal crops grown in warm agricultural areas across the globe (Shephard, 2008; Liu and Wu, 2010) [23, 20]. Aflatoxin contamination in maize and sorghum is ubiquitous and it can end up in milk from animals fed contaminated feed (Shephard, 2008; Udomkun *et al*., 2017) [23, 25]. Cereals provide a highly porous substrate for the formation of mould. Mold growth may lead to the contamination of the crops with mycotoxins, depending on the environmental conditions in the field and during storage. It has been reported that approximately 25% of the total cereal's world production is contaminated by at least one mycotoxin (Devegowda *et al*., 1998) [13]. Mycotoxins, especially aflatoxins (AFs) are stable compounds and their degradation is limited at high temperatures. Therefore, mycotoxins can enter and contaminate the human food chain through cereal derived food products (Kabak, 2012) [17] Several *Aspergillus* species possess the ability to produce aflatoxins although the major causal agent of contamination globally is *Aspergillus flavus* Link (Klich, 2007) [18]. Aflatoxigenic *Aspergillus* strains that contaminate grains prior to harvest result in postharvest aflatoxins contamination (Waliyar *et al*., 2015) [27]. The range of daily AF consumption worldwide was 3.0 to 17.1 ng/kg bw, with rice, wheat, and maize making up the majority of that amount (Andrade and Caldas, 2015) [2]. The maximum permissible concentration of AFs in grains is 10 g/kg (10 ppb) (Ayelign *et al*., 2018) [4]. According to the CDC (2004) [7], eating foods with high levels of aflatoxin can have immediate health effects like liver cirrhosis and death, while sub-lethal chronic exposure can have long-term effects like cancer, immune system suppression, impaired food conversion, interference with micronutrient metabolism, increased incidence and severity of infectious diseases, stunted child growth, and poor productivity in humans and animals (Williams *et al*., 2004; Liu and Wu, 2010; Chan-Hon-Tong *et al*., 2013) [30, 20, 8]. Women who ingest aflatoxin-contaminated foods during pregnancy and breastfeeding may expose their unborn child to aflatoxins (Chan-Hon-Tong *et al.*, 2013) [8]. Aflatoxin exposure affects 4.5 billion individuals worldwide, mostly in developing nations (CAST, 2003; Williams *et al*., 2004) [6, 30].

Integrated management of aflatoxins
Aflatoxin contamination is a complicated process that begins in the field and continues in storage (Lillehoj *et al*., 1980; Williams, 2006) [19, 32]. Implementing good agricultural practises (GAP) is the most successful and cost-efficient technique for producing 'aflatoxin-free' crops

and commodities. A number of pre-harvest and post-harvest management techniques have been suggested to decrease the buildup of aflatoxin (Hell *et al.*, 2008) [15]. Cultural methods, biological management of aflatoxin-producing fungi, and correct post-harvest handling are examples of these (Lillehoj *et al.*, 1980; Jones, 1987; Hell *et al.*, 2008; Bandyopadhyay *et al.*, 2016) [19, 16, 15, 5].

Pre-harvest management of aflatoxins

Pre-harvest aflatoxin contamination can be reduced by ploughing to bury crop waste that serves as a food source for *A. flavus*, choosing the right planting date (to take advantage of periods of rainfall and avoid end-season drought consequences), seed dressing with systemic fungicides or biocontrol agents, maintaining good plant density in the fields, eliminating prematurely dead plants, managing weeds, pests and diseases and appropriate fertiliser treatment (Lillehoj *et al.*, 1980; Jones, 1987; Hell *et al.*, 2008) [19, 16, 15]. These methods reduce the growth of *A. flavus*, which produces aflatoxin.

Resistant crop varieties

When stressed-out plants are cultivated, there is an increase in the amount of aflatoxin contamination (Bandyopadhyay *et al.*, 2016) [5]. Using crop cultivars with major biotic stress resistance, drought tolerance, and insect pest tolerance will lessen plant stress and help reduce aflatoxin contamination. There is a complicated and multi-gene regulated level of resistance to aflatoxin contamination in maize populations (Warburton and Williams, 2014) [28]. There has been progress in selecting maize inbred lines that are resistant to aflatoxin buildup (Windham and Williams, 2002; Warburton and Williams, 2014) [33, 28]. Yet, despite all of the efforts, the resistance level in the existing maize hybrids is still insufficient to stop unacceptable aflatoxin contamination.

Bio-control of aflatoxins

Biological management of aflatoxins is considered to be the best technique for pre-harvest aflatoxin control because it requires very little of the farmer's effort (Bandyopadhyay *et al.*, 2016) [5]. It makes advantage of *A. flavus* strains' ability to efficiently outcompete toxic strains for the same ecological niche (Cotty, 2006) [10]. Atoxigenic *A. flavus* strains are dispersed in the field on heat-killed carriers (such as wheat, sorghum, or barley grain) which additionally serve as sources of nutrients (Bandyopadhyay *et al.*, 2016) [5]. Atoxigenic *A. flavus* has benefits over local aflatoxin producers in terms of reproduction and dissemination due to the biocontrol formulation (Cotty *et al.*, 2008) [10]. The timing of biocontrol applications is critical for success; typically, they are applied 2-3 weeks prior to crop blooming, before resident *Aspergillus* populations start to proliferate, allowing for the effective displacement of aflatoxin production (Atehnkeng *et al.*, 2014; Bandyopadhyay *et al.*, 2016) [3, 5]. Aflatoxin contamination is reliably reduced by more than 80% when the biological control is being used and the effect seems to last into storage (Atehnkeng *et al.*, 2014) [3].

Post-harvest management of aflatoxins

However post-harvest techniques should be added to pre-harvest strategies that will further reduce aflatoxin levels (Table 1). Before storing, the crop should be adequately dried to an acceptable moisture level (10-13%) in order to lessen and avoid the growth of fungus (Hell *et al.*, 2008) [15]. It is best to dry fresh cobs or grain off the ground, on tarpaulins, or on raised platforms. Solar dryers have been developed for faster and more effective corn drying in a controlled environment with better sanitation (Sharma *et al.*, 2009; Ogunkoya *et al.*, 2011) [22, 21]. Affordable, low-maintenance solar dryers are necessary for smallholder farmers in to promote the use of solar technology (Sharma *et al.*, 2009; Ogunkoya *et al.*, 2011) [22, 21].

Table 1: Strategies for integrated management of aflatoxin in cereals for improved food safety and health. (Lillehoj *et al.*, 1980; Jones, 1987; Hell *et al.*, 2008; Sharma *et al.*, 2009; Ogunkoya *et al.*, 2011) [19, 16, 15, 22, 21]

Sl. No.	Stage	Action
1.	Pre-harvest	Biological management by competitive exclusion; timing of planting; crop variety used; genotype of seed planted; irrigation and pesticides the harvesting period.
2.	Post-harvest	Drying and Storage Hand sorting; Drying on mats; Sun drying; Storing bags on wooden pallets or elevated platforms; Use of insecticides and hermetic storage structures; Rodent control.

Improved storage structures

It has been demonstrated that the use of controlled environment storage (hermetic) with high CO_2 and low O_2 reduces the synthesis of aflatoxin in grains and inhibits *A. flavus* growth (Anankware *et al.*, 2012; De Groote *et al.*, 2013) [1, 12]. Hermetic storage is particularly effective at reducing aflatoxin contamination in storage when used with grain sorting to remove damaged grain (Chulze, 2010). There are several storage solutions available, including metal silos and hermetic storage bags for smallholder farmers, such as super grain bags (Anankware *et al.*, 2012; De Groote *et al.*, 2013) [1, 12].

Conclusion

Aflatoxins' contamination of cereal crops at pre- and post-harvest conditions can be controlled to some extent by the implementation of good agricultural practices (GAPs) and good storage practices (GSPs). Inappropriate storage, higher humidity and temperature allow the growth and proliferation of aflatoxins producing fungi (*Aspergillus flavus* and *Aspergillus parasiticus*). Fungi metabolites can contaminate up to 25% of stored grains when exposed to unsuitable storage conditions. Higher levels of contaminations were reported in cereals such as rice, wheat, maize and millets account for greater contaminations in humans. Control of aflatoxins contamination requires a holistic approach that will protect throughout the production chain. The danger can be mitigated by decent agricultural, storage and processing practices; including production of resistant varities, proper and adequate drying, insect and mold control during storage, good manufacturing practices including proper and adequate cleaning and processing.

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