AFLATOXINS IN FOOD GRAINS: CONTAMINATION, DANGERS AND CONTROL

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**ABSTRACT**

The most concern postharvest safety issue in food grains is aflatoxins production in contaminated stored grains. Consumption of aflatoxins contaminated grains can lead to complicated health issues that can lead to death. Aflatoxins are secondary metabolites commonly produced by Aspergillus flavus and Aspergillus parasiticus. They were reported to disturb foetus development, causes changes in the population and microbes, and among other things. In addition, aflatoxins, mutagenic secondary metabolites such as cyclopiazonic acid, inhibit the immune system and causes many forms of cancers. Aflatoxin B1 was classified under group 1 carcinogens by the International Agency for Research on Cancer. Aflatoxins contamination affects food security and can hinder international trade due to the strict ban enforce by many nations. Contaminations were reported in raw and processed grains (including ready-to-eat), milk and meat of farm animals and human breastmilk and blood. Major causes of grains aflatoxins contamination are wrong harvesting time and method, improper drying, poor storage and processing and higher moisture in the grains. Literature was gathered through an online search on Google Scholar, attention was given to the articles published in the last 5 years. Causes of fungal contamination, aflatoxins production and their control measures were deliberated, possible means of mitigating aflatoxins contamination through consumption of food grains were also recommended.

**Keywords:** mycotoxins, storage, drying, cereals, legumes

**INTRODUCTION**

Fungi can attack grains before or after drying and cause serious damage to raw materials and processed foods during storage and transportation (Aldars-García et al., 2016). Appropriate drying to a moisture content below microbial thriving levels is critical to the stability, postharvest storage and processing qualities of all stable grains (Bradford et al., 2018). Inappropriate storage and packaging materials that allow moisture permeation rises relative humidity during storage and favours insects and microbial activities (Bradford et al., 2018). Postharvest grain losses cause great constrain to food and nutritional security (Afoognon et al., 2015; Likhayo et al., 2018; Mezgebe et al., 2016), economy and health (Khaneghah et al., 2018; Kumiari et al., 2020).

Aflatoxins (AFs) are immunosuppressive, carcinogenic (Kachapulula et al., 2017), mutagenic and teratogenic (Blankson and Mill-Robertson, 2016; Kebede et al., 2020) secondary metabolites produced by fungi (Aron et al., 2017), mainly Aspergillus (Eljack, 2012; Maringe et al., 2016; Valencia-Quintana et al., 2020), Fusarium (Kebede et al., 2020) and Penicillium (Eliaś, 2016) during storage of contaminated grains. Aspergillus flavus and Aspergillus parasiticus occurs more frequently than other fungi in grains and produced more AFs including AFB1 (Mom et al., 2020). Ezekiel et al. (2020) recently discovered new fungi species suspected to be potential toxin producers. Mycotoxins production depends on certain environmental factors; fungi grow optimally in a humid environment rich in nutrients essential to them (Adeyeye, 2016). Grains can be contaminated by either field fungi, store fungi, or both (Ncube and Maphosa, 2020; Tola and Kebede, 2016). Ramirez et al. (2018) reported changes in the population and types of fungi during the storage of chickpea. AFs contamination accounts for about 25 % of global crop loss (Serdar et al., 2020). There are four types of AFs: B1, B2, G1 and G2 (Ahmadi et al., 2020). Aflatoxin B1 (AFB1) is the most mutagenic, carcinogenic and teratogenic material found in foods (Ahmadi et al., 2020; Nesct et al., 2016). It is the most potent known liver carcinogen (Jallow et al., 2018). It was classified under group 1 carcinogens by the International Agency for Research on Cancer (Al-Zoreky and Saleh, 2019). AFB1 is very stable and can be toxic at a meagre dose (Ponzilacqua et al., 2018). The menace of AFB1 is common to many staple foods in most developing countries. Groundnut is the most disposed crop to AFB1 contamination (Jallow et al., 2018). More than 90 % of food samples collected by Eshete et al. (2020) from Sidama zone, Ethiopia contains AFB1 above the EU permissible limit. Traditionally processed infant food in Ouagadougou, Burkina Faso contains AFB1 900 times higher than the EU limit of 0.1 µg/kg (Ware et al., 2017). More than 41 % of maize market samples in Ghana contain AFB1 above Ghana and EU permissible limits (Kortei et al., 2021). Sulaiman et al. (2018) associated urine AFB1 with cereal products consumption. AFB1 estimated daily intake of 0.23 µg/kg/bwd and 0.153 µg/kg/bwd were reported in Ghanaian infants and children respectively (Blankson and Mill-Robertson, 2016). The results of a laboratory experiment conducted by Bran et al. (2017) showed that Plerotus eryngii (king oyster mushroom) can degrade AFB1 in malt extract broth.

In addition to AFs, fungi also produced other carcinogenic and mutagenic secondary metabolites such as cyclopiazonic acid, aflatem (Ojiambo et al., 2018), ochratoxin A, fumonisins (Sun et al., 2017), deoxynivalenol, zearalenone, T-2 toxin and HT-2 toxin (Kunz et al., 2020). Fusarium graminearum produces...
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zearalenone and deoxynivalenol in grains particularly during slow drying or due to higher moisture in stored grains (Portell et al., 2020). Ochratoxin A and fumonisins were reported to cause renal cancer and liver cancer respectively (Huong et al., 2016).

The menace of mycotoxins contamination is a threat to food safety during storage and distribution (Aldars-García et al., 2016). AFS are persistent and their contamination can occur before or during harvesting (Kortert et al., 2019) and at various points along the supply chain depending on the handling condition (Manna and Kim, 2017; Neme and Mohammed, 2017; Udomkun et al., 2017). Bamba et al. (2021) reported AFS contamination in the spathes, cobs and grains of maize. Contamination occurs mostly during drying and storage (Njorge et al., 2019; Quellhorst et al., 2020).

Aflatoxins Contamination

Postharvest AFS contamination occurs when aflatoxigenic strains of Aspergillus contaminates grains before harvest (Waliyar et al., 2015). Global consumption of AFSs ranged from 3.0 to 17.1 ng/kg bw/day with rice, wheat and maize having the highest contributions (Andrade and Caldas, 2015). The maximum permissible limit for AFSs in grains is 10 µg/kg (10 ppb) (Ayelign et al., 2018).

AFS contamination occurs in grains due to exposure to certain pre-and post-harvest conditions (Aron et al., 2017). Contaminations are mostly associated with poor agricultural practices (Nleya et al., 2018). Tuan et al. (2018) reported that non-dormant seeds and that with low levels of dormancy can germinate while attached to the mother plant, this can reduce yield and trigger mould growth and AFSs accumulation before harvest. Kachapuluta et al. (2017) reported that unincultivated lands are loaded with more AFSs producing organisms than cultivated lands. Mould growth and AFSs contamination depend greatly on grain moisture content and temperature and relative humidity of the storage or packaging environment (Neme and Mohammed, 2017; Tola and Kebede, 2016).

Major factors that account for AFS contamination are wrong harvesting time and method, improper drying, inadequate storage and processing and higher moisture in the grains (Chakwukere et al., 2021; Neme and Mohammed, 2017). Aron et al. (2017) also reported that poor postharvest handling of grains causes AFSs contamination. Seetha et al. (2017) witnessed AFB1 increase in maize, sorghum, Bambara nut, groundnut, and sunflower during storage. Tibagonzeka et al. (2018) reported that grains dried on the bare surface are more prone to AFSs contamination than grains dried on a covered surface.

Except for few crops such as rice, many kinds of cereal and legumes are disposed to AFSs contamination (Gonçalves et al., 2019; Sun et al., 2017). Contaminations were reported during the pre-and postharvest stages in groundnuts, millet, sesame seeds, maize, wheat, rice, fig, spices, cocoa, and processed products such as peanut butter, cooking oil (Mahato et al., 2019), bakery products, coffee, macaroni (Serdar et al., 2020) and processed flours (Adelaye, 2016) among other grain products. Legumes in general are more prone to AFSs contamination (Eljack, 2012) and groundnut is more disposed than other legumes (Maringe et al., 2016). Sorghum, groundnut and maize contributed to AFSs contamination more than other grains (Neme and Mohammed, 2017; Tibagonzeka et al., 2018), their prevalence of AFSs contamination can be as high as 91 %, 55 % and 44 % respectively (Tibagonzeka et al., 2018). Maize, peanut and peanut oil are the most disposed food to AFSs contamination in sub-Saharan Africa (Ingenbleek et al., 2019). Higher temperatures and relative humidity facilitate mould growth and AFSs formation (Sun et al., 2017; Valencia-Quintana et al., 2020). The prevailing weather condition in sub-Saharan Africa characterized by heavy downfall and higher temperatures, facilitate mould growth and AFSs production in grains (Ingenbleek et al., 2019; Ncube and Maphosa, 2020; Nleya et al., 2018).

The danger is more common and likewise more extreme in developing countries (Udomkun et al., 2017). Mycotoxins contamination is more common in African countries due to poor socio-economic conditions (Kebede et al., 2020). The results of the survey conducted by Wangia-Dixon et al. (2020) in Makueni and Siaya Counties, Kenya showed that children from low-income families are more prone to AFSs contamination. About 49 % of complimentary food samples collected by Aron et al. (2017) from Bahi District, Tanzania reported being contaminated with AFSs. A significant proportion of maize, sorghum and millet samples collected from Makueni and Nandi, Kenya contains AFSs and fumonisins above the recommended levels of 10 ppb and 2 ppm respectively (Kang’Ethe et al., 2017). The AFSs levels in recently harvested groundnuts, beans, cowpeas and Bambara nuts samples from Shampa and Makoni districts, Zimbabwe is alarming and may significantly upsurge during storage (Maringe et al., 2016). Blankson et al. (2019) reported that 96 % of processed infant food sold in Accra, Ghana possessed AFSs above the EU permissible limit. The finding of Obade (2015) revealed that weaning foods commonly used Kisumu County, Kenya are contaminated with AFSs above permissible amounts. About 93 and 42 % of household and industrially processed foods samples respectively collected from Lagos and Ogun States, Nigeria are contaminated with mycotoxins including AFSs (Ojuri et al., 2019). Rice and beans samples collected from Enugu, Nigeria contain AFSs above permissible limits (Dozie-Nwakile et al., 2020). Likewise, maize samples collected from Dutsinma, Nigeria was heavily contaminated with Aspergillus fungi (Mzungu et al., 2018). About 58 % of basmati rice samples collected from Lahore, Narowal, Faisalabad and Multan, Pakistan reported to content aflatoxins above permissible limits (Makhtar et al., 2016). Aflatoxins content between 0.09 and 579 µg/kg were reported in nutty food samples collected from Jidda markets in Saudi Arabia (Tawila et al., 2020). More than 95 % of complimentary food samples collected from Amhara, Tigray and Oromia, Ethiopia were contaminated with AFSs (Ayelign et al., 2018). About 72 % of infant foods samples collected from Accra, Ghana contains AFB1 above EU permissible limits (Blankson and Mill-Robertson, 2016). Total AFSs content in maize, sorghum and millet flours collected from commercial milling centers in Nairobi, Kenya was found to be 59.73, 39.21 and 34.80 µg/kg respectively (Wanjeri et al., 2017). Eshete et al. (2020) detected AFSs above EU permissible limits in 5.3 % of breastmilk samples collected from Sidama zone, Ethiopia.

Developing countries with strict food regulations reported lower levels of AFSs contamination. Values within permissible limits were reported by Ahmadi et al. (2020) in peas, red beans, lentils, mung bean and cotyledons samples collected from Tehran, Iran. Likewise, rice samples collected from imported bulk in Saudi Arabia (Al-Zoreky and Saleh, 2019). Fungal hydrolytic enzymes also lead to the degradation of proteins and carbohydrates in grains, this can lead to a poor...
Dangers Associated with Aflatoxins Contamination in Grains

Inappropriate handling and storage of grains after harvesting expose them to optimum conditions for fungal growth and AFs production (Waliyar et al., 2015). The quality and safety of processed grains and their by-products depend to the large extent on the pre-and post-harvest qualities of the grains (Pratap et al., 2016). The danger of microbial postharvest losses is beyond losing grains qualities, it can as well lead to dangerous health problems including cancers (Schmidt et al., 2018).

Mycotoxin (including AFs) contaminations through consumption of inadequately dried and contaminated foods are affecting about 4.5 billion people in the world (Bradford et al., 2018). AFs can pass through the metabolic system unchanged and accumulate in body organs (Khaneghah et al., 2018). Therefore, AFs can be found in the milk and meat of farm animals fed on the contaminated diets (Wangia-Dixon et al., 2020). AFs were also found in human serum (Sabuncuoglu et al., 2015) and breast milk (Eshe et al., 2020).

Consumption of foods contaminated with AFs is a threat to human and animal health (Manna and Kim, 2017; Ojiambo et al., 2018). Depending on cereal legume-based composites exclusively as complimentary food exposed children to malnutrition and AFs and fumonisins contaminations (Mollay et al., 2021). AFs contamination can lead to poor growth and development (Achaglinkame et al., 2017), vaccine interference (Wangia-Dixon et al., 2020) and iron deficiency (Opoku et al., 2018) in infants and children. Can also lead to grave health issues including liver cancer (Maringe et al., 2016), immune suppression, embryo toxicity and nutritional deficiencies (Granados-Chinchilla et al., 2017). Acute aflatoxicosis can lead to haemorrhage, severe liver damage, oedema, and death (Khaneghah et al., 2018). In addition to aflatoxicosis, food fungal contamination can also cause other serious diseases such as aspergillosis (Dozie-Nwikile et al., 2020) and infections in patients with immune-compromised and hypersensitive reactions such as asthma and allergic alveolitis (Muhie and Bayisa, 2020).

Control of Aflatoxins Contamination in Grains

Controlling AFs in grains is quite challenging because many fungal species are toxigenic and their mycotoxins synthetic pathways and factors affecting them are not yet fully understood (Aldars-García et al., 2016). Postharvest decontamination of grains is crucial to the postharvest quality and safety of grains and their products (Schmidt et al., 2019). Preventing the growth of AFs producing microorganisms will inevitably prevent AFs contamination in cereals and legumes (Achaglinkame et al., 2017). Sirma et al. (2018) opined that the addition of AFs absorbents and enzymes can significantly lower AFs contamination. Many plant extracts and essential oils were reported to mitigate fungal growth and AFs production (Ponzilacqua et al., 2018). Telles et al. (2017) reported that peanut and azuki bean phenolic extracts can protect beans against fungal contamination and AFs production.

AFs contamination can effectively be control in grains through decent agricultural practice, (Achaglinkame et al., 2017; Gonçalves et al., 2019), production of fungi resistant varieties (Neube and Maphosa, 2020), fast and proper drying, insects control, use of natural and synthetic antifungal, irradiation (Neme and Mohammed, 2017), cleaning and sanitizing storage facilities, avoiding conditions that will favour mold growth and AFs production (Gagiu et al., 2018), avoiding grains damage, ensuring good postharvest practices (Manna and Kim, 2017), prevention legislation and policy (Khaneghah et al., 2018) and public enlightenment (Achaglinkame et al., 2017; Michael et al., 2018). Training farmers on AFs contamination mitigating techniques yielded positive results in Tanzania (Seetha et al., 2017). Nesci et al. (2016) recommended the use of food-grade antioxidants microcapsules in the prevention of fungal attacks and AFs production. Incorporation of savannah tea leaves as bio-pesticide into hermetic bag reduces aflatoxins contamination in cowpea during 8 months of storage (Constant et al., 2016).

Cleaning and processing operations such as sorting, milling, fermentation, roasting, baking, flaking and extrusion cooking are reported to lower mycotoxins levels in food (Neme and Mohammed, 2017). Products of lactic acid fermentation were reported to prevent AFs synthesis (J. Prakash, 2016). Ibityou et al. (2020) reported a decrease in the growth rate of A. flavus and a reduction in AFB1 and AFB2 production in sorghum and millet treated with monoculture and co-culture LAB. Processing methods and severity also affect AFs concentration, Ojuri et al. (2019) reported that household processed foods are more contaminated with mycotoxins than industrially proceed foods. Kamula et al. (2018) reported that sorting by handpicking, proper sun drying on an elevated surface, chemical treatment before storage and dehulling of maize before milling lower AFs intake in Tanzanian infants by 78 %. Microwaving, vacuum packaging and high hydrostatic pressure inhibited fungal growth and AFs production in wheat (Schmidt et al., 2019). Waliyar et al. (2015) reported a higher concentration of AFB1 in groundnut paste than in groundnut seed in market samples collected from Kolokani, Kayes, and Kita districts, Mali. The higher concentration of the AF in the processed product may result from post-process exposure to environmental conditions that favours AFs production. The finding of Udomkun et al. (2019) showed that combining staple grains with other locally available crops reduces grains AFs contamination. While combining other grains with groundnut drastically increase AFs in the resultant composite (Temba et al., 2017). Similarly, much higher contaminations were reported in cereal legume-based foods than in cereal-based products (Opoku et al., 2018).

A meaningful advancement in controlling AFs contamination was reported in biological control using atoxigenic (nonAFs producing) strains of A. flavus (Ojiambo et al., 2018). Sarrocco and Vannacci (2018) reviewed the possibility of applying beneficial fungi at the pre-harvest stage to prevent postharvest fungal contamination and mycotoxins production in cereals, apples and grapes. N2 saturated atmosphere (98.5 %) greatly reduces growth and sporulation of all AFs producing Aspergillus and destroy Stiphostiis oryzae and Tribolium confusum after 3 and 7 days in wheat and its flour respectively (Lorenzo et al., 2020).

AFs contamination in developing countries requires a collective approach that will simultaneously consider food safety, food production and humans and animal health (Aron et al., 2017). Most consumers in developing countries are not familiar with the dangers associated with the consumption of moldy foods.
(Adeyeye, 2020). Njoroge (2018) opined that success in the fight against AFs contamination will only be achieved in Africa if consumers realised the dangers associated with the consumption of AF-contaminated foods and start demanding better quality and safe foods. Technical and financial support from international donors is required to minimise or eliminate AFs contamination since many developing countries lack adequate resources (Elias, 2016). Achaaglinkame et al. (2017) recommended the substitution of cereal-legume blend with a tuber-based blend for infant formula, this could not provide some essential nutrients and can only be possible if the blends will be enriched with the essential nutrients deficient in tuber crops. Farmers and other stakeholders in Africa need to be sensitized on the activities of Partnership for Aflatoxin Control in Africa (PACA), stakeholders are required to present valid evidence for AFs contamination to access AFs mitigation technologies (Njoroge, 2018).

**Recommendations**

1. Consumers should avoid crops with higher AFs accumulation. Sorghum, groundnut and maize were reported to habitually accumulate AFs. These can be substitute by underutilized grains such as millet which was reported to have excellent nutritional and health benefits (Birania et al., 2020)

2. Recently harvested grains with alarming levels of fungi and/or AFs contaminations should be processed immediately to avoid AFs accumulation during storage

3. Countries in sub-Saharan Africa need to urgently develop and enact regulations on AFs food contamination as the region is the most reported in the literature, possibly due to the prevailing weather condition that favours fungal growth.

4. Researches in plant genetics and molecular biology should be focused on developing grains that will be resistant to fungal contamination. The development of insect and mold resistance grains will surely improve safety and minimize storage challenges particularly among farmers that cannot afford modern storage and packaging materials.

5. The possibility of eliminating Aspergillus fungus during the storage of grains through microbiological succession using benign microorganisms should be studied.

6. Microorganisms and insects continue to develop resistance to the various postharvest treatments, hence unceasing research is necessary in this area.

**CONCLUSION**

The jeopardy of AFs contamination is a threat to public health in many developing countries. Inappropriate storage and packing systems with higher humidity and temperature allow the growth and proliferation of aflatoxins producing fungi. Contamination can also occur during harvest and pre-harvest time. Fungi metabolites can contaminate up to 25% of stored grains when exposed to unsuitable storage conditions. Higher levels of contaminations were reported in legumes grains, however, staples grains such as wheat, rice and maize account for greater contaminations in humans. Control of AFs contamination requires a holistic approach that will protect throughout the supply chain. The danger can be mitigated by decent agricultural, storage and processing practices; including production of resistance varieties, proper and adequate drying, insect and mold control during storage, good manufacturing practices including proper and adequate cleaning and processing, education and enlightenment, and extenuating legislation and policy that will ensure acceptance of only good quality commodities.

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