FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 5 No. 4, December, 2021, pp 22 - 29
DOI: https://doi.org/10.33003/fjs-2021-0504-776

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 living cells, suppresses the immune system and causes many forms of cancers. Aflatoxin B_1 was classified under group I 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 dying 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 (Affognon *et al*., 2015; Likhayo *et al*., 2018; Mezgebe *et al*., 2016), economy and health (Khaneghah *et al*., 2018; Kumari *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* (Elias, 2016) during storage of contaminated grains. *Aspergillus flavus* and *Aspergillus parasiticus* occurs more frequently than other fungi in grains and produced more AFs including AFB_1 (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; B_1, B_2, G_1 and G_2 (Ahmadi *et al*., 2020). Aflatoxin B_1 (AFB_1) is the most mutagenic, carcinogenic and teratogenic material found in foods (Ahmadi *et al*., 2020; Nesci *et al*., 2016). It is the most potent known liver carcinogen (Jallow *et al*., 2018). It was classified under group I carcinogens by the International Agency for Research on Cancer (Al-Zoreky and Saleh, 2019). AFB_1 is very stable and can be toxic at a meagre dose (Ponzilacqua *et al*., 2018). The menace of AFB_1 is common to many staple foods in most developing countries. Groundnut is the most disposed crop to AFB_1 contamination (Jallow *et al*., 2018). More than 90 % of food samples collected by Eshete *et al*. (2020) from Sidama zone, Ethiopia contains AFB_1 above the EU permissible limit. Traditionally processed infant food in Ouagadougou, Burkina Faso contains AFB_1 900 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 AFB_1 above Ghana and EU permissible limits (Kortei *et al*., 2021). Sulaiman *et al*. (2018) associated urine AFB_1 with cereal products consumption. AFB_1 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 Branà *et al*. (2017) showed that *Plerotus eryngii* (king oyster mushroom) can degrade AFB_1 in malt extract broth.

In addition to AFs, fungi also produced other carcinogenic and mutagenic secondary metabolites such as cyclopiazonic acid, aflatrem (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 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 (Kortei *et al*., 2019) and at various points along the supply chain depending on the handling condition (Mannaa 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 (Njoroge *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 AFs 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 AFs 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 AFs accumulation before harvest. Kachapulula *et al* (2017) reported that uncultivated lands are loaded with more AFs producing organisms than cultivated lands. Mould growth and AFs 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 (Chukwukere *et al*., 2021; Neme and Mohammed, 2017). Aron et al. (2017) also reported that poor postharvest handling of grains causes AFs contamination. Seetha et al. (2017) witnessed AFB_1 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 AFs contamination than grains dried on a covered surface.

Except for few crops such as rice, many kinds of cereal and legumes are disposed to AFs 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 (Adeyeye, 2016) among other grain products. Legumes in general are more prone to AFs contamination (Eljack, 2012) and groundnut is more disposed than other legumes (Maringe *et al*., 2016). Sorghum, groundnut and maize contributed to AFs contamination more than other grains (Neme and Mohammed, 2017; Tibagonzeka *et al*., 2018), their prevalence of AFs 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 AFs contamination in sub-Sahara Africa (Ingenbleek *et al*., 2019). Higher temperatures and relative humidity facilitate mould growth and AFs formation (Sun *et al*., 2017; Valencia-Quintana *et al*., 2020). The prevailing weather condition in sub-Sahara Africa characterized by heavy downfall and higher temperatures, facilitate mould growth and AFs 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 AFs contamination. About 49 % of complimentary food samples collected by Aron et al. (2017) from Bahi District, Tanzania reported being contaminated with AFs. A significant proportion of maize, sorghum and millet samples collected from Makueni and Nandi, Kenya contains AFs and fumonisins above the recommended levels of 10 ppb and 2 ppm respectively (Kang'Ethe *et al*., 2017). The AFs levels in recently harvested groundnuts, beans, cowpeas and Bambara nuts samples from Shamva 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 AFs above the EU permissible limit. The finding of Obade (2015) revealed that weaning foods commonly used Kisumu County, Kenya are contaminated with AFs 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 AFs (Ojuri *et al*., 2019). Rice and beans samples collected from Enugu, Nigeria contain AFs above permissible limits (Dozie-Nwakile *et al*., 2020). Likewise, maize samples collected from Dutsinma, Nigeria was heavenly 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 (Mukhtar *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 AFs (Ayelign *et al*., 2018). About 72 % of infant foods samples collected from Accra, Ghana contains AFB_1 above EU permissible limits (Blankson and Mill-Robertson, 2016). Total AFs 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 AFs 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 AFs 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 quality dough and bad baked products (Schmidt, 2018). AFs contamination is seriously affecting the economy of many developing nations due to strict AFs contamination regulations in international trade (Eljack, 2012; Tumukunde *et al*., 2020; Udomkun *et al*., 2017).

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 breastmilk (Eshete *et al*., 2020).

Consumption of foods contaminated with AFs is a threat to human and animal health (Mannaa 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 aspergilloma (Dozie-Nwakile *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 (Ncube 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 (Mannaa 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). Ibitoye et al. (2020) reported a decrease in the growth rate of *A. flavus* and a reduction in AFB_1 and AFB_2 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. Kamala 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 AFB_1 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. N_2 saturated atmosphere (98.5 %) greatly reduces growth and sporulation of all AFs producing *Aspergillus* and destroy *Sitophilus 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). Achaglinkame *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-Sahara 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 existing 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 verities, 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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