Ghana Journal of Science, Technology and Development
Vol. 7, Issue 2. February 2021
www.gjstd.org
e-ISSN: 2343-6727

DOI: https://doi.org/10.47881/264.967x

Aflatoxin contamination in groundnut (*Arachis hypogaea* L.); its causes and management

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ABSTRACT

Groundnut is a very important legume that is recognized worldwide for its benefits. It is grown in over 100 countries. The nutritional benefits such as its provision of important vitamins cannot be overemphasized. However, the production, marketing and consumption of groundnut is threatened by mycotoxins with aflatoxin being the major. Aflatoxin is produced by a difficult to control, complex pathogen, Aspergillus species that contaminate groundnut with this mycotoxin both in the field and during storage especially Aspergillus flavus which is the most common in nature. The response of moisture, temperature and even soil type all influence the proliferation of this pathogen and its subsequent aflatoxin contamination. In view of the many health challenges that this mycotoxin poses to humans and animal, various control measures involving biological, use of resistant groundnut genotypes, chemical strategies and physical separation have been proposed to be a remedy to this global issue.

Keywords: *Mycotoxin, Aflatoxin, Aspergillus flavus, Health hazards, Groundnut.*

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an annual legume also known as peanut, earthnut, monkey nut and goobers and plays a very important role in human diets as one of the world's most valued oil seed crops (Dwivedi *et al*., 2003). Groundnut occupies a very strategic position on the list of the world's cultivated crops; placing 13th in the world as well as being the 4th most important oil seed crop (Surendranatha *et al*., 2013). More than 100 countries worldwide produce groundnut and developing countries constitute 94% of global production of the crop (Madhusudhana, 2013).

The kernel of the crop is a high deposit of nutrients including vitamin E, niacin, riboflavin, thiamine, falacin, calcium, phosphorus, magnesium, zinc, iron and potassium as well as considerable quantities of fat (40-50%), protein (20-50%), and carbohydrate (10-20%) (USDA, 2010). The benefits of the crop cannot be overemphasized in any setting as the entire crop is useful. Aside consuming the kernels in the boiled, roasted or raw state, a good amount of oil can be extracted from them and the remaining oilcakes are used as fertilizer (Ayele, 2010). The entirety of groundnut usage leaves no waste in the system or to the farmer as every part of the crop is beneficial.

The origin of cultivated groundnut is South America (Weiss, 2000). According to FAOSTAT (2018), the world production of the crop was 4,097,498 tons. China is the leading producer of the crop with a yearly production of 17,150, 121 tons. Nigeria however is the 4th largest producer of the commodity in the world and the first in Africa. Ghana comes as the 17th largest producer of groundnut in the world producing up to 420,000 tons yearly.

The crop is affected by various diseases, from the leaves to the seeds. Diseases such as late leaf spot (*Phaeoisariopsis personata* Berk and Curt), early leaf spot (*Cercospora arachidicola* Hori), collar rot (*Aspergillus niger* Tiegh), rust (*Puccinia arachidis* Speg), and bud necrosis (bud necrosis virus (Ephrem, 2015). Groundnut seeds are also affected by molds of the Aspergillus family with the common in nature been *Aspergillus flavus*, it's responsible for the production of aflatoxins contamination (structurally related toxic polyketide-derived secondary metabolites) (Waliyar *et al*., 2006). The major producers of aflatoxins are *Aspergillus flavus* and *Aspergillus parasiticus* (Richard and Payne, 2003; Vargra *et al*., 2011). Contamination of groundnut with aflatoxins can occur at every stage of the cropping season and afterwards. Contamination can occur in the field before harvest, during harvest or after harvest. Several agricultural commodities are contaminated by aflatoxin producing fungi and consuming these produce may results in health threats to both human and livestocks (Kumar *et al.,* 2017; Sarma *et al.,* 2017; Ezikiel *et al.,* 2019). Moreover, the contamination of crops especially groundnut by aflatoxins in developing countries leads to serious economic losses. According to Shephard (2003), aflatoxin contamination of stable crops like maize and groundnut poses major health challenges in Africa. Rural people who may not have other food options are forced to ingest aflatoxin contaminated crops daily. This moderate, chronic intake of aflatoxin through contaminated food can result in severe pathological conditions, such as liver cancer, immune system deficiency and impaired development of children (Wild *et al*., 1992; Wild *et al*., 1993; Gong *et al*., 2004; Williams *et al*., 2004).

Aflatoxin and its origin

Aflatoxin is a secondary metabolite of the fungus *Aspergillus* species and is a group of highly toxic, cancer-causing mycotoxins produced by several members of the fungal genus, *Aspergillus* (IARC, 2012). Aflatoxins are carcinogenic, teratogenic and immunosuppressive secondary metabolites produced by several *Aspergillus* species (Frisvad *et al.*, 2019). *A. flavus* is the most common aflatoxin producing spp. in nature (Amaike and Keller, 2011) but depending on locations/time, *A. parasiticus*, *A. nomius*, and other species may be significant contributing agents to aflatoxin contamination (Probst *et al.,* 2014; Kachapulula *et al.,* 2017; Kumar *et al.,* 2017). The name aflatoxin was derived from a toxin producing fungus which caused a disease referred to as "Turkey X disease" around 1960 in England (Forgaes, 1962). The disease resulted in the death of 100,000 young turkeys. The fungus was later identified as *Aspergillus flavus* in 1961 by Blout and the toxin produced was named aflatoxin due to origin (letter "A" for the genus *Aspergillus*, the next set of three letters, "FLA", for the species *flavus*, and the noun Toxin, means poison). The fungus *Aspergillus* sp., belongs to the class Deuteromycetes (Fungi Imperfecti; subclass Hyphomycetes); their teleomorphs can be found in the Ascomycetes (Akrobortu, 2018). The fungi adapts easily on food commodities as good substrate for growth because of the large number of enzymes it secretes for substrate digestion during its development (Hell, 1997). Pelczar *et al*. (1993) indicated that the Ascomycete produce sexual spores (ascospores) endogenously in a well differentiated ascocarp while the Deuteromycetes reproduce vegetatively by conidia. Hell (1997) stated that aflatoxins are only produced by two related species: *A. flavus* and *A. parasiticus*, with the latter species producing specifically the G-type of aflatoxin. However, recent studies indicate that nine different species of *Aspergillus* and two different *Emericella* species produce aflatoxin (Frisvad *et al*., 2006).

Based on chromatographic and fluorescence characteristics, all aflatoxins known to date can be classified into 18 different types. The major ones are aflatoxin B1, B2, G1 and G2 (Figure 1), as well as M1and M2 (Lerda, 2010). Other aflatoxins have less commonly been found in nature since they are metabolic derivatives mostly found in pure cultures (Franco *et al*., 1998). Among these compounds, B1 is normally predominant in concentrations in cultures as well as in food products (Oliviera and Germano, 1997). Aflatoxin M1 and M2 are hydroxylated forms of B1 and B2 (Dors *et al*., 2011). When B1 in contaminated feed or foodstuffs is ingested by domestic animals, such as dairy cows, the toxin undergoes liver biotransformation and is converted into aflatoxin M1. Aflatoxin M1 then becomes the hydroxylated form of B1. Aflatoxin M1 is subsequently excreted in milk, tissues and biological fluids of these animals (Oatley *et al*., 2000; Peltonem *et al*., 2001). Aflatoxins are carcinogens and genotoxins that directly influence the structure of DNA (Williams *et al*., 2004).

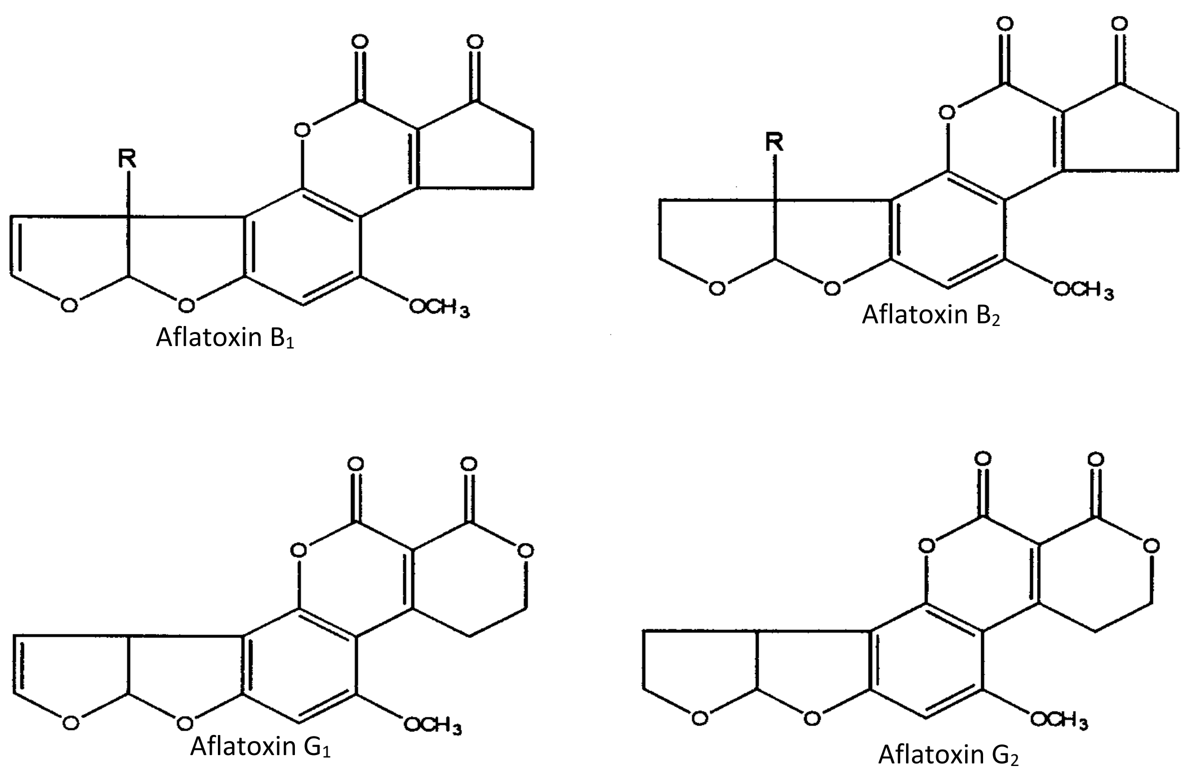

FIGURE 1. **The major groups of aflatoxins**

Economic importance of aflatoxin in groundnut

A. flavus and *A. parasiticus* are the two main fungi responsible for the production of aflatoxins. Aflatoxins are extremely toxic substances that can cause severe health challenges in both humans and animals. This toxic substance has been found to be the cause of different types of cancers particularly the liver cancer and hepatitis B and C. In Africa and some part of the world, aflatoxin is believed to be involved in malnutrition (protein insufficiency) in children (Turner, 2013; Ephrem, 2015; Benkerroum, 2020). Moreover, it is reported that children with *kwashiorkor* (childhood malnutrition from protein insufficiency) were detected with high levels of aflatoxin in the Sudan, South Africa and Nigeria. Ninety-three percent (93%) of children between 6-9 years old were tested and found to be positive for aflatoxin albumin adducts in Gambia (Turner, 2013; Ephrem, 2015). Aflatoxins are pervasive in warm and humid regions which makes most of the commodities from these areas especially groundnut contaminated with aflatoxin (Dohlman, 2003). Throughout the world, aflatoxin contamination has caused diverse health challenges and economic risks. Aflatoxin contamination of crops leads in economic losses to farmers and to countries due to rejection of the produces (Bryden, 2012). India being the second largest producer of groundnuts has low export of 800,000 tons per year due to aflatoxin contamination (Suneja, 2019). It is reported that, Africa loses more than $750 million annually due to aflatoxin contamination of agricultural crops and commodities (Pandey *et al*., 2019). Interestingly, the greatest proportion of worldwide groundnut production is from developing countries amounting up to 95%. Meanwhile they are unable to meet the standards of the international market to sell the commodity due to aflatoxin contamination (Ephrem, 2015).

Awareness of aflatoxins

Wu and Khlangwiset (2010) viewed awareness and education among farmers, government functionaries, and the public as crucial to allocating finances to fight aflatoxin contamination of food. Awareness of the health effects of aflatoxin-contaminated food is low among the public in Ghana. It is reported that aflatoxin awareness is low among producers, buyers and even well-educated consumers (Florkowski and Kollavalli, 2013) According to Agbetiameh *et al*. (2018), majority of Ghanaians were not aware of the aflatoxins and its harmful health impact. Smallholder farmers manually sort discoloured kernels or infected kernels, then sell the clean kernels at higher price and often consumed the sorted kernel due to lack of knowledge of the health effects of aflatoxins (Matacic, 2016). In some part of West Africa such as Nigeria, education is very important to consumer awareness of aflatoxin contamination (Ezikiel *et al.*, 2018). It was reported that 85% of consumers lack awareness of aflatoxin contamination in the snacks and possible health risks associated with it ingestion. Findings revealed that socio-economic characteristics such as education level, participation in social and extension services, market orientation, economic motivation and general perception has effect on farmers knowledge of aflatoxin contamination. Farmer do not consider management of mycotoxin as a challenge in agriculture because there is no price incentives for uncontaminated products (Udomkun *et al.*, 2017). According to Jolly *et al*. (2009), "Awareness of Aflatoxin contamination of groundnuts had a positive effect on Ghanaian professionals' abilities to take action to reduce its level of contamination." Therefore there is need for continual education of the general public on the effects of aflatoxin contamination on the health especially children.

Status of aflatoxin contamination of groundnut in Africa

A comparison among some African countries on aflatoxin levels in groundnut and groundnut products showed varying results which means that aflatoxin contamination in groundnut is a canker. Some Africa countries have regulatory measures for management of aflatoxin contamination. Maximum risk limit of aflatoxin contamination for Ghana is 20 ppb (Torres *et al.,* 2014), Kenya is 10 µg/kg (Ncube and Maphosa, 2020), Zimbabwe is 5 ppm (Nziramasanga, 2014), South Africa is 10 ppb (Njoroge, 2018), and Malawi is 5 ppb (FAO, 2004). Aflatoxin levels in groundnut in Mali between 2009 and 2010 were found to be more than 10 ppb in 35-61% of samples from farmers' fields and 39-91% samples from farmer's stores. Peanut paste in Mali had high aflatoxin level of more than 300 ppb. In Nigeria, aflatoxin levels in groundnut oil had 500 µg/g (Alakonya and Monda, 2013). In Ghana, aflatoxin levels in groundnut were reported to be 216 µg/g while groundnut paste had 3,278 µg/g and groundnut sauce 943 µg/g (Alakonya and Monda, 2013). According to Bediako *et al*. (2019), findings shown that aflatoxin contamination in Ghana exceeded the acceptable limit of 20 ppb set by Ghana Standard Authority. Moreover, a study in Kenya also indicated that, 37% of groundnuts and its products did not meet the total aflatoxin limit set by Kenya Bureau Standard of 10 µg/kg (Ncube and Maphosa, 2020). Also, because of aflatoxin contamination, groundnuts from Malawi cannot access more limiting markets such as those in the EU (Njoroge, 2018). These show that immediate strategies must be developed to curb this challenge in Africa.

Pre-harvest factors influencing aflatoxin contamination of groundnut

Climate change and weather conditions

Climate change is unfriendly to agriculture production which threatening food and feed security in many parts the world, including Sub-Saharan Africa (Wheeler and Von Braun, 2013). Occurrences of severe aflatoxin contamination both in regions prone to aflatoxin contamination and regions that as of now are relatively unaffected are expected to increase as a result of hotter, dryer conditions influence by climate change (Magan *et al.,* 2011; Battilani *et al.*, 2016). Moreover, drought stress during plant growth development is among the most important weather conditions that gives favourable condition for the growth of *Aspergillus* spp. (Torres *et al.*, 2014). Finding by Njoroge (2018) indicated that, at preharvest, aflatoxin contamination occurs when toxigenic fungi infects the developing pods or seeds by drought and high temperature. It was also reported that, on the field groundnuts are susceptible to aflatoxin contamination when the plant is stressed by high temperature and drought (Jordan *et al.*, 2018).

Soil type

The type of soil in which groundnut seeds are grown is able to influence the proliferation of *A. flavus* and the subsequent aflatoxin contamination of groundnut in that area. Light sandy soil promotes the rapid spread of *A. flavus*, especially under dry conditions in the later growth and development period. Moreover, reduction in the level of aflatoxin contamination in groundnut seeds can occur in heavier soil because it have a higher water-holding capacity (CAC, 2004; Torres *et al*., 2014).

Maturity

Aflatoxin contamination of groundnut is prominent in smaller and immature seeds that matured seeds. Several studies have proven that both *A. flavus* invasion and aflatoxin contamination are higher in smaller, more immature kernels than in mature kernels (Sanders *et al*., 1981; Cole *et al*., 1982; Hill *et al*., 1983; Cole *et al*., 1985; Sanders *et al*., 1985). Mature groundnut seeds possess a certain level of sustained resistance to aflatoxin contamination (Dorner *et al.*, 1989).

Factors during harvesting

Late and mechanical harvesting of groundnut can cause aflatoxin contamination (Heathcote and Hibbert, 1978; Torres *et al*., 2014). The time of harvest however depends on the maturity of the crop and the prevailing weather conditions during harvesting. Over mature or immature pods at harvest can all lead to high contamination of aflatoxins in the final products. Harvesting in very humid weather conditions lead to high aflatoxin contaminations than in the dry weather (Kabak *et al*., 2006). The damage caused to groundnut seeds during mechanical harvesting makes them prone to infection by *A. flavus* and subsequent aflatoxin contamination (Heathcote and Hibbert, 1978).

Post-harvest factors influencing aflatoxin contamination of groundnut

The moisture level of groundnut seeds after harvest influences their contamination with aflatoxins. Kernel moisture contents of 10% or higher after harvest is likely to be more prone to aflatoxin contamination. Drying at the appropriate time and keeping the moisture content at the required level can be effective in controlling aflatoxin contamination of groundnut after harvest (Torres *et al*., 2014). The practice of sorting seeds before storage is effective in reducing aflatoxin in groundnut (Cole *et al.*, 1995; Dorner, 2008). However, it is also important to check the temperature and moisture in the storage area to prevent contamination during storage (Dickens, 1977; CAC, 2004).

Management of aflatoxin in groundnut

Aflatoxin infection by *Aspergillus* sp. increases basically with a subsequent increase in temperature, humidity, insect damage and nitrogen deficiency. The effects of temperature and humidity on aflatoxin infection are therefore important in aflatoxin management. Aflatoxin contamination can be higher under stress condition such as drought (CAC, 2005). Therefore, early planting and also use of drought resistance groundnut varieties is recommended for management of aflatoxin contamination. Prevention or management procedures of aflatoxin contamination should be pointed to both the process of contamination and the fungi causing contamination. The process of contamination can be divided into two stages based on crop maturity (Cotty *et al*., 2001). The first stage occurs during the development of the crop and this stage is usually associated with physical damage to the crop typically by either physiologic stress or insect activity (Russell, 1982; Cotty *et al*., 2001). Crop mechanisms contaminated during the first phase often fluoresce a bright green-yellow as a result of kojic acid production in crop tissue by the aflatoxin-producing fungi (Zeringue *et al*., 1999). After maturity, the crops remain vulnerable to contamination, providing a space during which a second phase of contamination may occur (Cotty *et al*., 2001; Bock and Cotty, 1999). Proper management of aflatoxin contamination in agricultural crops especially groundnut starts in the farmer's field and continues through harvest, drying, storage and processing (Vincelli and

Parker, 2002). The various strategies that have been designed to manage aflatoxins should adhere to the following: a) aflatoxin must be transformed to non-toxic products, b) fungal spores and mycelia should be destroyed to prevent formation of new toxins, c) the food or feed material should retain its nutritive value and palatability, d) the physical properties of raw material should not change significantly and it must be cost efficient (Rustom, 1997; Awad *et al*., 2010).

Pre- harvest management strategies

The adoption of good agronomical and cultural practices (selection of appropriate planting date, and seed dressing with systemic fungicides), can minimize aflatoxin contamination in groundnuts (Njoroge, 2018; Jordan *et al*., 2018). Use of resistant cultivar is essential and recommended if aflatoxin contamination must be reduced (Waliyar *et al.,* 2013). Use of non aflatoxigenic strains as biological control can reduced aflatoxin levels (Bandyopadhyay and Cotty, 2013). Planting at the onset of the rains can also reduce aflatoxin contamination (Chalwe *et al*., 2016). Moreover, during preharvest stages of the crop, aflatoxin contamination can be reduced by adequate soil water management during pods development in groundnuts (Chalwe *et al.,* 2016). Therefore, to minimizing pre-harvest aflatoxin contamination in groundnuts, there should be adequate soil moisture and planting on set of rains.

Biological control

The biological strategy used in controlling the aflatoxin producing fungi involves the application of atoxigenic *A. flavus* strains to groundnut fields (Bandyopadhyay and Cotty, 2013). Dorner (2009) reported that the application of the nontoxigenic strains significantly reduce aflatoxin contamination. The use of biocontrol agents as seed dressing and soil application aided in the control of the population of *A. flavus* in the geocarposphere and subsequently on pre-harvest kernel infection of groundnut (Anjaiah *et al.,* 2006).

Use of resistant groundnut genotypes

Aflatoxin reduction in groundnut can be achieved through planting *A. flavus*-resistant genotypes. Aflatoxin reduction genetic manipulation is an old strategy that has been attempted in several groundnut-producing countries since the late 1960s. Breeding resistant cultivars can be achieved when sources of stability and high-level groundnut resistance is readily available. Research scientists, especially plant breeders have identified groundnut germplasm resistant to pre-harvest and post-harvest aflatoxin contamination. Studies have shown the use of RNAi to suppress *A. flavus* growth and aflatoxin production in groundnut (Pandey *et al.*, 2019). Also, some aflatoxin resistant genotypes have been identified for various resistance mechanism. Examples of resistant genotypes include 12CS-104 and 73-33 (Dieme *et al.* 2018), ICG 12625 and ICG 4750 (Jiang *et al.*, 2010); ICGV 98305, ICGV 98348, ICGV 98353 and Tifton 8 (Girdthai *et al.*, 2010); Igola, Serenut 1, Serenut 2 and entry 99527 (Olwari *et al.*, 2013); ICG 1471, NC3033, ICGV 88145 and GT-C20 (Korani *et al.,* 2018). However, availability of resistant varieties will be the best solution for farmers to minimize aflatoxins contamination.

Post-harvest management strategies

Storage

In Africa, smallholder farmers conventionally store groundnuts in containers that are usually made of wood, bamboo, thatch, or mud placed on raised platforms and covered with thatch or metal roofing sheets (Hell and Mutegi, 2011).

More improved storage containers such as polypropylene bags are now being used, but because these are not airtight, groundnut pods are still susceptible to fungal and aflatoxin contamination (Hell *et al*., 2000; Udoh *et al.,* 2000). In bag storage, a major precaution is making sure that the bags are clean when reusing them. Reused bags have been identified to be associated with spores of *A. flavus* which makes it important to clean them before reuse (Hell *et al*., 2000). Bulaong and Dharmaputra (2002) reported that grain moisture content, mould growth, aflatoxins, and free fatty acid content were significantly higher in groundnut pods which were stored in jute bags than in those stored in polyethylene-doubled jute bags. The use of hermetic triple-layer bags (PICS, Purdue Improved Crop Storage) for grain and kennel storage has proved effective against aflatoxin contamination over traditional storage devices (Murdock *et al*., 2003; Hell *et al*., 2010). Studies on hermetic packaging have showed that hermetic packages and containers are capable of protecting groundnuts from moulds and aflatoxin contamination (Paramawati *et al.,* 2006). Apart from the storage containers, the condition of the kernels and the prevailing conditions in the storage structure are important factors that can influence aflatoxin contamination. Kernel moisture of 7.5%, temperature of 10 °C, and relative humidity of 65% are optimal bulk storage conditions for groundnut, allowing storage of up to one year (Pattee and Young, 1982). Groundnut seeds with moisture content of 10% and above should be avoided to prevent mouldy growth (Diener and Davis, 1977). Reports by Awuah and Ellis (2002) shows that groundnuts dried to 6.6% moisture levels are free of fungi for six months notwithstanding the storage protectant used. These safe moisture levels are applicable to both unshelled and shelled groundnuts. The maximum moisture content for storage of unshelled groundnuts is 9%, higher than that for shelled groundnuts (7%). At these moisture levels, if the relative humidity is maintained at 70% and temperature at 25-27 °C, groundnuts can be stored for one year (Odogola, 1994). Community-based intervention studies in Guinea, West Africa, showed that proper drying of groundnut seeds and proper storage conditions is one sure way to combat aflatoxin contamination of this crop (Turner *et al*., 2005). Maintaining low moisture levels during storage, transportation, and sales is very important as well. This can be achieved by avoiding other moisture sources such as leaking roofs and condensation arising from inadequate ventilation (Wagacha and Muthomi, 2008). Biological activity during storage should be minimized to preserve grain quality by adequate drying to <10% moisture, elimination of insect activity, low temperature, and inert atmosphere (Turner *et al.*, 2005; Lanyasunya *et al.,* 2005). Storage of dry pods in airy, dry, and clean rooms reduces aflatoxin accumulation (Rahmianna *et al*., 2007). Sanitation measures such as cleaning storage structures prior to bringing in new produce can lead to a reduction in aflatoxin levels (Hell *et al.,* 2000).

Chemical control of aflatoxins

The use of ammonia at 0.5-7% coupled with long exposure time, ambient temperature and pressure has proved effective in successfully deactivating aflatoxin in contaminated commodities, such as groundnut meal, cottonseed and maize. This chemical control method has been tested and endorsed by leading safety and regulatory agencies, such as Food and Agriculture Organization (FAO), Food and Drug Administration (FDA), and United States Department of Agriculture (USDA) (Ephrem, 2015). The use of antifungal materials from natural sources and chemical preservatives is a solid practice to prevent post-harvest aflatoxin contamination in groundnuts (Onyeagba *et al*., 2004; Haciseferogullary *et al*., 2005). Although effective, the application of eugenol which is the active ingredient of these oils is expensive. However, methyleugenol (4-allyl-1,2-dimethoxybenzene) can be a cost-effective derivative of eugenol and can be applied for post-harvest protection of groundnut pods and kernels from *A. flavus* and aflatoxin contamination when sprayed at 0.5% concentration (Sudhakar *et al*., 2009).

Physical separation

Harvesting groundnuts with hoes leads to a significant damage to shells and kernels, thus predisposing them to fungal infection during storage (Kaaya and Warren, 2005). About 80% of aflatoxin contamination of groundnut results from small, shrivelled seeds (Davidson *et al*., 1982), mouldy and stained seeds (Fandohan *et al*., 2008), and damaged seeds (Hamid, 1997). Therefore, it is an essential practice to sort kernels and to remove discoloured or damaged/shrivelled pods to reduce aflatoxin levels (Awuah and Kpodo, 1996; Park, 2002; Afolabi *et al*., 2006). Groundnuts of low quality have considerably higher aflatoxin levels than groundnuts of high quality (Mutegi *et al*., 2009). Sorting can be done by physical characteristics (colour, size, density) and by near-infrared reflectance (DeMello and Scussel, 2009). Floating and density segregation also reduces aflatoxins in storage units; kernels that float in tap water contain up to 95% aflatoxins (Kirskey *et al*., 1989; Phillips *et al*., 1994). Electronic sorting and hand-picking methods are also adopted to minimize aflatoxin levels significantly in shelled groundnuts (Dickens and Whitaker, 1975). Technological advancement (infrared and UV sorting coupled with colour-detection technology) are now available to enable inspection of aflatoxin-contaminated products on a large scale (Womack *et al*., 2014).

CONCLUSION

The increasing rate of aflatoxin contamination has become a worldwide challenge that requires immediate action. The many diseases and cankers this toxigenic mycotoxin have resulted in is alarming. Reducing aflatoxin contamination in agricultural commodities especially groundnut means bringing the population of the aflatoxin producing fungi under proper control. Finally, the involvement of all major research institutions and groundnut producers will aid in combating this mycotoxin.

REFERENCES

Afolabi, C. G., Bandyopadhyay, R., Leslie, J. F., Ekpo, E. J. A. (2006). Effect of sorting on incidence and occurrence of fumonisin and fumonisin-producing *Fusarium* species on maize (*Zea mays* L.) in Nigeria. *Journal of Food Protection*, 69, 2019-2023.

Agbetiameh, D., Ortega-Beltran, A., Awuah, R. T., Atehnkeng, J., Cotty, P. J., and Bandyopadhyay, R. (2018). Prevalence of aflatoxin contamination in maize and groundnut in Ghana: population structure, distribution, and toxigenicity of the causal agents. *Plant Disease*, 102, 764-772.

Akrobortu, D. K. (2018). Aflatoxin contamination of maize from different storage locations in Ghana. An unpublished MSc. Dissertation, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, 45pp.

Alakonya A. E. and Monda E. O. (2013). A new approach in aflatoxin management in Africa: Targeting Aflatoxin/Sterigmatocystin Biosynthesis in *Aspergillus* species by RNA Silencing Technique. Intech. http://dx.doi.org/10.5772/51440

Amaike, S. and Keller, N. P. (2011). *Aspergillus flavus*. *Annual Review of Phytopathology*, 49, 107-133.

Anjaiah, V., Thakur, R.P. and Koedam, N., (2006). Evaluation of bacteria and Trichoderma for biocontrol of pre-harvest seed infection by *Aspergillus flavus* in groundnut. *Biocontrol Science and Technology*, 16(4), 431-436.

Awad, W. A., Ghareeb, K., Bhm, J. and Zentek, J. (2010). Decontamination and detoxification strategies for Fusarium mycotoxin deoxynivalenol in animal feed and the effectiveness of microbial biodegradation. *Food Addidives and Contaminants Part A*, 27, 510-520.

Awuah, R. T. and Ellis, W. O. (2002). Effects of some groundnut packaging methods and protection with *Ocimum* and *Syzygium* powders on grain infection by fungi. *Mycopathologia*, 154, 26-29.

Awuah, R. T. and Kpodo, K. A. (1996). High incidence of *Aspergillus flavus* and aflatoxins in stored groundnut in Ghana and the use of a microbial assay to assess the inhibitory effect of plant extracts on aflatoxin synthesis. *Mycopathologia*, 134, 109-114.

Ayele, A. (2010). Evaluation of symbiotic effectiveness of rhizobia (*Bradyrhizobium* spp.) with groundnut (*Arachis hypogaea* L.) in Eastern Hararghe zone of Oromiya regional state, Ethiopia. M.Sc thesis, Haromaya University, Haromaya, 121p.

Bandyopadhyay, R., and Cotty, P. J. (2013). Biological controls for aflatoxin reduction. In: Aflatoxins: Finding solutions for improved food safety. D. Grace and L. Unnevehr, eds. International Food Policy Research Institute, Washington, DC.

Bandyopadhyay, R., Cotty, P. (2011). Presentation at Annual Meeting of APS/IAPPS 6-10 August, 2011, Honolulu, Hawaii.

Battilani, P., Toscano, P., Van der Fels-Klerx, H., Moretti, A., Camardo Leggieri, M., Brera, C., Rortais, A., Goumperis, T. and Robinson, T. (2016). Aflatoxin B1 contamination in maize in Europe increases due to climate change. *Scientific Reports*, 6, 24328.

Bediako, K. A., Dzidzienyo, D., Ofori, K., Offei, S. K., Asibuo, J. Y., Amoah, R. A. and Obeng, J. (2019). Prevalence of fungi and aflatoxin contamination in stored groundnut in Ghana. *Food Control*, 104, 152-156.

Benkerroum, N. (2020). Chronic and acute toxicities of aflatoxins: Mechanisms of action. *International Journal of Environmental Research and Public Health*, 17, 423.

Bock, C. H. and Cotty, P. J. (1999). The relationship of gin date to aflatoxin contamination of cotton-seed in Arizona. *Plant Disease*, 83, 279-285.

Bryden, W. L. (2012). Mycotoxin contamination of the feed supply chain: implications for animal productivity and feed security. *Anim. Feed Sci. Tech.*, 173, 134-158.

Bulaong, S. S. P. and Dharmaputra, O. S. (2002). Fungal population, aflatoxin and free fatty acid contents of peanuts packed in different bag types. *Biotropia*, 19, 1-25.

Cardwell, K. F., Desjardins, D. and Henry, S. H. (2004). The cost of achieving food security and food quality, (http://www.apsnet.org/online/ festure/mycotoxin/ top.html), (Accessed on July 1, 2018).

Chalwe, H., Mweetwa, A. M., Lungu, O. I., Phiri, E., Njoroge, S., and Brandenburg, R. (2016). Reducing pre-harvest aflatoxin content in groundnuts through soil water. Pp. 921-926. In: RUFORUM Working Document Series 14. Available from http://repository.ruforum.org

Codex Alimentarius Commission CAC. (2004). Code of Practice for the prevention and reduction of aflatoxin contamination in peanuts. CAC/RCP. 55 pp.

Codex Alimentarius Commission CAC. (2005). Code of practice for the prevention and reduction of aflatoxin contamination in tree nuts. www.codexalimentarius.net/ download/standand/10221/CXP_--_059e.pdf.

Cole, R. J., Dorner, J. W. and Holbrook, C. C. (1995). Advances in mycotoxin elimination and resistance. In H.E. Pattee and H.T. Stalker (Eds.), *Advances in peanut science.* Stillwater, OK, USA. *American Peanut Research Educational Society*, 456-474.

Cole, R. J., Hill, R. A., Blankenship, P. D., Sanders, T. H. and Garren, K. H. (1982). Influence of irrigation and drought stress on invasion of *Aspergillus flavus* of corn kernels and peanut pods. *Developments in Industrial Microbiology*, 23, 229-236.

Cole, R. J., Sanders, T. H., Hill, R. A. and Blankenship, P. D. (1985). Mean geocarposphere temperatures that induce preharvest aflatoxin contamination of peanuts under drought stress. *Mycopathologia*, 91, 41-46.

Cotty, P. J. (2005). Ecology and biological control of aflatoxin-producing fungi. P. 29. In: Proceedings of the Conference on Reducing Impact of Mycotoxins in Tropical Agriculture with Emphasis on Health and Trade in Africa. Accra, Ghana, September 13-26, 2005.

Cotty, P. J., Jaime-Garcia, R. and Kobbeman, K. (2001). The S strain of *A. flavus* in South Texas. *Phytopathology*, 91, 19

Coulibaly, O., Hell, K., Bandyopadhyay, R., Hounkponou, S. and Leslie, J. F. (2008). Mycotoxins: detection methods, management, public health and agricultural trade. Published by CAB International, ISBN 9781845930820.

Davidson, Jr. J. I, Whitaker, T. B. and Dickens, J. W. (1982). Grading, cleaning, storage, shelling, and marketing of peanuts in the United States. In: Pattee, H.E., Young, C.T. and Yoakum, T. X. (eds.) Peanut science and technology. American Peanut Research and Education Society, Inc., Yoakum, TX, USA, 571-623.

DeMello, F. R. and Scussel, V. M. (2009). Development of physical and optical methods for in-shell Brazil nuts sorting and aflatoxin reduction. *Journal of Agricultural Science*, 1, 3-14.

Dickens, J. W. (1977). Aflatoxin control program for peanuts. *Journal of American Oil Chemical Society*, 54, 225-228.

Dickens, J. W. and Whitaker, T. B. (1975). Efficacy of electronic color sorting and hand picking to remove aflatoxin contaminated grains from commercial lots of shelled peanuts. *Peanut Science*, 2, 45-50.

Dieme, R. M. A., Faye, I., Zoclanclounon, Y. A. B., Fonceka, D., Ndoye, O. and Diedhiou, P. M. (2018). Identification of sources of resistance for Peanut *Aspergillus flavus* colonization and aflatoxin contamination. *International Journal of Agronomy*, 5468602.

Diener, U. L. and Davis, N. D. (1977). Aflatoxin formation in peanuts by *Aspergillus flavus*. Agricultural Experimental Station, Bulletin 493.

Dohlman, E. (2003). Mycotoxin hazards and regulations: Impacts on food and animal feed crop trade, International trade and food safety: Economic theory and case studies, Jean Buzby (ed.), Agricultural Economic Report 828, USDA, ERS.

Dorner, J. W. (2009). Development of biocontrol technology to manage aflatoxin contamination in peanuts. *Peanut Science*, 36, 60-67.

Dorner, J. W. (2008). Management and prevention of mycotoxins in peanuts. *Food Additives and Contaminants*, 25, 203-208.

Dorner, J. W. and Cole, R. J. (2000). Effect of application of nontoxigenic strains of *Aspergillus flavus* and *A. parasiticus* on subsequent aflatoxin contamination of peanuts in storage. *Proceeding of America Peanut Research and Education Society*, 32, 26.

Dorner, J. W., Cole, R. J., Sanders, T. H. and Blankenship, P. D. (1989). Interrelationship of kernel water activity, soil temperature, maturity and phytoalexin production in preharvest aflatoxin contamination of drought-stressed peanuts. *Mycopathologia*, 105, 117-128.

Dors, G. C., Caldas, S. S., Feddem, V., Bemvenuti, R. H., Hackbart, H. C. S., Souza, M. M. *et al*. (2011). Aflatoxins: Contamination, Analysis and control. In: Guevara-Gonzalez RG (Ed), Aflatoxins-Biochemistry and Molecular Biology, In Tech, 415-438. Available at http://cdn.interchopen.com/pdfd/2040/InTechAflatoxins_contamination_analysis_and_control.pdf. Accessed 13th May, 2019.

Dwivedi, S. L., Crouch, J. H., Nigam, S. N. (2003). Ferguson ME Paterson AH.

Molecular breeding of groundnut for enhanced productivity and food security in the semi-arid tropics: Opportunities and challenges. *Advanced Agronomy*, 80, 153-221.

Ephrem, G. (2015). Aflatoxin contamination in groundnut (*Arachis hypogaea* L.) caused by *Aspergillus* Species in Ethiopia. *Journal of Applied & Environmental Microbiology*, 3(1), 11-19.

Ezekiel C. N., Ortega-Beltran, A., Oyedeji, E. O., Atehnkeng, J., Kössler, P., Tairu, F., Hoeschle-Zeledon, I., Karlovsky, P., Cotty P. J. and Bandyopadhyay, R. (2019). Aflatoxin in chili peppers in Nigeria: extent of contamination and control using atoxigenic *Aspergillus flavus* genotypes as biocontrol agents. *Toxins,* 11, 429. doi: 10.3390/toxins11070429.

Ezekiel, C. N., Ayeni, K. I., Misihairabgwi, J. M., Somorin, Y. M., Chibuzor-Onyema, I. E., Oyedele, O. A., Abia, W. A., Sulyok, M., Shephard, G. S., and Krska, R. (2018). Traditionally processed beverages in Africa: a review of the mycotoxin occurrence patterns and exposure assessment. *Compr. Rev.Food Sci. Food Saf*. 17, 334-351.

FAO, (2004). Worldwide Regulations for Mycotoxins in Food and Feed in 2003. Food and Agriculture Organization of the United Nations.

FAOSTAT (Food and Agriculture Organization Statistics) (2018). Food loss analysis: caused and solutions, case study on the groundnut value chain in the Republic of Malawi. ISBN 978-92-5-130636-9.

Fandohan, P., Hell, K. and Marasas, W. F. (2008). Food processing to reduce mycotoxins in Africa. In J.F. Leslie, R. Bandyopadhyay and A. Viscont, Mycotoxins: detection methods, management, public health and agricultural trade. Wallingford: CAB International, 309-316 p.

Florkowski, W. J., and Kolavalli, S. (2013). “Aflatoxin control strategies in the groundnut value chain in Ghana,” in Proceedings of the IFPRI Ghana Strategy Support Program Working Paper, (Washington, DC: IFPRI), 33.

Forgaes, J. (1962). Mycotoxicosis-the neglected disease. *Feedstuffs*, 34, 124-134.

Franco, C. M., Fente, C. A., Vaz, B. I., Cepada, A., Mahuzier, G. and Prognon, P. (1998). Interaction between Cyclodextrins and Aflatoxin Q_1, M_1 and P1: Flourescens and chlomatographic studies. *Journal of Chromatography A*, 815 (1), 21-29.

Frisvad, J. C., Hubka, V., Ezekiel, C. N., Hong, S. B., Novakova, A., Chen, A. J. (2019). Taxonomy of Aspergillus section Flavi and their production of aflatoxins, ochratoxins and other mycotoxins. *Stud. Mycol*., 93, 1-63. doi: 10.1016/j.simyco.2018.06.001

Frisvad, J. C., Thrane, U., Samson, R. A. and Pitt, J. I. (2006). Important mycotoxins and fungi which produce them. In: Hocking, A. D., Pitt J. I., Samson, R. A., Thrane, U. (eds.). Advances in Food Mycology

57. Advances in Experimental Medicine and Biology, New York, Springer Science and Business Media, 3.3.

Girdthai, T., Jogloy, S., Vorasoot, N., Akkasaeng, C., Wongkaew, S., Holbrook, C. C., Patanothai, A. (2010), Associations between physiological traits for drought tolerance and aflatoxin contamination in peanut genotypes under terminal drought. *Plant Breeding*, 129, 693-699.

Gong, Y. Y., Hounsa, A., Egal, S., Turner, P. C., Sutcliffe, A. E., Hall, A. J., Cardwell, K. and Wild, C. P. (2004). Postweaning exposure to aflatoxin results in impaired child growth: A longitudinal study in Benin, West Africa. *Environmental Health Perspectives*, 112, 1334-1338.

Haciseferogullary, H., Ozcan, M., Demir, F. and Calysyr, S. (2005). Some nutritional and technological properties of garlic (*Allium sativum*). *Journal of Food Engineering*, 68, 463-469.

Hamid, A. B. (1997). "Present status and future prospects of research on the groundnuts aflatoxin problem in Malaysia," In aflatoxin contamination problem in groundnut in Asia: Proceeding of the first Asia working Group meeting eds Mehan VK, Gowda CLL. editors. (Hyerabad): *International Crop Research Institute for the Semi-Arid Tropics*, 32-35.

Heathcote, J. G. and Hibbert, J. R. (1978). Aflatoxin chemical and biological aspects. Elseiver Scientific Publishing Company, Amsterdam, 16-29 pp.

Hell, K. (1997). Factors contributing to the distribution and incidence of aflatoxin producing fungi in stored maize in Benin. An unpublished PhD Dissertation, University of Hannover.

Hell, K. and Mutegi, C. (2011). Aflatoxin control and prevention strategies in key crops of sub-Saharan Africa. *African Journal of Microbiology Research*, 5, 459-466.

Hell, K., Cardwell, K. F., Setamou, M. and Poehling, H. M. (2000). The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *Journal of Stored Products Research*, 36, 365-382.

Hell, K., Ognakossan, K. E., Tonou, A. K., Lamboni, Y., Adabe, K. E. and Coulibaly, O. (2010). Maize stored pests control by PICS-Bags: technological and economic evaluation. Presentation at the 5th World Cowpea Conference. 27 September-1 October, 2010. Saly, Senegal.

Hill, R. A., Blankenship, P. D., Cole, R. J. and Sanders, T. H. (1983). Effect of soil moisture and temperature on preharvest invasion of peanuts by the *Aspergillus flavus* group and subsequent aflatoxin development. *Applied and Environmental Microbiology*, 45, 628-633.

IARC (International Agency for Research on Cancer) (2012). A review of human carcinogens. Vol. 100F: Chemical agents and related occupations. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, Lyon, France.

Jiang, H. F., Ren, X. P., Wang, S. Y., Zhang, X. J., Huang, J. Q., Liao, B. S., Holbrook, C. C., and Upadhyaya, H. D. (2010). Development and evaluation of peanut germplasm with resistance to *Aspergillus flavus* from core collection. *Acta Agron. Sin*., 3, 428-434.

Jolly, C. M., Bayard, B., Awuah, R. T., Fialor, S. C. and Williams, J. T. (2009). Examining the structure of awareness and perceptions of groundnut aflatoxin among Ghanaian health and Agricultural professionals and its influence on their actions. *Journal of Socio-Economics*, 38, 280-287.

Jordan, D., Hoisington, D., Brandenburg, R., Abudulai, M., Adhikari, K., Akromah, R., Appaw, W., Balota, M., Boote, K., Bowen, K., Bravo-Ureta, B., Budu, A., Chalwe, H., Chen, J., Dankyi, A., Ellis, W., Hoffman, V., Jelliffe, J., MacDonald, G., Magnan, N., Mallikarjunan, K., Mochia, B., Muitia, A., Mwangwela, A., Mweetwa, A., Ngulube, M., Njoroge, S., Okello, D., Opoko, N., Payne, G., and Rhoads, J. (2018). Preventing mycotoxin contamination in groundnut cultivation. In: Achieving sustainable cultivation of grain legumes. S. Sivasankar, D. Bergvinson, P. Gaur, S. Kumar, S. Beebe, and M. Tam`o, eds. Burleigh Dodds Scientific Publishing, London.

Kaaya, N. A. and Warren, H. L. (2005). A review of past and present research on aflatoxin in Uganda. *African Journal of Food Agriculture and Nutritional Development*, 5, 1-17.

Kabak, B., Dobson, A. D. W. and Var, I. (2006). Strategies to prevent mycotoxin contamination of food and animal feed: A review. *Critical Reviews in Food Science and Nutrition*, 46, 593-619.

Kachapulula, P. W., Akello, J., Bandyopadhyay, R., and Cotty, P. J. (2017). Aspergillus section Flavi community structure in Zambia influences aflatoxin contamination of maize and groundnut. *Int. J Food Microbiol*. 261, 49-56.

Kirskey, J. W., Cole, R.J. and Dorner. J.W. (1989). Relationship between aflatoxin content and buoyancy in florunner peanuts. *Peanut Science*, 16, 48-51.

Klich, M. A. (2002). Biogeography of *Aspergillus* species in soil and litter. *Mycologia*, 94, 21-27.

Korani, W., Chu, Y., Holbrook, C. C., and Ozias-Akins, P. (2018). Insight into genes regulating postharvest aflatoxin contamination of tetraploid peanut from transcriptional profiling. *Genetic*, 209, 143-156.

Kumar, P., Mahato, D. K., Kamle, M., Mohanta, T. K., and Kang, S. G. (2017). Aflatoxins: a global concern for food safety, human health and their management. *Front. Microbiol.* 7:2170.

Lanyasunya, T. P., Wamae, L. W., Musa, H. H., Olowofeso, O. and Lokwaleput,

I. K. (2005). The risk of mycotoxins contamination of dairy feed and milk on smallholder dairy farms in Kenya. *Pakistan Journal of Nutrition*, 4, 162-169.

Lerda, D. (2010). Mycotoxin fact Sheet. 3rdedition.JRC. Technical notes. IRRM, Geel Belgium.

Logrieco, A. and Visconti, A. (2004). *An Overview on Toxigenic Fungi and Mycotoxins in Europe*. Kluwer Academic Publishers, Dordrecht Netherlands. http://dx.doi.org/10.1007/978-1-4020-2646-1.

Madhusudhana, B. (2013). A Survey on area, production and productivity of groundnut crop in India. *IOSR Journal of Economics and Finance*, 1(3), 1-7.

Magan, N., Medina, A. and Aldred, D. (2011). Possible climate-change effects on mycotoxin contamination of food crops pre- and postharvest. *Plant Pathology*, 60, 150-163.

Manabe, M. and Tsuruta, O. (1978). Geographical distribution of aflatoxin-producing fungi inhabiting in Southeast Asia. *Japan Agricultural Research Quarterly*, 12, 224-227.

Marsh, P. B. and Taylor, E. E. (1958). The geographical distribution of fiber containing fluorescent spots associated with *Aspergillus flavus* in the United States cotton crop of 1957. *Plant Disease Reporter*, 42, 1368-1371.

Matacic, C., (2016). Fungal toxins are poisoning Africa's children, says new report. Science. DOI: https://doi.org/10.1126/science.aaf4085

Moustafa, A. M., Losso, J. N., King, J. M. and Park, D. L. (2001). Ammoniation of aflatoxin contaminated raw peanuts at ambient temperature and pressure. In: Proceedings of the Institute of Food Technologists Annual Meeting. June 23-27, 2001, New Orleans, Louisiana, 30-55 pp.

Murdock, L. L., Seck, D., Ntoukam, G., Kitch, L. and Shade, R. E. (2003). Preservation of cowpea grain in sub-Saharan Africa-Bean/Cowpea CRSP contributions. *Field Crops Research*, 82, 169-178.

Mutegi, C. K., Ngugi, H. K., Hendriks, S. L. and Jones, R. B. (2009). Prevalence and factors associated with aflatoxin contamination of peanuts from Western Kenya. *International Journal of Food Microbiology*, 130 (1), 27-34.

Ncube, J. and Maphosa M. (2020). Current state of knowledge on groundnut aflatoxins and their management from a plant breeding perspective: Lessons for Africa. Scientific African 1-7. https://doi.org/10.1016/j.sciaf.2020.e00264.

Njoroge, S. M. C. (2018). A critical review of aflatoxin contamination of peanuts in Malawi and Zambia: The Past, Present, and Future. *Plant Disease*, 102, 2394-2406.

Nziramasanga, N. (2014). Aflatoxins in Zimbabwe, legislative frameworks against level of awareness: A perspective from a laboratory. Paper presented at Huang Shan Hall, Peacock Hotel, Lilongwe, Malawi.

Oatley, J. T., Rarick, M. D., Ji, G. E. and Linz, J. E. (2000). Binding of aflatoxin B1 to bifidobacteria *in vitro*. *Journal of Food Production*, 63 (8), 1133-1136.

Odogola. W. R. (1994). Postharvest management and storage of food legumes. Technical Systems for Agriculture. UNDP/OPS Regional Programme, RAF/92/R51. Harare, Zimbabwe.

Oliviera, C. A. F. and Germano. P. M. C. (1997). Aflatoxins in foosdstuffs: Current concepts on mechanisms of toxicity and its involvement in the etiology of hepatocellular carcinoma. *Journal of Public Health*, 3, 417-424.

Olwari, F., Bisikwa, J., Kaaya, A. N., Okello, D. K. (2013). Tolerance levels of peanut varieties against *Aspergillus flavus* infection. *Journal of Plant Pathology and Microb*iology, 4, 195.

Onyeagba, R. A., Ugbogu, O. C, Okeke, C. U. and Iroakasi, O. (2004). Studies on the microbial effects of garlic (*Allium sativum* Linn), ginger (*Zingiber officinale* Roscoe) and lime (*Citrus aurantifolia* Linn.). *African Journal of Biotechnology*, 3, 552-554.

Pandey, M. K., Kumar, R., Pandey, A. K., Soni, P., Gangurde, S. S., Sudini, H. K. (2019). Mitigating aflatoxin contamination in groundnut through a combination of genetic resistance and post-harvest management practices. *Toxins*, 11, 315.

Paramawati, R., Widodo, P., Budiharti, U. and Handaka, D. (2006). The role of postharvest machineries and packaging in minimizing aflatoxin contamination in peanut. *Indonesian Journal of Agricultural Science*, 7, 15-19.

Park, D. L. (2002). Effect of processing on aflatoxin. *Advances in Experimental Medicine and Biology*, 504, 173-179.

Pattee, H. E. and Young, C. Y. (1982). Peanut Science and Technology. American Peanut Research and Education Society Inc., Yoakum, TX, USA, 1982, 655-688.

Pelczar, Jr. M. J., Chan, E. C. S., Krieg, N. R., Pelczar, M. F. and Edwards, D. D. (1993). Microbiology: Concepts and Applications, McGraw-Hill, Inc., 279-286.

Peltonem, K., El-Nezami, H., Haskard, C., Ahokas, J. and Salminon, S. (2001). Aflaoxin B1 binding by dairy starins of lactic acid bacteria and bifidobacteria. *Journal of Daily Science*, 84, 2152-2156.

Phillips, T. M., Clement, B. A. and Park, D. L. (1994). Approaches to reduction of aflatoxins in foods and feeds. In: Eaton, D.L. and Groopman, J.D. (eds.). The toxicology of aflatoxins: human health, veterinary and agricultural significance. Academic Press, San Diego, CA., 383-399.

Probst, C., Bandyopadhyay, R., and Cotty, P. J. (2014). Diversity of aflatoxin producing fungi and their impact on food safety in sub-Saharan Africa. *Int. J. Food Microbiol*. 174, 113-122.

Rahmianna, A. A., Taufiq, A. and Yusnawan, E. (2007) Effect of harvest timing and postharvest storage conditions on aflatoxin contamination in groundnuts harvested from the Wonogiri regency in Indonesia. *SAT eJournal*, 5, 1-3.

Richard, J. L. and Payne, G. A. (2003). Mycotoxins in plant, animal, and human systems. Task Force Report No. 139. Council for Agricultural Science and Technology (CAST), 2003.

Russell, T. E. (1982). *Aflatoxins in Cotton Seed*. Publication Q422, University of Arizona Cooperative Extension Service, Tucson, Arizona.

Rustom, I. Y. S. (1997). Aflatoxin in food and feed. Occurrence, legislation and inactivation by physical methods. *Food chemistry*, 59, 57-67.

Sanders, T. H., Cole, R. J., Blankenship, P. D. and Hill, R. A. (1985). Relation of environmental stress duration to *Aspergillus flavus* invasion and aflatoxin production in preharvest peanuts. *Peanut Science*, 12:90-93.

Sanders, T. H., Hill, R. A., Cole, R. J. and Blankenship, P. D. (1981). Effect of drought on occurrence of *Aspergillus flavus* in maturing peanuts. *Journal of American Oil Chemical Society*, 58, 966-970.

Sarma, U. P., Bhetaria, P. J., Devi, P., and Varma, A. (2017). Aflatoxins: implications on health. *Indian J. Clin. Biochem*. 32, 124-133.

Sharma, K. K. and Mathur, B. P. (2006). Peanut (*Arachis hypogaea* L.). Methods in Molecular Biology, 343, 347-358.

Shephard, G. S. (2003). Aflatoxin and Food Safety: Recent African Perspectives. *Journal of Toxicology: Toxins Reviews*, 22 (2-3), 267-286.

Sudhakar, P., Latha, P., Sreenivasulu, Y., Bhaskar, R. B. V., Hemalatha, T. M., Balakrishna, M. *et al*. (2009). Inhibition of *Aspergillus flavus* colonization and aflatoxin (AFB1) in peanut by methyleugenol. *Indian Journal of Experimental Biology*, 47, 63-67.

Suneja, K. (2019). India Ropes in Global Institution to Curb Contamination in Spice Shipments. Geneva: World Trade Organization.

Surendranatha, E. C., Sudhakar, C., Eswara, N. P. (2013). Aflatoxin contamination in groundnut induced by *aspergillus flavus*: a critical review. *International Journal of Applied Biology and Pharmaceutical Technology*, 2, 2-9.

Torres, A. M., Barros, G. G., Palacios, S. A., Chulze, S. N. and Battilani, P. (2014). Review on pre- and post-harvest management of peanuts to minimize aflatoxin contamination. *Food Research International*, 62, 11-19.

Turner, C. P. (2013). Molecular epidemiology of chronic aflatoxin driven impaired child growth. Scientifica. Pp. 21.

http://dx.doi.org/10.1155/2013/152879

Turner, P. C, Sylla, A., Gong, Y. Y., Diallo, M. S., Sutcliffe, A. E., Hall, A. J. *et al*. (2005) Reduction of exposure to carcinogenic aflatoxins by postharvest intervention measures in West Africa: a community-based intervention study. *The Lancet*, 365, 1950-1956.

Udoh, J. M., Cardwell, K. F. and Iltotun, T. (2000). Storage structures and aflatoxin content of maize in five agroecological zones of Nigeria. *Journal of Stored Products Research*, 36, 187-201.

Udomkun, P., Wiredu, A. N., Nagle, M., Bandyopadhyay, R., Muller, J. and Vanlauwe, B. (2017). Mycotoxins in Sub-Saharan Africa: Present situation, socio-economic impact, awareness, and outlook. *Food Control*, 72, 110-122.

USDA (United States Department of Agriculture). (2010). National agricultural library nutrient database, 2010. (http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl) (Accessed on July 5, 2019).

Varga, J., Frisvad, J. C. and Samson, R. A. (2011). Two new aflatoxin producing species and an overview of Aspergillus section Flavi. *Stud. Mycol*., 69, 57-80.

Vincelli, P. and Parker, G. (2002). Fumonisin, vomitoxin, and other mycotoxins in corn produced by Fusarium fungi. University of Kentucky Cooperative Extension Service. ID 121, 8 pp.

Wagacha, J. M. and Muthomi, J. W. (2008). Mycotoxin problem in Africa: current status, implications to food safety and health and possible management strategies. *International of Food Microbiology*, 124, 1-12.

Waliyar, F., Osiru, M., Sudini, H. K. and Njoroge, S. (2013). Aflatoxins: Finding solutions for improved food safety-reducing aflatoxins in groundnuts through integrated management and biocontrol. International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006-1002 USA.

Waliyar, F., Craufurd, P., Padmaja, K. V., Reddy, R. K., Reddy, S. V., Nigam, S. N. and Kumar, P. L. (2006). Effect of soil application of lime, crop residue and biocontrol agents on pre-harvest *Aspergillus flavus* infection and aflatoxin contamination in groundnut. In: International Conference on Groundnut Aflatoxin Management and Genomics, 5-10 November 2006, Gungdon Hotel, Guangzhou, China, 45 pp.

Waliyar, F., Kumar, P. L., Ntare, B. R., Diarra, B. and Kodio, O. (2008). Pre-and post-harvest management of aflatoxin contamination in peanuts. In: Leslie, J.F., Bandyopadhyay, R. and Visconti, A. (eds.) Mycotoxins: detection methods, management, public health and agricultural trade. CABI Publishing, Wallingford, UK, 209-218 pp.

Weiss, E. A. (2000). Oil Seed Crops. 2nd edition. Blackwell Science Ltd., Oxford, London, 31-36 pp.

Wheeler, T. and Von Braun, J. (2013). Climate change impacts on global food security. *Science*, 341, 508-513.

Wild, C. P., Hudson, G. J., Sabbioni, G., Chapot, B., Hall, A. J., Wogan, G. N. et al. (1992). Dietary-intake of aflatoxins and the level of albumin-bound aflatoxxin in peripheral-boold in the Gambia. *West Africa Cancer Epidemiology, Biomarkers and Preventions*, 1, 229-234.

Wild, C. P., Jansen, L. A., Cova, L. and Montesano, R. (1993). Molecular dosimetry of aflatoxin exposure; Contribution to understanding the multifactorial etiopathogenesis of primary hepatocellular carcinoma with particular reference to hepatitis B virus. *Environmental Health Perspectives*, 99, 115-122.

Williams, J. H., Phillips, T. D., Jolly, P. E., Stiles, J. K., Jolly, C. M. and Aggarwal, D. (2004). Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions. *American Journal of Clinical Nutrition*, 80, 1106-1122.

Womack, E. D., Brown, A. E., Sparks, D. L. (2014) A recent review of non-biological remediation of aflatoxin-contaminated crops. *Journal of the Science of Food and Agriculture*, 94, 1706-1714.

Wu, F. and Khlangwiset, P., (2010). Health economic impacts and cost effectiveness of aflatoxin-reduction strategies in Africa: case studies in biocontrol and post-harvest interventions. Food Additives & Contaminants: Part A 27, 496-509.

Wu, F. and Khlangwiset, P. (2010). Costs and efficacy of public health interventions to reduce aflatoxin-induced human disease. *Food Additives and Contaminants*, 27(7), 998-1014.

Zeringue, H. J. J., Shih, B. J., Maskos, K. and Grimm, D. (1999). Identification of the bright-greenish-yellow-fluorescence (BGY-F) compound on cotton lint associated with aflatoxin contamination in cottonseed. *Phytochemistry*, 52, 1391-1397.