**Aflatoxins Contamination in Groundnut and Their Control**

**Amir Afzal\*****1, Hafiz Husnain Nawaz****2, Sharmin Ashraf1, Zaheka tul Jannat3, Javed Iqbal1, Rubab Altaf4, Sairah Syed1**

*1Barani Agricultural Research Institute, Chakwal*

*2Centre of Excellence for Olive Research and Training*

*3Fatima Jinnah Medical College, Lahore*

*4The University of Haripur, Haripur*

*\*For Correspondance: rajaamirafzal@gmail.com*

**Abstract**

Many fungi are free-living organisms capable of surviving in the environment (soil, air and water) and can find their way into crop products easily especially when the weather conditions are suitable. Several of these fungi are free-living organisms and can survive in the environment even without the crops we grow. Consumption of groundnuts are hindered by Ascomycota fungi Aspergillus flavus and Aspergillus parasiticus the critical fungi that create aflatoxins (Aflatoxins), which are profuse in hot and moist areas of the biosphere. Aflatoxins are associated with severe and enduring noxiousness. Aflatoxin contamination can arise before harvest, and after harvest, during carriage and in store. Agronomic practices such as crop rotation, use of resistant varieties, insect control, timely planting and harvesting, weed control, adequate fertilization and late season irrigation can reduce pre-harvest aflatoxin production. Additionally, atoxigenic fungi can be applied in the field to competitively displace toxigenic fungi to reduce the population of toxigenic fungi in the soil. Post-harvest aflatoxin contamination of groundnuts can be minimized by rapid and proper drying following harvesting, proper transportation and packaging, sorting and post-harvest insect control. Sourcing information from different research and review articles, and book chapters, this paper provides extensive review on the predisposing factors and management of groundnut aflatoxin contamination before and after harvest.

**Keywords**: Aflatoxin, *Aspergillus* *flavus*, *Aspergillus* *parasiticus*, AFB1, Aflatoxin contamination

**Novelty Statement**

Aflotoxins do not damage yield but but make the food toxic. Toxicity of aflatoxin is deleterious due to the fact it is not destroyed at the temperature used in cooking. Moreover, it is alarming body system is unable to alter its chemical composition and livestock and poultry fed contaminated feed produce contaminated milk, meat and eggs. It means once aflatoxins have established cannot be eliminated however with the application of techniques chances of contamination can be reduced significantly. The present investigation has been conducted to highlight the significance of aflatoxin contamination and strategies suggested for their mitigation in food chain by experts in the light of findings of work conducted already. The work conducted is an effort to invite scintific community to conduct experiments in their native circumstances and data revealed will be beneficial to improve awareness in farmers about the harshness of dilemma and enable farmers to adopt practical strategies to ensure producing safe food.

**Introduction**

Groundnut (*Arachis* *hypogaea* L.) belongs to tribe Aeschynomeneae of the family Leguminosae has significant commercial status for rainfed regions in Pakistan, is an annual, geocarpic herb (Zeashan et al., 2019). Groundnut seeds are rich source of protein (25-28%) as well as edible oil (43-55%) (Naeem et al., 2009). Groundnut acquires 13th rank among important food crops worldwide (Nigam, 2014). Groundnut is summer season crop in Pakistan. This crop is well adopted to sandy loam soils. In Pakistan it is cultivated in three provinces Punjab, KPK and in Sindh (Fig. 1). Jhelum, Rawalpindi, Chakwal and Attock in Rawalpindi division and Mianwali and Khushab in Sargodha division are the main areas under groundnut cultivation in the Punjab. It is cultivated on limited areas of district Sukkar and Sanghar in province of Sindh. In Khyber Pakhtunkhwa Swabi, Kohat, Karuk, Malakand in D.I. Khan division and Parachinar District Kurram are the regions where groundnut is grown. Its main utility is as nuts in roasted form or kernels dusted with salt as confectionery in Pakistan. Besides grain yield its stems are also used for livestock feed.

**Figure 1: Contribution of Area Under Groundnut Cultivation by three**

**provinces in Pakistan**

Naeem-ud-Din, Mahmood A, Khattak GSS,

Saeed I, Hassan MF. 2009. High yielding

groundnut (Arachis hypogea L.) variety “Golden”.

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Naeem-ud-Din, Mahmood A, Khattak GSS,

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**Aflatoxins**

Several plant diseases effect quantity and quality of food leading to significant economic losses (Shuping and Ellof, 2017). Some pathogens deteriorate food safety (Massomo, 2020). Aspergillus, Fusarium, Penicillium and Alternaria are the main genera of fungi producing mycotoxins (Kumar et al., 2021). Toxic metabolites in groundnut during field and storage known as aflatoxin are produced by fungal species belonging to genus Aspergillus (Jeyaramraja et al., 2018). Consumption of aflatoxin contaminated diet damages liver seriously (Gong et al., 2016; Kew 2013). Aflatoxins are found cosmopolitan, toxic ingredients; contaminate food crops and pose a hazard to health of human and livestock when consumed (Boutrif, 1998). Rajarajan et al. 2013 characterized various groups virulent against AF described as oilseeds (Groundnut, sunflower, soybean and cotton), Cereals (maize, wheat, pearl millet sorghum and rice), spices (black pepper, chilies, coriander, turmeric, and ginger), nuts (Brazil nut, walnut, almond, pistachio and coconut), yam and several milk foods.

There are mostly six different types of Aflatoxins: B1, B2, G1, G2, M1, and M2 (Quadri et al. 2012). Out of these B1, B2, G1, G2 are found in crops or their foodstuffs (AEFS. 2013), whereas M1 (Metabolite of B1) and M2 are found in the by-products of mammals for instance milk products (Lalah et al., 2020). Aflatoxins are highly lethal, mainly contaminate extensive array of food commodities (Mutegi et al., 2009; Perrone et al., 2014; Iqbal et al., 2015). Among the twenty identified Aflatoxins there are four major Aflatoxins viz. AFB1, AFB2, AFG1 and AFG2 (Pitt, 2000). A flavus produce B type Aflatoxins while A parasiticus produce G Aflatoxins. ([Kumar et al., 2017](https://www.frontiersin.org/articles/10.3389/fmicb.2019.02266/full#B63); Bennett and Klich, 2003).

**Specific Traits of Aflatoxin Producing Fungi**

Aspergillus flavus is the core aflatoxigenic species (Klich, 2007), with a huge level of genetic diversity, several of diverse vegetative similarity clusters (Amaike and Keller, 2011) and morphologically variable types, differentiated into two morphotypes based on sclerotia size, i.e., Group I (S strains) with sclerotia 400 µm in diameter (Cotty, 1989). L strains produce aflatoxins B1 and B2, are quite variable in the levels of aflatoxin produced and also include strains non-aflatoxigenic. Conversely, S strains show less variation in aflatoxin production, are generally higher aflatoxin producers than L strains and can produce aflatoxins G1 and G2 in addition to aflatoxins B1 and B2 (Cotty, 1997). Another important aflatoxigenic species is A. parasiticus, which is able to produce all four of the above aflatoxins. Aspergillus flavus and A. parasiticus differ in host range and habitat. Aspergillus flavus occurs more widely on cereals, oilseeds and dried fruits, including economically important crops, such as groundnuts and corn (Abbas, 2002; Torres et al., 2014), while A. parasiticus is more strictly associated with soil environment and infections of belowground plant organs (Horn et al., 2017).

**How aflatoxins are injurious?**

Aflatoxins damage the safety as well as worth of food and feed cause problems within the food chain because they contaminate yields so cause safety, security, nutrition of food at risk and consequently affect a country’s ability to trade (Ismaiel and Papenbrock, 2015). Usually, the contamination of food products with Aflatoxins is not present in high level. Generally, these low levels of contamination do not cause instant health effects on humans, but do have a longer-term influence if used recurrently. that being the case Aflatoxins are treated casually (Ismaiel & Papenbrock, 2015). Aflatoxins contain alternating groups of carbonyls called polyketides that are carcinogenic, immunosuppressive, hepatotoxic and may produce corporeal and functional defects in human embryo or fetus after the expecting woman is exposed to the substance (Amaike & Keller 2011; Kensler et al., 2011).

These Aflatoxins are stable compounds that cannot be abolished by any ordinary cooking temperature (Mohsenzadeh et al., 2016; Kumar et al., 2017; [Medina et al., 2017](https://www.frontiersin.org/articles/10.3389/fmicb.2019.02266/full#B79)). The living cells are unable to destroy or excrete Aflatoxins (Brown, 2018). Aflatoxins can pass into meat, eggs and milk when animals fed contaminated feed (Fratamico et al., 2008) e.g., contaminated feed of poultry is the cause of AF-contaminated eggs and chicken meat in Pakistan (Iqbal et al., 2014). It is one of the most important constraints limiting production of quality seed (Nigam et al., 2009). AC in groundnut seeds, prevents transnational trade (Wagacha and Muthomi 2008).

AFB1, is the most injurious AF to man and animal as it is oncogenic resulting in liver cancer (IARC, 2012) and is the most investigated among other [aflatoxins](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/aflatoxin) that is why, it also signifies all the aflatoxins (Goto et al., 1996).  Aflatoxicoses in humen and animals is caused by taking Aflatoxins contaminated food and feed in large amount in one dose or small amount for longer period (Williams et al., 2004). Benkerroum et al. 2020, clustered Aflatoxins according to severity of the aflatoxicoses, as acute leading to sudden death and chronic leading to death by degrees. Jaimez et al., 2000, designated the level of poisonousness related with AF variation with the sorts existing as Aflatoxins-B1 > Aflatoxins-G1 > Aflatoxins-B2 > Aflatoxins -G2.

**Management of Aflatoxins**

Controlling AC is vital with an objective to ensure food security (Wu and Khlangwiset, 2010). AF causes infection of groundnut in the field, during and after harvesting and during storage. That is why it becomes necessary to adopt tactics to control contamination during pre-harvesting, post-harvesting and in storage as well to move towards high quality food with reduced food security risk. Fungal colony of A. flavus is green in color and can flourish under several stress circumstances. The heat stress and moisture during shell growth, wound to the shells by nematodes and insects, and other injuries during cultural processes are the reasons that enable seed infection at preharvest (Mehan et al., 1991; Jeyaramraja et al. 2018). Hence, proper crop management at pre- and post-harvest times ensures reduced AC (Hesseltine, 1974). The execution of good agricultural practices (GAPs), good manufacturing practices (GMPs) and good storage practices (GSPs) at pre- and postharvest conditions can alleviate Aflatoxins’ contamination of crops to a certain extent (Kamle et al., 2019). To control Aflatoxins in food chains and increase productivity of agricultural crops, many modern techniques and control plans are available that can be used during pre- and post-harvest period. Currently, depending upon single strategy is not practical style to solve this dilemma. An integrate management from the field up to food or feed processing is compulsory to decrease the effect of aflatoxins. This review recapitulates the development in mitigating the influence of aflatoxins in regions where groundnuts are grown.

**Pre-Harvest strategies**

Several factors determine growth of fungi and AC in crops: some are ecological while others are related with crop management. Environmental situations are generally beyond control; however, adaptation of agronomic practices in crop production may ensure decreased fungal infection, development and aflatoxin production. These strategies mitigate infection by fungi during preharvest phase. Providing crops with the superlative possible growing atmosphere it becomes effective to reduce damage by insects, drought and later on by fungi.

**Good Agricultural Practices**

Groundnut crop sown earlier avoids dry conditions near maturity that generally make shells liable to cracking and entrance by A. flavus. Appropriate weed eradication supports to hold soil moisture critical for plant development and escaping drought that predisposes growing shells to crack. To prevent damage to pods, it is important to keep in check and control the growth of termite particularly as the crop ripens. Lack of moist in the field while the crop is in developing phase is a favorable to fungal infection following aflatoxin contamination. Tied ridges can improve water penetration into the soil, thus decreasing contact of the rising crop to A. flavus infestation. Tied ridges should be put in place initially in the cropping season to detention abundant precipitation and decrease impact of drought near maturity. Mulching is also helpful to conserve moisture in the field (ICRISAT, 2016).

Addition of various soil amendments (Farmyard manure, gypsum and cereal crop residue) mitigated AC significantly as compared to control however, different amendments performed equally in reducing AC quantified with ELISA. That was observed that soil amendments not only resulted in decreased contamination of AF but improved the yield as compared to control as well. So, it is recommended to add at least any one soil amendments to reduce AC (Ijaz 2021). Calcium is one of the most important elements in the growth of groundnut pods (Jain et al., 2011). Well-developed pods are not punctured by insects and this reduces the entrance of fungi into the tissue of seed. Gypsum (Calcium-containing soil amendments) curtails pre-harvest aflatoxin contamination in groundnuts (Reding et al., 1993; Waliyar et al., 2013; Gebreselassie et al., 2014; Ijaz, 2021). Bairagi et al., 2017 reported addition of gypsum at the rate of 250 Kg per hectare enhanced yield significantly as compared with control.

**During harvesting**

Immature kernels have high succulence contents that support fungal infection and growth leading to aflatoxin contamination. Hence, harvesting when the crop is full matured restrict the contact of the produce to high temperature, unpredicted precipitation or drought, which excite infection, thus reducing perspective of aflatoxin contamination at pre harvest. Damage to pods can be prevented by careful digging. To gain kernels undamaged, appropriate harvesting confirms that digging focused mainly at rooting zone. Removal of all the soil attached to the pods in collection is helpful in avoidance of carrying the fungus into stores (ICRISAT, 2016).

**Application of Biocontrol Agents**

The major source of infection to groundnut kernels by A. flavus is the groundnut shell that matures underground (Horn et al., 1995; Horn and Dorner, 1998). Application of biological control agents for instance antagonistic organisms are an important pre-harvest tactic to depress aflatoxin contamination. Many organisms have been studied to explore their potentials in management of aflatoxin contamination of crops.

In vitro studies of numerous organism, have shown that growth of fungus and formation of Aflatoxins by *Aspergillus* spp can be controlled. These strains yet, did not perform under field condition (Dorner, [2004](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2565741/#B11)). Like bacteria some yeast species have capacity to retard growth of *Aspergillus* significantly in vitro. Even if these yeast species have potential to act as biocontrol agents for controlling of Aflatoxins (Hua et al., [1999](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2565741/#B19); Masoud and Kaltoft, [2006](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2565741/#B20))., more trials in field are essential to confirm their usefulness in decreasing AC under field conditions (Yin et al., 2008). When A. flavus strains not producing toxin were applied to groundnut field reduced aflatoxin contamination by toxin producing strains effectively (Yan et al., 2021). Genetic differentiation in *A*. *flavus* populations is independent of geographic distance. This information can be valuable in the development of a suitable biocontrol management strategy of AF producing species of *A*. *flavus* (Acur et al., 2020). The aptitude of fungus to contend with closely associated strains depends on numerous aspects e.g., Yin et al., 2008 described following provisions to achieve the target successfully.

1. The selection of nontoxigenic strains occupying the same niches as the toxigenic strains are accomplished of competing and replacing toxigenic strains.
2. The nontoxigenic strains must be overriding in the farming settings when the crops are vulnerable to be infected by the toxigenic strains to accomplish the target of successful exclusion. The aspects those determine the efficiency of this approach.
3. The preparation of biocontrol strains must be precisely practical holding creation and distribution potential of conidiospores more capable than toxigenic strains in soil.
4. Apply at appropriate time.

Findings of work conducted by Ehrlich, 2014 has stressed significance of pH and soil type in addition to the accessibility of water, carbon, nitrogen, and minerals for successful management of aflatoxin through application of biological agents.

**Post-Harvest strategies**

There is an opinion that there are more probabilities of aflatoxin contamination after harvesting (Wild and Hall, 2000). Inappropriate management practices and incompatible climatic situations during and after harvesting are factors making produce disposed to post-harvest aflatoxin contamination. Substantial grain deteriorations caused by molds in stores attributed to improper storage. Waliyar et al., 2015 suggested following tactics for post-harvest AF management that are feasible at the famer/trader level are

1. Decreasing moisture content to ≤8% during storage
2. Application of pesticides to ensure avoidance of insect attack and fungal infection during storage
3. Grading and sorting of produce.
4. Re-drying of groundnut shells and seeds after grading.
5. Appropriate storage confirms adverse circumstances for growth of mould.
6. Avoid re-humidification of shells.
7. It is need of hour to conduct research to evolve techniques of detoxification of contaminated products
8. Improving consciousness of smallholders about existing knowhows and more generally about aflatoxin contamination.

Rather than depending on one or two possibilities for reducing post-harvest aflatoxin contamination, conjunctive application of sustainable and lucrative approaches will be more helpful for management of the problem.

**Breeding Groundnut for resistance against A. flavus**

Once fungal infection causing aflatoxin contamination is established it cannot be eliminated completely through postharvest processes (Nigam et al., 2009). Following proper postharvest techniques aflatoxin contamination can be minimized. However, these practices are not very successful if the AF is existing previously in the kernel before drying and storage. Moreover, mostly the small land-holders in the developing countries, which produce approximately 60% to the world groundnut production do not adopt these practices broadly (Upadhyaya et al., 2002). Identification of sources of resistance against the fungus causing aflatoxin contamination and deployment of resistant cultivars is more practical approach than others if achieved.

Rao and Tulpule (1967) were the first to insist occurrence of genetic diversity in groundnut against production of AF. Mixon and Roger (1973) are the pioneers to advocate management of aflatoxin through breeding. They established a procedure of rehydrating groundnut seeds in vitro to categorize the groundnut germplasm into resistant and susceptible to aflatoxin producing fungi and identified two genotypes from Valencia group of groundnuts possessing significant resistance in vitro seed colonization (IVSC) by A. flavus and A. parasiticus. There are three resistance mechanisms against invasion by aflatoxin producing fungi viz. 1. *In-vitro* seed colonization resistance (IVSC). 2. Resistance to pre-harvest aflatoxin contamination (PAC). 3. Resistance to aflatoxin production in seeds have been identified in groundnut. However, the aflatoxin is produced only in the cotyledons of groundnut kernels after fungal infection (Lianget al 2006). Various workers identified resistant sources to these mechanisms separately (Mehan et al 1989; Anderson et al., 1995, Upadhyayaet al 2002; Waliyar, *et al*. 2016). Nayak et al., 2017 recognized candidate genes for IVSC resistance in groundnut, the study identified the genes involved in host-pathogen interface and markers that information can be exploited in breeding process resistant varieties.

Since trait of aflatoxin resistance is influenced highly by the circumstances (Cotty and Jaime 2007), This situation complicated breeding for incorporating resistance against aflatoxin. Genotypes possessing tolerance against drought have been found resistant to aflatoxin contamination, screening for drought tolerance is useful tool to identify sources of resistance against aflatoxin contamination indirectly (Holbrook et al., 2009). Trait of aflatoxin resistance is highly influenced by environment that is why mechanism associated with inheritance of resistance against aflatoxin is ambiguous. Application of molecular tools can generate reliable data that can be used to evolve durable resistant genotypes. Several genes associated in host-pathogen interactions have branded as a result of progress in mycological expressed sequence tags, microarrays, and genome sequencing procedures. Furthermore, projects finding genes coding for antimycotic compounds, resistance linked proteins and QTL allied with resistance against aflatoxin are in progress (Jeyaramraja et al., 2018).

Work conducted in 90s and in the beginning of 21st century revealed broad sense heritability (low to moderate) and combining ability of resistance sources (Rao et al., 1989; Utomo et al., 1990; Upadhyaya et al., 1997; Xue, 2004). Utomo et al. (1990) determined three resistance mechanisms and that dissimilar gene controlled them and claimed there did not exist significant associations among these mechanisms. Later findings of study conducted by Upadhyaya et al. (2002) supported Utomo et al. (1990). Xue (2004) described largely nonadditive genetic variance for AF production, proposed selection for this trait in early generations will be useless. The genetics of resistance mechanisms is not established. Moreover, the allelomorphic association among several sources for each resistance characteristic requires to be explained for defining improved approaches for breeding for resistance to aflatoxin contamination. Genetic diversity prevails in Groundnut for various mechanisms of resistance viz. resistance to colonization in seed, pre- and post-harvest fungal infection and AF production against Aspergillus spp. Thus far, there is no genotype that collects all these resistance mechanisms to deal successfully with the AF challenge (Pandey et al., 2019).

**Conclusion**

Target of food security cannot be achieved with ample food only if is not safe and nourishing. aflatoxins, are a family of toxins caused by certain fungi that are originated in crops for instance corn, groundnuts, cottonseed, and tree nuts. Aflatoxin-producing fungi can contaminate crops in field, at harvest and during storage. Several crops are prone to aflatoxin contamination however maize and groundnut are most susceptible. Groundnut is vulnerable to *A. flavus* and *A.* *parasiticus.* Aflatoxins produced by these spp. contaminate in food most common. In this review article deleterious effects of the aflatoxins and management strategies during pre-harvest and post-harvest, along with prospective of plant breeding for improvement of crop resistance has been discussed in detail. Reviewing up-to-date literature, the association of moisture content and aflatoxin contamination in groundnut at preharvest are deliberated. Generally, an integrated strategy to assure circumvention enterence of aflatoxins in food chain, Aflatoxins are controlled at all stages from the farmer field to the table is essential for reduction in hazard. Consequently, by eliminating the sources of contamination through supporting improved agronomic and animal husbandry practices in the field, during harvesting, storage and, encouraging healthier livestock feeding may reduce threats caused by aflatoxins in food chain. Furthermore, application of atoxigenic molds in the field to relocate toxigenic fungi to mitigate the toxigenic fungi in the soil. Crops are disposed to aflatoxin contamination in the field as well as in storage that is why various agronomic practices during pre-harvest as well as post-harvest are necessary to minimize the chances of contamination. Soil amendments before sowing, addition of nontoxigenic strains of A. flavus have been found very effective in decreasing the population of toxic Aspergillus spp. Genetic diversity in groundnut against A. flavus is not indeterminate, however the data has not been utilized successfully to develop resistant cultivar although it is well known that it may prove best strategy to control aflatoxin contamination effectively if succeeded. Social campaign may generate consciousness about individual protection from aflatoxins.

**Reference:**

Abbas, H.K. 2002. Aflatoxin and fumonisin contamination of commercial corn (*Zea* *mays*)

hybrids in Mississippi. J. Agric. Food Chem50: 5246–5254..,

Acur, A., R.S. Arias, S. Odongo, S. Tuhaise, J. Ssekandi, J. Adriko, D. Muhanguzi, S. Buah and A. Kiggundu. 2020. Genetic Diversity of AF-Producing Aspergillus Flavus Isolated from Selected Groundnut Growing Agro-Ecological Zones of Uganda. BMC Microbiol. 20: 252.

AEFS. 2013. Aflatoxins (sum of B1, B2, G1, G2) in cereals and cereal-derived food products. Efsa Supporting Publications.;10: n/a-n/a

Amaike, S. and N.P. Keller. 2011. *Aspergillus* *flavus*. Annu. Rev. Phytopathol. 49: 107–133.

Anderson, W.F., C.C. Holbrook, D. M. Wilson, and M.E. Matheron, 1995. Evaluation of preharvest aflatoxin contamination in several potentially resistant peanut genotypes. Peanut Science 22:29-32.

Bairagi M.D., A.A. David, T. Thomas and P.C. Gurjar .2017. Effect of different level of N P K and gypsum on soil properties and yield of groundnut (*Arachis hypogaea* L.) var. Jyoti. International Journal of Current Microbiology and Applied Sciences 6(6):984-991.

Benkerroum N. 2020. Chronic and Acute Toxicities of Aflatoxins: Mechanisms of Action. Int. J. Environ. Res, 17: 423. https://doi.org/10.3390/ijerph17020423

Bennett, J.W. and M, Klich. 2003. Mycotoxins. Clin. Microbiol. Rev. 16: 497-516.

Boutrif, E. 1998. Prevention of AF in pistachios. Food Nutr. Agric. 21: 32–38.

Brown, L.R. 2018. Aflatoxins In Food and Feed Impacts, Risks, and Management Strategies. 6 Pages DOI: <https://doi.org/10.2499/p15738coll2.134485>

Cotty, P and R. Jaime. 2007. Influence of climate on aflatoxin producing fungi and aflatoxin contamination. Int. J. Food Microbiol. 119: 109-15. 10.1016/j.ijfoodmicro.2007.07.060.

Cotty, P.J. 1989. Virulence and cultural characteristics of two Aspergillus flavus strains pathogenic on cotton. Phytopath. 79: 808–814.

Cotty, P.J. 1997.Aflatoxin-producing potential of communities of Aspergillus section Flavi from cotton producing areas in the United States. Mycol. Res. 101: 698–704.

Dorner, J.W. 2004. Biological control of aflatoxin contamination of crops. J. Toxicol. Toxin Rev*.* 23(2&3):425–450.

Ehrlich, K. C. 2014. Non-aflatoxigenic Aspergillus flavus to prevent aflatoxin contamination in crops: advantages and limitations. Front.Microbiol. 5: 50.

Fratamico, P.M., A.K. Bhunia and J.L. Smith. 2008. Foodborne Pathogens: Microbiol. Mol. Biol. Norofolk, UK: Horizon Scientific Press. [ISBN](https://en.wikipedia.org/wiki/ISBN_(identifier)) [978-1-898486-52-7](https://en.wikipedia.org/wiki/Special:BookSources/978-1-898486-52-7).

Gebreselassie, R., A. Dereje and H. Solomon. 2014. On-farm pre harvest agronomic management practices of Aspergillus infection on groundnut in Abergelle, Tigray. J. Plant Pathol. Microbiol. 5:1-6

Gong, Y.Y., S. Watson, M.N. Routledge. 2016. Aflatoxin Exposure and Associated Human Health Effects, a Review of Epidemiological Studies. Food Safety. 4:14–27.

Goto, T., D. T. Wicklow and Y. Ito, 1996. Aflatoxin and cyclopiazonic acid production by a sclerotium-producing *Aspergillus Tamarii* strain. Appl. Environ. Microbiol. 62: 4036–4038. doi: 10.1128/aem.62.11.4036-4038.1996

Hesseltine, C. W. 1974. Natural occurrence of mycotoxins in cereals. Mycopathol. Mycol. Appl. 53: 141–153. doi: 10.1007/bf02127204

Holbrook C. C., B.Z. Guo, D.M. Wilson, and P. Timper.2009. The U.S. Breeding Program to Develop Peanut with Drought Tolerance and Reduced Aflatoxin Contamination. Peanut Sci. 36:50–53

Horn, B.W., and J.W. Dorner. 1998. Soil population of Aspergillus species from section Flavi along a transect through groundnut-growing regions of the United States. Mycologia, 90: 767–776.

Horn, B.W., J.H Ramirez-Prado and I. Carbone, 2017. The sexual state of Aspergillus parasiticus. Mycologia. 101: 275–280.

Horn, B.W., R.L. Greene, and J.W. Dorner. 1995. Effect of corn and groundnut cultivation on soil populations of Aspergillus flavus and Aspergillus parasiticus in southwestern Georgia. Appl. Environ. Microbiol. 61: 2472–2475.

Hua, S.S.T., J. L. Baker and M. Flores-Espiritu, 1999. Interactions of saprophytic yeasts with a nor mutant of Aspergillus flavus. Appl. Environ. Microbiol., 65(6):2738- 2740.

IARC .2012. International Agency for Research on Cancer. Review of Human Carcinogens: Chemical Agents and Related Occupations. Geneva: WHO.

ICRISAT. 2016. How to Reduce Aflatoxin Contamination in Groundnuts and Maize A Guide for Extension Workers. Patancheru 502 324, Telangana, India: ICRISAT 24 pp.

Ijaz, M. 2021. Pre- and Post-Harvest Management of AF Contamination in Groundnut. Final Research Progress Report for PARB’S CGS Project No.599. Barani Agricultural Research Institute Chakwal (Under Publication).

Iqbal, S. Z., S. Jinap, A.A. Pirouz and A. R. A. Faizal. 2015. AF M1 in milk and dairy products, occurrence and recent challenges: a review. Trends Food Sci. Technol. 46: 110–119. doi: 10.1016/j.tifs.2015.08.005

Iqbal, S.Z., S. Nisar, M.R. Asi and S. Jinap. 2014. Natural incidence of Aflatoxins, ochratoxin A and zearalenone in chicken meat and eggs. Food Control*.* 43:98–103. doi:10.1016/j. foodcont. 2014.02.046

Ismaiel, A.A. and J. Papenbrock. 2015. Mycotoxins: Producing Fungi and Mechanisms of Phytotoxicity. Agriculture 5: 492–537

Jaimez, J., C. A. Fente, B. I. Vazquez, C. M. Franco, A. Cepeda, G. Mahuzier and P. Prognon. 2000. Application of the assay of aflatoxins by liquid chromatography with fluorescence detection in food analysis. J. Chromatogr. A. 882 (1-2): 1–10. doi: 10.1016/S0021-9673(00)00212-0

Jain, M., B.P. Pathak, A.C. Harmon, B.L. Tillman and M. Gallo .2011. Calcium dependent protein kinase (CDPK) expression during fruit development in cultivated groundnut (Arachis hypogaea) under Ca2+ - sufficient and -deficient growth regimens. J. Plant Physiol. 168 (18): 2272-2277

Jeyaramraja, P. R., S. N. Meenakshi and F. Woldesenbet. 2018. Relationship between drought and preharvest aflatoxin contamination in groundnut (*Arachis* *hypogaea* L.). World Mycotoxin J. 11: 187–199. https://doi. org/10.3920/WMJ2017.2248

ICRISAT. 2016. How to Reduce Aflatoxin Contamination in Groundnuts and Maize A Guide for Extension Workers. Patancheru 502 324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 24 pp.

Kamle, M., D. K. Mahato, S. Devi, K. E. Lee, S. G. Kang and P.Kumar. 2019. Fumonisins: impact on agriculture. food, and human health and their management strategies. Toxins 11:328. doi: 10.3390/toxins11060328

Kensler, T.W., B. D. Roebuck, G.N. Wogan and J.D. Groopman. 2011. Aflatoxin: A 50-year odyssey of mechanistic and translational toxicology. Toxicol. Sci. 120: S28–48.

Kew MC. 2013 Aflatoxins as a cause of hepatocellular carcinoma. J Gastrointestin Liver Dis. 3:305-10.

Klich, M.A. 2007. Aspergillus flavus: The major producer of aflatoxin. Mol. Plant Pathol. 8: 713–722.

Kumar, A., H. Pathak, S. Bhadauria and J*.* Sudan. 2021 Aflatoxin contamination in food crops: causes, detection, and management: a review. Food Prod. Process. and Nutr. 3**:**17 (2021). <https://doi.org/10.1186/s43014-021-00064-y>

Kumar, P., D. K. Mahato, M. Kamle, T. K. Mohanta and S. G. Kang 2017. Aflatoxins: a global concern for food safety, human health and their management. Front. Microbiol*.* 7:2170. doi: 10.3389/fmicb.2016.02170

Lalah, J.O, S. Omwoma and D.A.O. Orony, 2020. Aflatoxin B1: Chemistry, environmental and diet sources and potential exposure in human in Kenya. In Aflatoxin B1 Occurrence, Detection and Toxicological Effects; BoD–Books on Demand: Norderstedt, Germany.

Liang, X. A., M. Luo, And B. Z. Guo. 2006. Resistance mechanisms to aspergillus flavus infection and aflatoxin contamination in peanut (arachis hypogaea). Plant Path. Jour. 5:115–124.

Masoud, W. and C.H. Kaltoft, 2006. The effects of yeasts involved in the fermentation of coffea arabica in East Africa on growth and ochratoxin A (OTA) production by *Aspergillus* *ochraceus*. Int. J. Food Microbiol., 106(2): 229-234. [doi: 10.1016/j.ijfoodmicro.2005.06.015]

Massomo, S.M.S. 2020. Aspergillus flavus and aflatoxin contamination in the maize value chain and what needs to be done in Tanzania. Sci. Afr. 10, e00606.

Medina, A., M. K. Gilbert, B. M. Mack, G. R. OBrian, A. Rodriguez, D. Bhatnagar, G. Payne and N, Magan.2017. Interactions between water activity and temperature on the Aspergillus flavus transcriptome and aflatoxinB1 production. Int. J. Food Microbiol. 256: 36–44. doi: 10.1016/j.ijfoodmicro.2017.05.020

Mehan, V.K. 1989. Screening groundnut for resistance to seed invasion by Aspergillus flavus and aflatoxin production. Pages 323-334 in Aflatoxin contamination of groundnut; proceedings of the International Workshop, 6 - 9 Oct 1987, ICRISAT Center, India (McDonald, D., and Mehan, V.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Mehan, V.K., D. McDonald, L.J. Haravu, and S. Jayanthi. 1991. The Groundnut AF Problem: Review and Literature Database. Patancheru, A.P. 502 324, India. ICRISAT.

Mixon, A.C. and K.M. Rogers. 1973. Groundnut accessions resistant to seed infection by *Aspergillus* *flavus*. Agron. J. 65:560-562.

Mohsenzadeh, M.S., N. Hedayati, B. Riahi-Zanjani G. Karimi. 2016. Immunosuppression following dietary AF B1 exposure: a review of the existing evidence. Toxin Rev. 35(3–4): 121–127.

Mutegi, C. K., Ngugi, H. K., Hendriks, S. L., and Jones, R. B. 2009. Prevalence and factors associated with AC of groundnuts from Western Kenya. Int. J. Food Microbiol. 130: 27–34. doi: 10.1016/j.ijfoodmicro.2008. 12.030

Naeem-ud-Din, A. Mahmood, G.S.S. Khattak, I. Saeed and M. F. Hassan .2009. High yielding groundnut (Arachis hypogea L.) Variety “Golden”. Pak. J. Bot. 41(5): 2217-2222.

Nayak, S. N., Agarwal, G., Pandey, M. K., Sudini, H. K., Jayale, A. S., Purohit, S., et al. (2017). *Aspergillus flavus* infection triggered immune responses and host-pathogen cross-talks in groundnut during in-vitro seed colonization. Sci. Rep. 7:9659. doi: 10.1038/s41598-017-09260-8

Nigam S.N., F. Waliyar, R. Aruna, S.V. Reddy .2009. Breeding peanut for resistance to aflatoxin contamination at ICRISAT. Groundnut Sci. 36: 42–49, doi:10.3146/AT07-008.

Nigam SN. 2014. Groundnut at a glance. Pp 121.

Pandey, M.K., R. Kumar, A.K. Pandey, P. Soni, S.S. Gangurde, H.K. Sudini, J.C. Fountain, B. Liao, H. Desmae, P. Okori, X. Chen, H. Jiang, V. Mendu, H. Falalou, S. Njoroge, J. Mwololo, B. Guo, W. Zhuang, X. Wang, X Liang and R.K. Varshey .2019. Mitigating AF contamination in groundnut through a combination of genetic resistance and post-harvest management practices. Toxins 11:13–21.

Perrone G, M Haidukowski, G Stea, F Epifani, R Bandyopadhyay, JF Leslie and A Logrieco. 2014. Population structure and AF production by Aspergillus Sect. Flavi from maize in Nigeria and Ghana. Food Microbiol. 41: 52–59. doi: 10.1016/j.fm.2013.12.005

Qasim M, K Bakhsh, S A Tariq, M Nasir, R Saeed and M A Mahmood. 2016. Factors affecting groundnut yield in pothwar region of punjab, Pakistan. Pakistan J. Agric. Res. 29: 76-83.

Quadri, S. H., N. Ms, C. Kc, U. Shantaram and E. Hs. 2012. An overview of chemistry, toxicity, analysis, and control of aflatoxins. Intern. J. Chem. Life Sci. 2: 1071–1078.

Rajarajan, P. N., K. M. Rajasekaran and N. K. Devi .2013. AF contamination in agricultural commodities. Indian J. Pharm. Biol. Res. 1(4): 148–151. https://doi.org/10.30750/ijpbr.1.4.25.

Rao, K.S. and P.G. Tulpule. 1967. Varietal differences of groundnut in the production of aflatoxin. Nature (London) 214:738-739.

Rao, M.J.V., S.N. Nigam, V.K. Mehan, and D. McDonald. 1989. Aspergillus flavus resistance breeding in groundnut: Progress made at ICRISAT Center, pp. 345-355. In McDonald D. and V.K. Mehan (eds.), Aflatoxin contamination of Groundnut. Proc. Int. Workshop, 6–9 Oct. 1987, ICRISAT Center, Patancheru, A.P. 502 324, India. ICRISAT

Reding, C.L.C., M.A. Harrison and C.K. Kvien. 1993. Aspergillus parasiticus growth and aflatoxin synthesis on florunner groundnuts grown in gypsum-supplemented soil. J. Food Prot. 56:593- 611

Shuping, D.S.S. and J.N. Eloff .2017. The use of plants to protect plants and food against fungal pathogens: A review. Afr. J. Tradit. Complement Altern. Med., 14:120–127.

Torres A.M., G.G. Barros, S.A. Palacios, S.N. Chulze and P. Battilani . 2014. Review on pre- and post-harvest management of groundnuts to minimize aflatoxin contamination. Food Res. Int. 62: 11-19

Upadhyaya, H.D., S.N. Nigam, and R.P. Thakur. 2002. Genetic enhancement for resistance to AC in groundnut, pp. 29-36. In Summary Proceedings of the Seventh ICRISAT Regional Groundnut Meeting for Western and Central Africa, 6–8 Dec. 2000, Cotonou, Benin. Patancheru 502: 324, Andhra Pradesh, India: ICRISAT.

Upadhyaya, H.D., S.N. Nigam, V.K. Mehan, and J.M. Lenne. 1997. Aflatoxin Contamination of groundnut - prospects of a genetic solution through conventional breeding, pp. 81-85. In Aflatoxin Contamination Problems in Groundnut in Asia: Proceedings of the First Working Group Meeting, 27–29 May 1996, Ministry of Agriculture and Rural Development, Hanoi, Vietnam (V.K. Mehan and C.LL. Gowda eds.). Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Utomo, S.D., W.F. Anderson, J.C. Wynne, M.K. Beute, W.M. Hagler, Jr., and G.A. Payne. 1990. Estimates of heritability and correlation among three mechanisms of resistance to Aspergillus parasiticus in groundnut. Proc. Amer. Groundnut Res. and Educ. Soc. 22:26. (Abstract). Vietnam (Mehan, V.K., and Gowda, C.L.L., eds.). Patancheru 502-324, Andhra Pradesh, India: ICRISAT.

Wagacha, J.M. and J.W. Muthomi. 2008. Mycotoxin problem in Africa: Current status, implications to food safety and health and possible management strategies. Int. J. Food Microbiol. 124: 1–12.

Waliyar, F., K. V. K. Kumar, M. Diallo, A. Traore, U.N. Mangala, H.D. Upadhyaya, and H. Sudini, 2016. Resistance to preharvest aflatoxin contamination in ICRISAT’s groundnut mini core collection. European Journal of Plant Pathology 145: 901-913. DOI 10.1007/s10658-016-0879-9

Waliyar, F., M. Osiru, H.K. Sudini and S.M.C. Njoroge 2013. Aflatoxins: Finding solutions for improved food safety-Reducing Aflatoxins in Groundnuts through Integrated Management and Biocontrol. Inter. Food Policy Res. Instt., 2033 K Street, NW, Washington, DC 20006-1002 USA

Waliyar, F., M. Osiru, B.R. Ntare, K.V.K. Kumar, H. Sudini, A. Traore, B. Diarr .2015. post-harvest management of aflatoxin contamination in groundnut. World Mycotoxin J., 8: 245-252

Wild, C.P. and A.J. Hall. 2000. Primary prevention of hepatocellular carcinoma in developing countries. Mutat. Res*.*, 462:381–393.

Williams J.H., T.D Phillips, P.E. Jolly, J.K Stiles, C.M Jolly, D. Aggarwal, 2004. Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions,  AJCN : 80, 1106– 1122,  <https://doi.org/10.1093/ajcn/80.5.1106>

Wu, F. and P. Khlangwiset .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, 27:4, 496-509, DOI: [10.1080/19440040903437865](https://doi.org/10.1080/19440040903437865)

Xue, H. 2004. Evaluation of groundnut (Arachis hypogaea L.) germplasm for resistance to AF production by *Aspergillus* *flavus* Link ex Fries. Ph.D. Thesis. North Carolina State University, Raleigh, NC.

Yan, L., W. Song, Y. Chen, Y. Kang, Y. Lei, D. Huai, Z. Wang, X. Wang, B. Liao. 2021. Effect of non-aflatoxigenic strains of Aspergillus flavus on aflatoxin contamination of pre-harvest groundnuts in fields in China. Oil Crop Sci. 6: 81-86

Yin, Y. N., L. Y. Yan, J. H. Jiang, and Z. H. Ma .2008. Biological control of AF contamination of crops. J. Zhejiang Univ. Sci. B, 9 (10):787–792. [https: //doi.org/ 10.1631/jzus. B0860003](https://doi.org/10.1631/jzus.B0860003)

Zeeshan, M., G. Nabi, S. Ali, M. Hussain, Saadia, A. Ali, M. I. Khan, W. Arshad, A. Batool .2019. Evaluation of groundnut (*Arachir* *hypodaea* L.) lines for their yield potential and adaptability under rainfed conditions. International Journal of Biosciences | IJB | 14 (5): 24-30,