



FROM FIELD TO FORKS: A DEEP DIVE INTO AFLATOXIN CONTAMINATION IN FOOD ITEMS

Avinash Jain and Shyam Govind Singh

Department of Botany, Agra College, Agra Affiliated to Dr. Bhimrao Ambedkar University, Agra, Uttar Pradesh, India

Email: avinash.jain1028@gmail.com

www.doi.org/10.59436/https://jsiane.com/archives3/4/105

Abstract

Aflatoxin contamination in food items brings a significant hazard to global foodstuff safety, public health, and economic stability. This assessment comprehensively examines the sources, risks, and potential solutions associated with aflatoxin contamination in various food products. Aflatoxins, produced by moulds of the *Aspergillus flavus*, contaminate crops during cultivation, harvest, storage, and processing stages. Consumption of aflatoxin-contaminated food items has been linked to severe health issues, including liver cancer, stunted growth, and immune system suppression.

This review delves into the diverse sources of aflatoxin contamination, ranging from agricultural practices and environmental factors to storage conditions. The risks associated with aflatoxin exposure are explored in detail, emphasizing on the global impact on both human health and economies, especially in vulnerable communities reliant on staple crops. Furthermore, the review discusses multifaceted solutions aimed at mitigating aflatoxin contamination. These solutions encompass agricultural strategies such as crop rotation, improved irrigation methods, and biocontrol agents, as well as advancements in food processing techniques like sorting, washing, and hermetic storage. Regulatory measures and international standards are critically evaluated, highlighting their role in ensuring food safety and preventing aflatoxin-related health crises.

Keywords : Aflatoxin, Contamination, Public Health, Global Foodstuff Safety

Received 05.09.2023

Revised 12.10.2023

Accepted 20.12.2023

Introduction

Historically, the year 1960 has been the most important, because the scientific concern about aflatoxins was generated during this year. The most prominent development in relation to aflatoxin research was the discovery of 'Turkey 'X' disease which inflicted heavy loss to turkey birds in UK, when over a lakh, young turkey poulted died in 1960, and the term mycotoxin was coined in England in 1962 (Stevens *et al.*, 1960). The aflatoxins were first isolated in crystalline form from toxic meals by Nesbitt *et al.* (1962) and identified with the help of UV light as aflatoxin B and G, as they emit blue and green fluorescence respectively. Hartley *et al.* (1963) further identified their closely related forms as B₁, B₂, G₁ and G₂. The occurrence of natural microbial contamination in agricultural produce is a global phenomenon and among these microorganisms, fungi contribute significantly in contaminating food and feeds. Christensen (1965) categorized fungi into three distinct, groups: Field fungi, which infiltrate grains or kernels prior to harvesting in standing crop, storage fungi, which do not invade cereals before harvest but get associated during postharvest operations and then affect stored grains and advanced decay fungi, specifically found on decayed corn cobs. Pre- and post-harvest food commodity losses can be attributed to a variety of biotic and abiotic sources. Descent of stored food items by fungi is a big issue in stifling hot and humid areas. Many types of fungi, including *Aspergillus*, *Penicillium*,

Alternaria, *Cladosporium*, *Fusarium*, *Mucor* and *Rhizopus*, have been found to infect harvested food grains (Mateus *et al.*, 2021). Some moulds and yeasts can contaminate food when they grow in the right conditions and release harmful secondary metabolites called mycotoxins. *Aspergillus*, *Penicillium*, *Fusarium*, and *Alternaria* are some of the most common toxin-producing fungal taxa (Khodaei *et al.*, 2021; Pandey *et al.*, 2022). *Aspergillus flavus* is responsible for the production of aflatoxin B₁ and B₂, whilst *A. parasiticus* is responsible for the synthesis of aflatoxin G₁ and G₂. Cereals like maize, sorghum, rice, pearl millet and wheat; oilseeds like peanuts, soybeans, cotton, and sunflower; and spices like chilli peppers, black pepper, coriander, cumin, fennel, ginger, and turmeric are all heavily contaminated with these toxins. Also vulnerable to contamination are yams, different milk products, and nuts like almonds, pistachios, coconuts, Brazil nuts, and walnuts (Rajarajan *et al.*, 2013). Mycotoxins in food have been shown to have harmful effects on human and animal health. Poultry, such as chickens and turkeys, as well as pigs and lambs, are prone to immune-suppression when exposed to aflatoxins. [CAST], 2003; Oswald *et al.*, 2005 and Meissonnier *et al.*, 2008). Factors determining fungal colonisation and mycotoxin biosynthesis are some environmental parameters such as water activity (aw), nutritional substrate, pH, and temperature (Schmidt *et al.*, 2008). Aflatoxins are toxic carcinogenic substances generated by fungi, particularly *A. flavus* and *A. parasiticus*.

These harmful compounds have the potential to taint numerous types of animal feeds, leading to substantial economic damages. The yearly losses attributed solely to the U.S. corn industry due to aflatoxin infection are predictable to range between US\$52.1 and US\$1.68 billion (Jiang *et al.*, 2021). Due to its carcinogenic qualities, especially its link to hepatocellular carcinoma, a type of liver cancer (Qureshi *et al.*, 2015), aflatoxin B₁ poses serious hazards to the health of both humans and animals. Because they interfere with the activity of immune-boosting cells, aflatoxins have negative waves on the immune systems of both people and animals. Aflatoxins can cause death and injury almost instantly at high dosages, whereas at lower quantities they can have immunologic or nutritional consequences over time. Regardless of the dosage, accumulation of aflatoxin in the body can ultimately lead to liver cancer, as highlighted in studies conducted by Marroquín-Cardona *et al.* (2014).

Favourable conditions for aflatoxin contamination-

The production of mycotoxins is influenced by the specific food source, enzymes, and a range of environmental factors. However, it's important to note that the conditions favourable for aflatoxigenic fungi don't always guarantee the production of aflatoxins, as pointed out by Mannaa and Kim in 2017.

Aflatoxin contamination is heavily influenced by a wide range of physical parameters, including pH, moisture, light exposure, temperature, relative humidity, water availability, and atmospheric gases. Aflatoxin-producing moulds and fungi can propagate in a broad pH range of 1.7 to 9.3, with the ideal pH falling between 3 and 7 (Yoshinari *et al.*, 2010). When the pH is lower, around 5, Aflatoxin B (AFB) is produced, but when the pH is higher, around 7, Aflatoxin G (AFG) is produced. Aflatoxin generation, however, is also influenced by the pH of the growth media (Dalié *et al.*, 2010). Darkness enhances aflatoxin manufacture, while sunlight deters it (Rushing and Selim, 2019). Elevated vapour levels are conducive to aflatoxin contamination, as they provide favourable conditions for fungal growth. An optimal relative humidity of 85% promotes aflatoxin production, and a relative humidity of 95% significantly increases aflatoxin production (Ding *et al.*, 2015). Aflatoxin fabrication can occur across a wide temperature range, but the most favourable temperature for production is between 25-35°C (Siciliano *et al.*, 2017). AFB production is often higher than AFG production at higher temperatures, although AFG and

AFB production levels are similar at lower temperatures (Matumba *et al.*, 2015). Moreover, aflatoxin production and fungal growth are impeded in environments with elevated CO₂ levels and reduced O₂ levels (Mahbobinejad *et al.*, 2019). Substrate and dietary variables such as carbon, nitrogen, amino acids, lipids and trace elements play important roles in aflatoxin formation. Substrates rich in carbohydrates facilitate higher production compared to oil, as carbohydrates readily provide the necessary carbon essential for robust fungal growth (Ma *et al.*, 2014). Increased aflatoxin formation by *A. flavus* has been linked to the addition of nitrogen in the form of nitrites and nitrates (Wang, Han, *et al.*, 2017). Aflatoxin generation is increased in *A. flavus*-infected defatted wheat when maize oil is added to the media (Liu *et al.*, 2016). In addition to bivalent metals like zinc and magnesium, certain amino acids like glycine, glutamate, and alanine can promote aflatoxin formation (Bolu *et al.*, 2014). Zinc concentrations of 20 mg/L, 50 mg/L, and 100 mg/L were associated with 4, 5 and 19 times higher levels of aflatoxin formation, respectively (Liu *et al.*, 2016). Tryptophan suppresses aflatoxin formation while amino acids like tyrosine increase it (Chang *et al.*, 2015). At a concentration of 0.5%, arginine, glycine, glutamic acid, and aspartic acid all contribute to the formation of AFB₁.

The quantity of aflatoxin produced is primarily determined by the specific types of fungi present. Stress caused by insect infestation in plants provides an opportunity for aflatoxigenic fungi to contaminate the affected site (Kinyungu, 2019). Aflatoxin production is also influenced by the fungal strains involved. *A. flavus* produces fewer aflatoxins in contrast to *A. parasiticus* (Manjunath and Mohana, 2018). However, *A. flavus* is the major species responsible for aflatoxin production and agricultural contamination. Compost piles, cotton, plant scraps, dead insects, field crops, stored grains, animal carcasses and animal fodder are only some of the organic nutrients it can grow on (Kakde, 2012). Notably, *A. flavus* can pollute both dicot and monocot seeds (Leger *et al.*, 2000) due to its lack of host specificity. If postharvest storage conditions encourage fungus growth, more contamination of the stored crops will occur. Aflatoxin contamination was found in about 92% of the millet samples, 69% of the maize samples, and 50% of the sorghum samples studied (Sirma *et al.*, 2015).

Max limits (µg/kg) established for aflatoxins in various countries for all food commodities-

Country	Food commodity	Aflatoxin (max limit)	References
Brazil	All edible items	15 (AFB ₁)	Aiko and Mehta (2015)
China	All edible items	30 (AFB ₁)	Ji <i>et al.</i> (2019)
EU	All edible items	5 (AFB ₁) 10(TAF _S)	EC (2006)
India	All edible items	30 (AFB ₁)	Anukul <i>et al.</i> (2013)
Indonesia	All edible items	35(AF _S), 20(AFB ₁)	Ji <i>et al.</i> (2019)
Japan	All edible items	10(AF _S)	Anukul <i>et al.</i> (2013)
Malaysia	All edible items	35(TAF _S)	Srianujata (2011)

Singapore	All edible items	5(AF _S)	Anukul <i>et al.</i> (2013), Mazumder and Sasmal (2001)
Vietnam	All edible items	10(AF _S)	Anukul <i>et al.</i> (2013)
Australia	All edible items	5(AF _S)	Anukul <i>et al.</i> (2013), Mazumder and Sasmal (2001)
Sri Lanka	All edible items	30(TAF _S)	Anukul <i>et al.</i> (2013)
Thailand	All edible items	20(AF _S)	Anukul <i>et al.</i> (2013), Mazumder and Sasmal (2001)
USA	All edible items	20(AF _S)	Ji <i>et al.</i> (2019), Mazumder and Sasmal (2001)

Methods to detect aflatoxin contamination

Aflatoxins are toxic and harmful substances that can appear in food items even in very minute amounts. Eating such food products poses a number of health hazards. Thus, in order to decrease before consumption, aflatoxins must be analysed and quantified using sensitive and precise techniques (Le *et al.*, 2021). Numerous analytical techniques have been used for the measurement and identification of mycotoxins in food (Berthiller *et al.*, 2017). Food mycotoxin analysis is important, however it might be challenging to identify mycotoxins in vegetable oils because of their complex matrix and comparatively low amounts when compared to other meals like cereal-based products.

Chromatographic techniques-

Aflatoxins can be found in many different foods, including vegetable oils, and chromatography is a common technique for analysing them. High-performance liquid chromatography (HPLC) has been used in a number of investigations to detect AFs in food-grade oils as evidenced by research conducted by Ferracane *et al.*, 2007; Afzali *et al.*, 2012; F. Ma *et al.*, 2013; Zhao *et al.*, 2017; Nabizadeh *et al.*, 2018; Karunarathna *et al.*, 2019; Wang *et al.*, 2019. This technique is universally applied across these investigations to analyse mycotoxin content in vegetable oils and other food items. Thin-layer chromatography (TLC) proves to be a cost-effective and straightforward mode for both qualitative and quantitative analysis of various mycotoxins, benefiting from its affordability, simplicity, and the presence of UV light fluorescent spots, as noted in the study by Janik *et al.* (2021). However, its limited sensitivity and accuracy pose challenges in precise quantification, as highlighted by Singh and Mehta in 2020. To address these limitations, liquid chromatography (LC) attached with tandem mass spectrometry (MS/MS) stands out as a reliable analytical approach. This method combines the efficient separation capabilities of LC with the high sensitivity of MS/MS, according to research, it is a useful method for simultaneously identifying and measuring mycotoxins in different matrices Adebo *et al.* (2018) and Gbashi *et al.* (2019). Specifically, for the quantification of different mycotoxins (AFB₂, AFB₁, AFG₂, AFG₁, OTA, ZEA, DON) in grain legumes, LC-MS/MS was employed, as described in the study conducted by Kunz *et al.*, 2020. The

limits of detection (LOD) for AFs using HPLC-FLD varied across studies. Elzupir *et al.* (2010) reported LODs ranging from 0.09 to 1.5 µg/kg, while Afzali *et al.* (2012) achieved LODs of 0.11 to 5.3 ng/L. Additionally, Nabizadeh *et al.* (2018) recorded LODs of 0.04 to 0.16 µg/kg, Karunarathna *et al.* (2019) observed LODs of 0.01 to 0.04 µg/kg, Wang *et al.* (2019) reported LODs of 0.005 to 0.03 µg/L, and F. Ma *et al.* (2013) noted LODs of 0.03 to 0.25 µg/kg in different matrices, employing diverse preparation methods. Afzali *et al.* (2012) achievement of the lowest LODs may be attributed to their effective cleanup procedures and more selective extraction methods. In a study conducted by Hidalgo-Ruiz *et al.* (2019), mycotoxins (AFB₁, AFB₂, AFG₂, and AFG₁) were analysed in 194 samples of corn oil, soybean oil, olive oil, and sunflower oil. The researchers employed UHPLC-QqQ-MS/MS coupled with the QuEChERS procedure for the analysis.

Immunochemical and biosensor techniques-

In addition to chromatographic methods, immunochemical assays and biosensors are gaining popularity for analysing mycotoxins in oil samples. Immunochemical detection relies on the unique binding between antibodies and antigens, encompassing a range of techniques from ELISA and basic lateral flow immunoassays (LFIA) to more sophisticated immunosensors (Turner *et al.*, 2015).

ELISA, a technique based on competitive reactions between antigens (such as mycotoxins) and antibodies, is a straightforward and relatively quick method. Qi *et al.* (2019) utilized ELISA to detect AFB₁ in peanut oil, achieving a LODs of 1.08 µg/kg. Positive ELISA results (>20 µg/kg) were cross-verified using the more sensitive UPLC-MS/MS method (with a LODs of 0.01 µg/kg). Additionally, ELISA has been employed to measure AFB₂, AFB₁, AFG₂, and AFG₁ levels in various oils such as coconut oil, soya bean oil, palm kernel oil, melon oil and groundnut oil. The findings revealed that the concentrations of AFs in all samples were below the regulatory limits, as demonstrated by Malu *et al.* (2017). Selective mycotoxins detection is achieved through the utilization of IAC (Immunoaffinity Columns), where specific monoclonal antibodies are employed, these antibodies bind to the target mycotoxin on the column. Subsequently, the mycotoxins are extracted from

the column using pure acetonitrile or methanol, as described in the study by Liu *et al.* (2018). In a similar manner, IAC was applied for the analysis of AFs in wheat bran, as detailed in the research conducted by Irakli *et al.* (2017).

Wang, Li *et al.* (2017) devised a highly precise nanobody-polyclonal antibody sandwich ELISA method to identify both *A. flavus* and *A. parasiticus*, achieving an impressive minimum detection limit of 1 µg/ml. Subsequently, genes linked to Aflatoxin biosynthesis in *A. flavus* were targeted using multiplex PCR during molecular screening to detect aflatoxin. To further enhance detection, the Visible/Near-Infrared technique (VNIR) was employed to identify toxin contamination. In various regions of North America, significant levels of AFB₁ were discovered on maize kernel's surfaces through VNIR analysis (Chu *et al.*, 2017). However, due to the limitations in image quality associated with VNIR, recent studies have concentrated on the joint utilization of Hyperspectral Imaging (HSI) and chemometric data analysis. This integrated approach has led to improved identification of AFB₁ on maize kernels' surfaces, as demonstrated by Kimuli *et al.* (2018). Various techniques employing nanoparticles such as quantum dots (QD), carbon-based nanomaterials (CBNs), and Au/Ag are employed to identify different aflatoxins in crop plants, as outlined by Xue *et al.* (2019). Biosensors employ biological molecules like enzymes, antibodies, bacteria, and DNA for both recognition and transduction purposes. Biosensors offer a cost-effective, efficient solution for aflatoxin detection, requiring minimal sample preparation and enabling quick and straightforward identification. These biosensors utilize an electrochemical enzyme-linked oligonucleotide array, allowing for portable and on-the-spot aflatoxin identification, as demonstrated in studies by Rotariu *et al.* (2016) and Selvolini *et al.* (2019).

Biosensors predominantly depend on two primary detection techniques, optical and electrochemical methods, for identifying mycotoxins (Yang *et al.*, 2020). Presently, the prevailing direction involves optical biosensors that utilize chemiluminescent approaches. Specifically, these can be categorized into CLIA (chemiluminescent immunoassay) and CLEIA (chemiluminescent enzyme immunoassay). Different biosensor variations, including aptamer and surface plasmon resonance types, have been utilized in mycotoxin detection within oils, as demonstrated in studies by Q. Chen *et al.* (2018), Lu *et al.*, 2015; X. Xia *et al.* (2018), and Zhu *et al.* (2015). A groundbreaking amperometric biosensor, incorporating the acetylcholinesterase (AChE) enzyme, was employed to identify AFB₁ contamination in olive oil. This innovative method yielded a limit of detection of 0.3 µM, along with reliable recovery data (Rejeb *et al.*, 2009). Meanwhile, Ma *et al.* (2015) pioneered a fluorescent aptamer for AFB₂ detection, utilizing aminated Fe₃O₄ magnetic nanoparticles. Their findings indicated that the selected aptamer could detect AFB₂ with a remarkable LOD of 50 ng/L. Additionally, in studies conducted by Lu *et al.* (2015), a Graphene oxide-aptamer-Q-dots fluorescence quenching system was employed, resulting in LODS of 1.0 nM for AFB₁ in aqueous systems and 1.4 nM for peanut oil.

Aflatoxins in some important food commodities:

Maize –

Maize in West Africa showed significant contamination by AFs, with varying levels recorded in different countries. In Ghana, AFs levels ranged from 0.4 to 490 µg/g, in Benin from 0.2 to 120 µg/g, and in Togo from 0.7 to 110 µg/g (James *et al.*, 2007). Alarmingly, 4 out of every 5 maize

samples from the Southern Guinea Savanna surpassed the international recommendation of 20 µg/g, set by global authorities. In India, out of 190 samples studied for multiple mycotoxin contamination, 34.8% were predominantly tainted by AFs, with 69 samples exceeding the permissible limits (Janardhana *et al.*, 1999). Moreover, stored maize grains exhibited a high AFs presence, with 43% of samples showing contamination, most of which exceeded 20 µg/kg. Specifically, samples from Egypt displayed 30 µg/kg of TAFs (Abdelhamid, 1990), those from Southern Guinea contained 77 µg/kg (Hell *et al.*, 2003), and maize obtained in Croatia between 1996 and 1997 exhibited AFB₁ levels ranging from 224 to 614 µg/kg (Jurjevic *et al.*, 2002). Notably, Croatia had the highest percentage of OTA positive samples (25%), indicating a significant OTA concentration of 31.7 µg/kg (Segvic *et al.*, 2009). A research study conducted in Italy between 1995 and 1999 uncovered alarming levels of AFs in maize samples. Two specific samples exhibited extraordinarily high AFB₁ levels, ranging from 109 to 158 µg/kg. On average, the seeds had AFs concentrations spanning from 0.3 to 4.10 µg AFB₁/kg (Pietri *et al.*, 2004). Similarly, samples from Turkey displayed significant contamination, ranging from 120.3 to 133 µg/kg (Giray *et al.*, 2009). Furthermore, a study conducted in Syria found AFS levels surpassing the 20 µg/kg threshold (Majid, 2007).

Study conducted by Shah *et al.* (2010) revealed that the concentration of aflatoxin B₁ ranged from none to 30.92 µg/kg, with higher averages observed in the upper Swat regions (average 14.94 µg/kg) and lower Swat regions (average 16.22 µg/kg). Out of the 24 stored maize samples, 12 were found to be contaminated with aflatoxin B₁. The levels of contamination ranged from 2.30 to 30 ppb as determined by TLC and from 270 to 500 ppb as determined by ELISA techniques (Hassan *et al.*, 2014). According to Kos *et al.* (2020) out of the 20 fungal metabolites examined, 20, 17, 13 and 17 were detected in maize samples collected in the years 2012, 2013, 2014 and 2015, respectively. Nsabiyumva *et al.* (2023) observed that merely a 3% fraction of maize exhibited aflatoxin levels surpassing the 10 µg/kg EAC limit.

Wheat-

In Several regions of Turkey, 41 wheat samples were collected and analysed. The results revealed the presence of *Aspergillus flavus* and *Aspergillus parasiticus* contamination, along with the production of AFs including B₂, B₁, G₂ and G₁, ranging from 10.6 to 643.5 µg/kg as reported by Giray *et al.* in 2007. Out of these samples, 59% tested positive for TAFs, namely B₂, B₁, G₂ and G₁ with individual percentages of 12%, 42%, 12%, and 37%. Additionally, various newly identified mycotoxins were also detected in these wheat samples. In 48 out of 185 tested wheat samples, AFB₁ was detected, constituting 25.9% of the samples. The concentration of AFB₁ varied between 0.05 mg/kg and 4.78 mg/kg, averaging at 0.51 ± 1.14 mg/kg. AFB₂, on the other hand, was present in only 13 samples, accounting for 7.0% of the total. The mean AFB₂ level in these samples was 0.02 ± 0.08 mg/kg, and the contamination ranged from 0.02 mg/kg to 0.48 mg/kg (Asghar *et al.*, 2016). Wheat faces various challenges throughout its growth and storage phases, primarily due to mycotoxin contamination. These toxins not only taint the wheat but also pose significant risks to both humans and animals when consumed as food or feed (Ghangro *et al.*, 2016).

Ghasemi-Kebria *et al.* (2013) performed a study on wheat flour in high-risk area of Iran and found that in all wheat flour samples, the average levels (standard deviation) of AFB₁, AFB₂, AFG₁, AFG₂, and total aflatoxins were 0.53 (0.88) ng/g, 0.31 (0.71) ng/g, 0.55 (0.93) ng/g, 0.6 (0.6) ng/g, and 1.99 (1.96) ng/g, respectively. During the summer season, the average total aflatoxin concentration in samples was 0.82 ng/g, whereas in winter, it rose to 1.99 ng/g. In summer, 3.1% of samples exceeded the globally accepted limits for Aflatoxin B₁, while in winter, this percentage increased to 7.4%. Aflatoxin contamination was most prevalent in winter samples, specifically aflatoxin B₂ (98%), while in summer, aflatoxin G₁ was more common, affecting 51% of the samples (Tahri *et al.*, 2012). Among the 108 samples analysed, 30.6% (38 samples) tested positive for at least one type of aflatoxin. Aflatoxin B₁ was the most prevalent, present in 27.8% of the samples, with the highest concentration recorded in a grain sample at 4.2 µg/kg. Aflatoxin G₁ and G₂ were found in 10.2% and 0.9% of the samples respectively (Trombete *et al.*, 2014).

Rice-

In a study from 1990, Jayaraman and Kalyanasundaram discovered that parboiled rice bran and rice bran samples contained up to 35% AFB₁. Rice samples were found to have higher levels of AFs (ranging from 184 to 2,830 µg/kg) compared to wheat and maize samples in a study conducted by Pande *et al.* 1990. A separate study by Liu *et al.* 2006 analysed 36 de-husked brown rice samples, revealing the presence of AFB₂, AFB₁, AFG₂ and AFG₁ at levels ranging from 0.99 to 3.87 µg/kg. Research conducted in India by Reddy *et al.* (2009a) indicated that 67.8% of the examined rice and paddy samples were positive for AFB₁, with toxin levels ranging from 0.5 to 38.5 µg/kg. Additionally, a study by Siruguri *et al.* (2012), focused on rice samples from six districts in Punjab, found that the PAU 201 variety of stored rice had AFB₁ levels below 15 µg/kg. In a subsequent study, Iqbal *et al.* (2016) examined 62 samples in Pakistan and discovered that 37% of these samples had AFB₁, with concentrations varying between 0.04 and 21.3 µg/kg. In Nigeria, Hussaini *et al.* (2009a) detected AFs in 97 out of 196 collected samples, with AF levels ranging from 24 to 1,164 µg/kg. Majeed *et al.* (2013) found that 50% of the examined rice samples were contaminated with AFs at levels ranging from 0.05 to 24 µg/kg. Another study by Majeed *et al.* (2018) identified 23 mycotoxins in 180 rice samples, with AFs being prevalent in 20-56% of the samples. The levels of aflatoxin B₁ and total aflatoxins in the examined rice samples were below 0.123 mg/kg and 2.58 mg/kg, respectively (Al zoreky *et al.*, 2017). From a total of 413 rice samples, including 58 paddy, 69 parboiled, 84 brown, 93 white, and 109 broken rice samples, aflatoxin contamination was present in 64% of paddy samples at an average concentration of 16.35±1.67 µg/kg, 38% of parboiled samples at 14.20±2.04 µg/kg, 33% of brown samples at 9.85±1.25 µg/kg, 42% of white samples at 7.10±1.39 µg/kg, and 50% of broken samples at 8.5±1.71 µg/kg (Iqbal *et al.*, 2012). In various regions of China, including Huantai, Huaian and Fusui, aflatoxin B₁ was detected in all 29 rice samples, with an average contamination level ranging between 0.5-0.6 mg/kg, as reported by Sun *et al.* (2011). These findings align with earlier research by Wang and Liu in 2007, which indicated contamination at an average of 0.79 mg/kg. Conversely, South Korea showed significantly lower contamination levels. Out of 88 samples, only 5 were found to be

contaminated, with mean values as low as 4.8 ng/kg, according to Park *et al.* (2004).

In contrast, rice samples from India displayed higher aflatoxin levels. A survey across 12 states revealed that out of 1511 samples, 256 exceeded the Indian permissible limit of 30 µg/kg for total aflatoxin, with 930 samples above 5 µg/kg and a median concentration of 45 µg/kg, as reported by Toteja *et al.* (2006). However, more recent studies in Punjab, India, conducted by Siruguri *et al.* (2012), indicated acceptable aflatoxin levels. The distribution of aflatoxins in Malaysia resembled that of China and the Philippines, 9 out of 13 samples in Malaysia exhibited aflatoxin B₁ contamination, averaging at 1.75 µg/kg (Reddy *et al.*, 2011). In contrast, Japan reported a different scenario, with all 83 rice samples found to be free from any type of aflatoxin, as stated in the research by Kumagai *et al.* (2008).

Peanuts:

Peanuts, globally recognized as the second most crucial legume following beans which face significant challenges due to inadequate storage methods. These challenges result in the emergence of mycotoxins, notably AFs, as highlighted in various studies (Kaaya *et al.*, 2006). Studies in India reported AF levels surpassing 30 µg/kg in various peanut samples (Kishore *et al.*, 2002). Aflatoxins types B and G, have been identified in peanuts cultivated in Argentina's Formosa province by *Aspergillus flavus* (Pildain *et al.*, 2004). Research conducted by Gonzalez *et al.* (2008) indicated AF levels ranging from 4.20 to 198.8 µg/kg, surpassing the USDA's maximum limit of 20 µg/kg in 90% of the samples examined by Ezekiel *et al.* (2012). Nakai *et al.* (2008) detected aflatoxin in 6.7% of the hull samples, specifically aflatoxin B₁ and B₂, while 33.3% of the kernel samples were contaminated with aflatoxin B₁ and B₂. The peanut cake samples showed AFs levels ranging from 10 to 346 µg/kg, with OTA levels remaining below the quantification limit of 2 µg/kg (Ediage *et al.*, 2011). Babu *et al.* (2011) showed that 55% of the aflatoxin present in the crude production consisted of the following ratio - B₁: B₂: G₁: G₂, with proportions of 100:0.15:0.22:0.02. Additionally, groundnuts from Ethiopia exhibited AF levels ranging from 15 µg/kg to a staggering 11,900 µg/kg (Chala *et al.*, 2013). Mohammed *et al.* (2016) found that, in the 2013/2014, 22.5% of the groundnut samples were found to be contaminated with aflatoxin, with an average concentration of 786 ng/g. However, in 2014/2015, 41.3% contamination was observed, with an average aflatoxin concentration of 3135 ng/g. Maringe *et al.* (2017) found that 12.5% of the groundnut samples were contaminated with aflatoxin, with contamination levels ranging up to 175.9 µg/kg by using HPLC. In Nigeria, investigations revealed TAFs content in groundnut cakes, roasted groundnuts, and boiled groundnuts at 11.15 µg/kg, 4.50 µg/kg, and 1.51 µg/kg, respectively, indicating that groundnut cakes had the highest incidence and concentrations of TAFs (Adefolalu *et al.*, 2021). Furthermore, these studies found that AF levels increased with prolonged storage duration.

Pulses and oilseed crops-

Research findings indicate that *Aspergillus* species have been found to produce varying amounts of AFB₁ in pulses and oilseed crops, ranging from 333 to 10,416 µg/kg (Begum and Samajpati, 2000). Another study examined 66 isolates of *Aspergillus flavus* from mustard seeds, revealing that 24 of these isolates produced AFs, with levels ranging from 0.25 to 22 µg/ml. Among these, eight isolates exhibited remarkably

high AF levels, while the remaining 16 isolates produced considerably lower amounts of AFs. Additionally, *Aspergillus parasiticus* from bean seeds were identified to produce significant concentrations of AFs (196.58 µg/kg as observed in the research conducted by Embaby *et al.* (2013). Further 4.3% of the cowpea samples showed aflatoxin contamination with levels ranging from 1.4 to 103.4 µg/kg (Maringe *et al.*, 2017). In a recent study in Nigeria, 81 cowpea samples were analysed, with all of them testing positive for AFs and the AFs concentrations ranged from 84 to 209 µg/kg (Afolabi *et al.*, 2019). In a study conducted by Nazir *et al.* (2019) on pulses revealed aflatoxin contamination in split chickpea, lentils, black gram beans to the extent of 11.2 ppb, 8.6ppb and 15.4 ppb respectively.

Fruit and fruit juices-

Apart from cereals, pulses, oil seeds and spices there is a potential risk of toxin contamination in fruits and fruit juices. *Aspergillus* species are well-known for producing toxins in fruits. Raisins in Brazil, Egypt, Greece, India and Morocco have been found to contain AFB₁ with concentrations ranging from 2 to 550 µg/kg (Saxena and Mehrotra, 1990; Juan *et al.*, 2008). The analysis of chloroform extracts from five distinct fruit juices and beverages (five samples each) using thin-layer chromatography showed that all five tested apple beverages were tainted with aflatoxin B and G. The concentrations of these contaminants ranged from 20-30 µg/L. Additionally, two out of the five guava juice samples tested were naturally contaminated with aflatoxin B at a concentration of 12 µg/L. (Abdel-sater *et al.*, 2001).

Natural contamination by aflatoxin has been observed in various fruits and fruit products. Oranges, apples, and apple juices have been reported to be affected (Drusch and Ragab, 2003). Reports suggest that grapes, specifically may contain significant levels of AFs (0.3%) and OTA (6.0%) as indicated by Serra *et al.* (2005). Aflatoxin B₁ (AFB₁) contamination has also been documented in grape juices and musts (EL Khoury *et al.*, 2008). Dried figs and raisins are most commonly affected and AFB₁ has been found in apricots, prunes, and dates as well (Trucksess and Scott, 2008). Out of the 30 mycotoxins examined, only 9 were found in measurable quantities in 49% of the analysed juices. These primarily included AOH, AME, PAT, OTA, AFB₁, AFB₂, AFG₂, ZAL, and HT-2 (Pallares *et al.*, 2019).

Other food commodities-

Dixit (2009), uncovered the presence of 30 different fungal species in fenugreek seeds, of which *Aspergillus flavus* was abundant and found that out of 101 isolates 61.2% showed aflatoxicity. Chauhan, (2012) analysed 50 samples (30 stored and 20 fresh) of Safed musli (*Chlorophytum borivillianum* L.), 12 out of 30 stored samples contained 9 to 50 µg/kg of AFB₁, and 2.00 to 4.40 µg/kg of AFB₂ in association with AFB₁. Fresh samples contained AFB₁ in the range of 0.1 to 2.60 µg/kg. Sharma *et al.* (2013) isolated 35 strains of *Aspergillus flavus* from chilgoza seeds (*Pinus gerardiana* Wall.), they found aflatoxin with a mean value ranging from 0.737±0.023 to 1.675±0.486 µg/g. According to Odongo *et al.* (2018); Chaudhari *et al.* (2020) and Schabo *et al.* (2020) noted that chia seeds are severely infected by a variety of

storage fungi and associated compounds including aflatoxin (mostly aflatoxin B₁), during storage.

Njeri *et al.* (2019) performed a study on chia seeds cultivated and sold in Kenya, they found the moulds count ranged from 1.33 x10³cfu/ml -2.67 x 10³cfu/ml. Jermnak *et al.* (2020) found AFs in 40% of the total samples, with value ranging from 04 to 10.99 ng/g. Three of the positive samples were found to surpass the European Union's regulatory limit (4 ng/g) for total AFs. The most commonly detected AF in chia seeds was AFB₁. Senthilkumar *et al.* (2021) found that 52.07% samples of pearl millet contained aflatoxin B₁. A co-occurrence of aflatoxin B₂ was detected alongside aflatoxin B₁ in 28.93% of the samples. On numerous occasions, *Aspergillus nigri* species were commonly obtained from various vineyards in Argentina. Investigations conducted on red grapes harvested from Mendoza vineyards indicated that species belonging to the *A. niger* aggregate were prevalent. Levels of aflatoxin G₁ reaching up to 78 mg/kg and aflatoxin B₁ reaching up to 63 mg/kg have been detected in eggs at various stages of production. Ozay *et al.*, 1991. Magnoli *et al.* (2003) and Houissa *et al.* (2019) found that out of 220 pearl millet samples analysed 91.4% grain samples contain fungal metabolite contamination. Among major mycotoxins, AFB₁ was present at an average level of 106 µg/kg exceeding the European thresholds of 5 µg/kg. Lahouar *et al.*, (2018) found that out of 64 samples, 38 samples of sorghum were contaminated with aflatoxin ranging from 0.03 – 31.7 µg/kg. Spanjer *et al.*, 2008 found LODS 0.5-200 µg/kg for aflatoxin in pistachio nut and peanuts. Ssepuuya *et al.*, (2018) studied aflatoxin contamination in sorghum and found mean concentration of AFB₁ to be 42.6 ± 58.8 µg/kg, AFB₂ to be 78.7 ± 9.34 µg/kg, ABG₁ to be 41.3 ± 110 µg/kg, AFG₂ to be 13.7 ± 9.49 µg/kg. In a study performed by Shetty and Bhatt, (1997), AFB₁ concentration in sorghum was found to be 5 to 125 µg/kg. Plants and their derived products, such as medicinal herbs, tea, and spices, often contain considerable levels of AF contamination, reaching up to 2,230 µg/kg, particularly noticeable in liver-healing herbal remedies sold in India (Trucksess and Scott, 2007). Zinedine *et al.* (2006) detected the natural occurrence of AFB₁ in Moroccan black pepper, ginger, red paprika, and cumin, averaging at 0.09, 0.63, 2.88, and 0.03 µg/kg, respectively. Among these, red paprika exhibited the highest contamination level at 9.68 µg/kg. Singh and Cotty, (2017) conducted a study on 33 chili samples obtained from markets in both the United States and Nigeria and revealed that AFB₁ was present in 64% of the chili samples from US markets and in 93% of the Nigerian chili samples. Among the US samples, 2% exceeded the regulatory limit for aflatoxin, which is set at 20 µg/kg, with the highest detected concentration reaching 94.9 µg/kg. Sumon *et al.*, (2021) found AFM₁ in 78.6% of dairy products, ranging from 5.0 to 198.7 ng/L. Within raw milk, AFM₁ was identified in 71.4% of samples (with an average of 41.1 ng/L and a range of 5.0-198.7 ng/L), while it was present in all pasteurized milk (with an average of 106 ng/L and a range of 17.2-187.7 ng/L) and UHT milk (with an average of 73 ng/L and a range of 12.2-146.9 ng/L) samples.

Aflatoxin Level Detected In Major Food Commodities-

Food Crop	Type of aflatoxin	Aflatoxin concentration	References
Corn	Total AFs	1.01-86.10 ppb	Kos <i>et al.</i> 2013
Rice	AFB ₁	37.26–113.20 ppb	Anthony <i>et al.</i> 2014
Wheat	AFB ₁	2.3 ppb	Al-Wadai <i>et al.</i> 2013
	AFB ₂	2.6 ppb	
	AFG ₁	1.3 ppb	
	AFG ₂	0.5 ppb	
Red chilli	AFB ₁	0.24-165 ppb	Golge <i>et al.</i> 2013
	AFB ₂	0.15-11.3 ppb	
	AFG ₁	0.15-3.88 ppb	
Maize	AFB ₁	188 µg/kg	Aristil <i>et al.</i> (2020)
Sorghum	AFB ₁	2 µg/kg	Lahouar <i>et al.</i> (2018)
Pearl millet	AFB ₁	106 µg/kg	Houissa <i>et al.</i> (2019)
Cashew nuts	Total AFs	0.60-31.50 ppb	Milhome <i>et al.</i> 2014
Groundnut	AFB ₁	72.97-195.17 ppb	Magembe <i>et al.</i> 2016
Rice	AFB ₁	0.04-21.30 ppb	Iqbal <i>et al.</i> 2016
Sunflower	AFB ₁	28 ppb	Mmongoyo <i>et al.</i> 2017.
Lentils	AFB ₁	0.57-1.74 ppb	Baydan <i>et al.</i> 2016
Figs	AFB ₁	0.1-12.5 ppb	Kabak 2016
	AFB ₂	0.07-0.72 ppb	
	AFG ₁	0.08-15.3 ppb	
	AFG ₂	0.1-0.38 ppb	
Mango seeds	Total AFs	61.7 ppb	Ezekiel <i>et al.</i> 2016
	AFB ₁	68.1 ppb	

Food Crop	Type of aflatoxin	Aflatoxin concentration	References
Chickpea	AFB ₁	167.4 µg/kg	Mohana <i>et al.</i> (2017)
Hazelnut	AFB ₁	56 ppb	Diella <i>et al.</i> 2018
Almond	AFB ₁	72 ppb	Diella <i>et al.</i> 2018
Apricot	AFB ₁	56.3 ppb	Diella <i>et al.</i> 2018
Pistachio	AFB ₁	48 ppb	Diella <i>et al.</i> 2018
Strawberry	AFB ₁	24.7–51.8 ppb	Saleem 2017
	AFB ₂	25.8–58.9 ppb	
	AFG ₁	33.0–75.2 ppb	
	AFG ₂	31.2–71.1 ppb	
Black pepper	AFB ₁	39.7–65.9 ppb	Nazir <i>et al.</i> 2019
Coriander	AFB ₁	33.4–67.9 ppb	Nazir <i>et al.</i> 2019
Cumin	AFB ₁	24.9–63.9 ppb	Nazir <i>et al.</i> 2019
Aniseed	AFB ₁	35.3–52.5 ppb	Nazir <i>et al.</i> 2019
Soyabean	AFB ₁	1.50 ppb	Pratiwi <i>et al.</i> 2015
	AFB ₂	0.88 ppb	
	AFG ₁	0.18 ppb	
	AFG ₂	0.43 ppb	
Ginger	Total AFs	0.11-9.52 ppb	Lippolis <i>et al.</i> 2017.
Guava	AFB ₁	0.163 ppb	Embaby and Hassan 2015
	AFG ₁	0.296 ppb	

Techniques for removing Aflatoxins from food products-

In the past few years, it has become essential to decontaminate mycotoxins particularly aflatoxins in food items because of their harmful impact on human and animal health. Across the globe, various methods such as chemicals, physical treatments, botanical solutions and biological approaches have been investigated to detoxify aflatoxins from contaminated food products. Despite numerous techniques being researched, only limited techniques have been practically implemented. Essential oils, botanical extracts, irradiation, ozone medication, pulsating light, freezing plasma, and microbiological procedures are only some of the novel ways for decontamination highlighted in this overview.

Physical methods of decontamination of Aflatoxins - Cold plasma-

Cold plasma stands out as an innovative and non-thermal method, generating reactive species like O, O₃, NO, OH and NO₂, which effectively break down Aflatoxins and transform them into less harmful compounds. This process offers numerous advantages, including preserving the quality of food products, as highlighted by Mir *et al.* (2021). In a study by Wielogorska *et al.* (2019a), a 65% reduction in AFB₁ and a 64% reduction in FB₁ in maize were achieved after a brief cold plasma treatment lasting 10 minutes at 20 Hz. Consequently, cold plasma exhibits promising potential as a mycotoxin decontamination strategy for various food commodities. Using the CP method, researchers were able to

eliminate 70-73% of injected AFB₁ in hazelnuts (Sen *et al.*, 2019). However, despite these promising attributes, these technologies come with certain limitations. Challenges such as protein oxidation, lipid oxidation, alterations in food colour, and changes in sensory properties hinder their widespread adoption within the food industry, as noted by Olatunde *et al.* (2021).

Irradiation –

Another method employed for mycotoxin decontamination in food products is irradiation, utilizing ionizing energy. While effective and non-thermal, irradiation can lead to the oxidation of lipids or vitamins, as well as the development of off-flavors and alterations in food colour, as pointed out by Mir *et al.* (2021). Gamma irradiation has been utilized on various cereals such as barley, maize, wheat, and rice, primarily to reduce AFB₁ levels, with studies by Aziz *et al.* (2004); Aquino *et al.* (2005) and Mohamed *et al.* (2015) providing evidence. However, it is worth noting that this method might not always eliminate all mycotoxin-producing fungi. Exposure to gamma radiation has been proven to decrease aflatoxin levels, as indicated by Aquino in 2011. Additionally, ultraviolet (UV) irradiation within the 220-400 nm wavelength range effectively degrades aflatoxins, notably AFB₁, AFB₂, and AFM₁, in diverse crops. Studies by Diao *et al.* (2015) demonstrated degradation rates ranging from 77 to 99.12%.

Pulsed light treatment-

The pulsed light technology, heralded as innovative and full of promise, boasts several advantages. Notably, it leaves no residues in food products, proving to be cost-effective. However, its decontamination action is limited to the surface of foods and has the additional effect of inhibiting seed germination, as highlighted by Mir *et al.* (2021). Research by Wang B. *et al.* (2016) demonstrated a 75% reduction in AFB₁ and a 39% reduction in AFB₂ in rice subjected to pulsed light at a dosage of 0.52 J/cm²/pulse for 80 seconds. This technology has also been combined with citric acid to effectively degrade AFs in peanuts, as evidenced by the study conducted by Abuagela *et al.* (2019). Despite these advantages, one of its primary drawbacks lies in its limited penetration power.

Other heat treatments-

Research has shown that several strategies, including the use of steam under pressure, dry roasting process, and other methods for cooking, have been successful in reducing or managing aflatoxin contamination in a variety of crops Peng *et al.* (2018). Significant reductions in aflatoxin levels have been observed through these methods. For instance, heating seed samples at 180°C led to a reduction of about 40-73% (Opoku, 2013). Roasting groundnut and corn seeds with 30% moisture at 100°C for 2 hours resulted in an impressive 85% decrease in aflatoxin content (Leong *et al.*, 2010). Additionally, roasting seeds at 150 °C for 15 minutes led to a 70% reduction in AFB₁ and a 79% reduction in AFG₁ concentrations (Jalili, 2016). Furthermore, exposing artificially infected maize and groundnut seeds to sunlight for 10-12 hours led to an 80% reduction in AFB₁ and a 17% reduction in groundnut aflatoxin content (Rushing and Selim 2019).

Chemical techniques for aflatoxin removal:

The most effective strategy to prevent aflatoxin contamination in food commodities is through proactive prevention rather than relying solely on detoxification or decontamination methods. This prevention primarily hinges

on proper agricultural practices. However, in many instances, it is challenging to entirely prevent fungal growth, which ultimately leads to aflatoxin formation. but it can reduce aflatoxin levels in multiple food items, as indicated by the research of Carvajal and Castillo (2009).

Bedi and Agarwal (2014) described the use of sodium bisulfite (0.5%) and sodium hydroxide (1%), respectively to remove aflatoxin from groundnut cake and chicken feed. Aiko and Mehta (2015) found that the growth of *A. flavus* and the formation of aflatoxin were suppressed by the addition of preservatives such as p-amino benzoic acid, propionic acid, crystal violet, boric acid, benzoic acid, and sodium acetate. To reduce its mutagenic potential, AFB₁ can be detoxified with citric acid by undergoing acid-catalyzed processes to convert it into a beta-keto acid structure, followed by hydrolysis of the lactone ring (Mendez-Albores *et al.*, 2005). This yields AFD₁, a molecule with reduced mutagenic potential. Hydrogen peroxide, ozonated water, and propionic acid are some other chemicals that can be used in these processes. When it comes to getting rid of mycotoxins without leaving behind any harmful byproducts, ozone therapy stands out as a top option. For instance, wheat treated with ozone at a dosage of 60 mg/L for 300 minutes reduced AFs by 48%, according to a study by Trombete *et al.* (2017). In a similar vein, Savi *et al.* (2014, 2015) treated wheat samples with 60 µmol/mol of ozone gas for 180 minutes, resulting in significant reductions of both AFB₁ (94.6%) and AFB₂ (84.5%), and for AFG₁ (80%) and AFG₂ (81%).

The research by Karlovsky *et al.* (2016) showed that ammoniation procedures in maize and other food commodities can reduce the generation of aflatoxins. According to the study conducted by Broková *et al.* (2015), several compounds such as formaldehyde, sodium bisulfite, calcium hydroxide, sodium borate, sodium hypochlorite, and sorbents have proven too substantially.

Various propionic acid salts, such as calcium and sodium propionates, have demonstrated the ability to diminish aflatoxin formation in maize, as evidenced by the study conducted by Hassan *et al.* (2015). Moreover, in groundnut cake, *Aspergillus flavus*-induced aflatoxin generation was suppressed by weak acids including citric acid, acetic acid, propionic acid, and sorbic acid at concentrations ranging from 0.25% to 1%, according to research conducted by Verma *et al.* (2000). In addition,azole fungicides have been used successfully to curb fungal expansion and aflatoxin formation, with prochloraz proving more efficient than tebuconazole, as reported by Mateo *et al.* (2017).

Biological methods of detoxification of aflatoxins-

Various biological agents, including bacteria, yeasts, moulds, and algae, display diverse capabilities in degrading aflatoxins within specific environments. The detoxification of aflatoxins through biological agents involves two processes: absorption and enzymatic breakdown, as detailed in the research by Jard *et al.* (2011). Biological approaches are eco-friendly and don't produce harmful residues, yet choosing non-toxic microorganisms for detoxification is challenging, and the process takes a longer time, as indicated by Mir *et al.* (2021).

Microorganisms such as *Bacillus subtilis*, *Bacillus licheniformis*, and *Saccharomyces cerevisiae* have been used to decontaminate food items. Microorganisms can directly absorb aflatoxins by binding them to their cell wall components, as demonstrated in the study by Motawe *et al.* (2014). Furthermore, aflatoxins can be absorbed even by

deceased microorganisms, a feature utilized in fluid decontamination processes, as observed in the research by Mwakinyali *et al.* (2019). Additionally, aflatoxins can undergo degradation through intra or extracellular enzymes, as explored in the study conducted by Aliabadi *et al.* (2013). The strain *Bacillus velezensis* DY3108's cell-free supernatant demonstrates robust AFB₁ degradation, achieving a remarkable 91.5% reduction, as reported by Shu *et al.* (2018). In the realm of thermophilic bacteria, strains like *Geobacillus* and *Tepidimicrobium* prove highly effective in degrading AFB₁, especially when utilized together as a microbial consortium, as highlighted by Wang, Zhao *et al.* in 2017. Furthermore, pre-harvest crops experienced a significant decrease in *A. flavus* growth through the introduction of antagonistic strains like *Trichoderma*, *Pseudomonas*, *Lactobacilli*, *Ralstonia*, *Burkholderia*, and *Bacillus* spp., as noted in the research by Akocak *et al.* (2015) and Yang *et al.* (2017).

In the study conducted by Ansari *et al.* (2015), kefir-grains were employed to decrease AFB₁ contamination in pistachios by an impressive 96.8%. Similarly, Farzaneh *et al.* (2012) utilized *Bacillus subtilis* UTBSP1 in the same context, achieving a notable 95% reduction in AFB₁ levels.

Essential oils for detoxification of Aflatoxins -

Several studies have shown that essential oils can be used to prevent *A. flavus* and *A. parasiticus* from expanding and producing aflatoxins. For instance, Maraqa *et al.* (2007) and El-Nagerabi *et al.* (2012) have examined this strategy. Complete inhibition of AFs generation in maize was seen using extracts of *Azadirachta indica* seeds at 500 and 1,000 mg/kg, and extracts of *Morinda lucida* seeds at the same dose (Bankole, 1997). Essential oils produced from *Adansonia* species significantly reduced TAFs and AFB₁ secretion by *Aspergillus flavus* (47.2- 95.7%; 28.1- 89.7%) and *Aspergillus parasiticus* (42.7 - 93.3%; 25.9 - 80.2%) (El-Nagerabi *et al.*, 2013). Furthermore, *Zataria multiflora* EO (at 150 mg/kg) significantly decreased AFs production (99.4%) (Gambori *et al.*, 2009). Similar to the findings of El-Nagerabi *et al.* (2012), who looked at the effects of *Nigella sativa* EO on *A. flavus* and *A. parasiticus*, they found that the EOS showed great promise in lowering AFB₁ levels. At concentrations of 0.5 and 0.75 ml/l, respectively, essential oils of *Foeniculum vulgare*, *Cymbopogon martini*, and *Trachyspermum ammi* were reported to suppress the formation of different toxins by *A. niger* and *A. flavus* (Gemedda *et al.*, 2014). Pandey *et al.* (2016) showed that *Lippia alba* EO suppressed AFB₁ synthesis in green gram. In addition, Sindhu *et al.* (2011) found that oil extracted from turmeric leaves inhibited AFs by 95.3% and 100%, and Prakash *et al.* (2011) found that EO extracted from *Ocimum gratissimum* inhibited AFs by a similar percentage.

Conclusion -

The growing population necessitates the accumulation of large quantities of healthy and safe food items particularly staple food item to be used in near future. However, improper storage of such food item leads to the invasion of mycotoxigenic fungi. As a result, food supplies become contaminated with multiple mycotoxins, which poses a global concern in relation to human health. Contamination of food crops and their resulting products particularly aflatoxins poses a significant danger to the lives of both humans and domestic animals. This issue is particularly critical in developing nations, where these toxin-infected products not only pose health risks but also cause decreased economic

value in the worldwide food market. Various methods involving chemicals, physical alterations, and biological approaches were employed to reduce or entirely remove aflatoxins levels in food products to safe consumption thresholds. It is crucial that while decontaminating these products, their taste, smell, nutritional value, and the avoidance of creating harmful byproducts remain unaffected. The efficient removal of aflatoxins presents a significant challenge. Conversely, using synthetic chemicals to control aflatoxins-producing fungi raises substantial concerns, both from a human-made and environmental perspective. Therefore, employing environmentally friendly strategies such as plant extracts and essential oils for managing aflatoxins would be a safer option for both users and the environment. Hence, further investigation is necessary to establish uniform standards for the quality of natural extracts, assess their safety, determine the optimal timing of application, and ascertain the most effective concentrations suitable for various food commodities.

References

- Abdelhamid, A. A. (1990). Occurrence of some mycotoxins (aflatoxins, ochratoxin A, citrinin, zearalenone and vomitoxin) in various Egyptian feeds. *Arch. Anim. Nutr.*, 40: 647–664.
- Abdel-Sater, M. A., A. A. Zohri. and M. A. Ismail. (2001). Natural contamination of some Egyptian fruit juices and beverages by mycoflora and mycotoxins. *J. Food Sci. Technol.*, 4:407–411.
- Abuagela, M. O., Iqdam, B. M., Mostafa, H., Yagiz, Y. and Marshall, M. R. (2019). Combined effects of citric acid and pulsed light treatments to degrade B-aflatoxins in peanut. *Food Bioprod. Process.*, 117:396–403.
- Adebo, O. A., Njobeh, P. B., Adebiyi, J. A. and Kayitesi, E. (2018). Co-influence of fermentation time and temperature on physicochemical properties, bioactive components and microstructure of ting (a Southern African food) from whole grain sorghum. *Food Biosci.*, 25: 118–127.
- Adefolalu, F. S., Apeh, D. O., Salubuyi, S. B., Galadima, M., Agbo, A. O. and Makun, H. A. (2021). Quantitative appraisal of total aflatoxin in ready-to-eat groundnut in north-Central Nigeria. *J. Chem. Risk.*, 12: 25–31.
- Afolabi, C. G., Ezekiel, C. N., Ogunbiyi, A. E., Oluwadairo, O. J., Sulyok, M., and Krska, R. (2019). Fungi and mycotoxins in cowpea (*Vigna unguiculata* L) on Nigerian markets. *Food Addit. Contam. Part B Surv.*, 13: 52–58.
- Afzali, D., Ghanbarian, M., Mostafavi, A., Shamspur, T., and Ghaseminezhad, S. (2012). A novel method for high preconcentration of ultra trace amounts of B1, B2, G1 and G2 aflatoxins in edible oils by dispersive liquid-liquid microextraction after immunoaffinity column cleanup. *Journal of Chromatography A*, 1247: 35–41.
- Aiko, V. and Mehta, A. (2015). Occurrence, detection, and detoxification of mycotoxins. *Journal of Biosciences*, 40(5): 943–954.
- Akocak, P. B., Churey, J. J. and Worobo, R. W. (2015). Antagonistic effect of chitinolytic pseudomonas and bacillus on the growth of fungal hyphae and spores of aflatoxigenic *Aspergillus flavus*. *Food Bioscience*, 10: 48–58.

- Aliabadi, M. A., Alikhani, F. E., Mohammadi, M. and Darsanaki, R. K. (2013). Biological control of aflatoxins. *European Journal of Experimental Biology*, 3(2): 162–166.
- Al-Wadai, A. S., Al-Othman, M. R., Mahmoud, M. A. and Abd El-Aziz, A. R. M. (2013). Molecular characterization of *Aspergillus flavus* and aflatoxin contamination of wheat grains from Saudi Arabia. *Genetics and Molecular Research*, 12(3): 3335–3352.
- Al-Zoreky, N. S. and Saleh, F. A. (2017). Limited survey on aflatoxin contamination in rice. *Saudi Journal of Biological Sciences*.
- Ansari, F., Khodaiyan, F., Rezaei, K., and Rahmani, A. (2015). Modelling of aflatoxin G1 reduction by kefir grain using response surface methodology. *J. Environ. Health Sci. Eng.*, 13:40.
- Anthony, M. H., Ojochenemi, A. D., Yemi, A. H. R., Tahir, N., Okechukwu, O. J., Saidu, M. A. and Ayobami, O. B. (2014). Determination of aflatoxins in sesame, rice, millet, and acha from Nigeria using HPLC. *Chemical Science Transactions*, 3(4): 1516–1524.
- Anukul, N., Vangnai, K. and Mahakarnchanakul, W. (2013). Significance of regulation limits in mycotoxin contamination in Asia and risk management programs at the national level. *J. Food Drug Anal.*, 21: 227–241.
- Aquino, S. (2011). Gamma radiation against toxigenic fungi in food, medicinal, and aromatic herbs. In A. Mendez-Vilas (Ed.), *Science against microbial pathogens: Communicating current research and technological advances*, 272–281.
- Aquino, S., Ferreira, F., Ribeiro, D. H. B., Correa, B., Greiner, R. and Villavicencio, A. L. C. H. (2005). Evaluation of viability of *Aspergillus flavus* and aflatoxins degradation in irradiated samples of maize. *Braz. J. Microbiol.*, 36 :352–356.
- Aristil, J., Venturini, G., Maddalena, G., Toffolatti, S. L. and Spada, A. (2020). Fungal contamination and aflatoxin content of maize, moringa and peanut foods from rural subsistence farms in South Haiti. *J. Stored Prod. Res.* 85:101550.
- Asghar, M. A., Ahmed, A., Iqbal, J., Zahir, E. and Nauman, H. (2016). Fungal flora and aflatoxin contamination in Pakistani wheat kernels (*Triticum aestivum* L.) and their attribution in seed germination. *Journal of food and drug analysis*, 24(3): 635–643.
- Aziz, N. H., Moussa, L. A. and Far, F. M. (2004). Reduction of fungi and mycotoxins formation in seeds by gamma-radiation. *J. Food Saf.*, 24: 109–127.
- Babu, G. R., Prasad, M.G. and Prasad, T. N. V. K. V. (2011). Isolation and quantification of aflatoxin from *Aspergillus flavus* infected rice. *International Journal of Pure and Applied Sciences and Technology*, 5(1):16-24.
- Bankole, S. A. (1997). Effect of essential oils from two Nigerian medicinal plants (*Azadirachta indica* and *Morinda lucida*) on growth and aflatoxin B1 production in maize grain by a toxigenic *Aspergillus flavus*. *Lett. Appl. Microbiol.*, 24: 190–192.
- Baydan, E., Küçükersan, S., Yurdakök, D. B., Aydin, F. G., Sevin, S., Arslanbaş, E. and Cetinkaya, M. A. (2016). Comparison of nutritional composition (moisture, ash, crude protein, nitrogen) and safety (aflatoxin, nitrate/nitrite) of organic and conventional rice and lentil samples consumed in Ankara. *Ankara Üniversitesi Veteriner Fakültesi Dergisi*, 63(4): 365–370.
- Bedi, P. S. and Agarwal, R. K. (2014). Detoxification of aflatoxin B1 by physical and chemical methods. *World Journal of Pharmacy and Pharmaceutical Sciences*, 3(12): 995–1002.
- Begum, H. and Samajpati, N. (2000). Mycotoxin production on rice, pulses and oilseeds. *Naturwissenschaften*, 87: 275–277.
- Berthiller, F., Cramer, B., Iha, M. H., Krska, R., Lattanzio, V. M. T., MacDonald, S., Malone, R.J., Maragos, C., Solfrizzo, M., Stranska-Zachariasova, M., Stroka, J. and Tittlemier, S.A. (2017). Developments in mycotoxin analysis: an update for 2016-2017. *World Mycotoxin J.* 11:5–32.
- Bolu, S. A., Elelu, N., Ahmed, R. N., Solajo, F. E., Daramola, K. F., Omotosho, V. S., Afeni, M. (2014). Effect of vitamins, amino acids, and Phyto-active biomolecules on *Aspergillus flavus* in poultry production. *Pharmacology and Therapeutics*, 21–58.
- Brožková, I., Šmahová, P., Vyřasová, J., Mořková, P., Pejchalová, M., and Šilha, D. (2015). Influence of chosen microbes and some chemical substances on the production of aflatoxins. *Potravinárstvo Slovak Journal of Food Sciences*, 9(1): 9–17.
- Carvajal, M. and Castillo, P. (2009). Effects of aflatoxins contaminating food on human health. *Tropical Biology and Conservation Management*, 7: 60–84.
- Chala, A., Mohammed, A., Ayalew, A. and Skinnes, H. (2013). Natural occurrence of aflatoxins in groundnut (*Arachis hypogaea* L.) from eastern Ethiopia. *Food Control*, 30: 2602–2605.
- Chang, P. K., Hua, S. S. T., Sarreal, S. B. L., and Li, R. W. (2015). Suppression of aflatoxin biosynthesis in *Aspergillus flavus* by 2-phenyl ethanol is associated with stimulated growth and decreased degradation of branched-chain amino acids. *Toxins*, 7(10): 3887–3902.
- Chaudhari, A. K., Singh, V. K., Das, S., Singh, B. K. and Dubey, N. K. (2020b). Antimicrobial, aflatoxin B1 inhibitory and lipid oxidation suppressing potential of anethole-based chitosan nano-emulsion as novel preservative for protection of stored maize. *Food and Bioprocess Technology*, 13:1462–1477.
- Chauhan, Y. (2012). Aflatoxin contamination of medicinally important root tubers of Safed musli (*Chlorophytum Borivilianum* L.) during field and storage Ph.D. thesis., DR. B.R. Ambedkar University, Agra.
- Chen, Q., Yang, M., Yang, X., Li, H., Guo, Z. and Rahma, M. (2018). A large Raman scattering cross-section molecular embedded SERS aptasensor for ultrasensitive Aflatoxin B1 detection using CS-Fe3O4 for signal enrichment. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 189: 147–153.
- Christensen, C.M. (1965). Fungi in cereal grains and their product. *The Botanical Review*, 16:9-14.
- Chu, X., Wang, W., Yoon, S. C., Ni, X. and Heitschmidt, G. W. (2017). Detection of aflatoxin B1 (AFB1) in individual maize kernels using short wave infrared (SWIR) hyperspectral imaging. *Biosystems Engineering*, 157: 13–23.
- Council for Agricultural Science and Technology [CAST], (ed.) (2003). “Mycotoxicosis of animals,” in *Mycotoxins: Risks in Plant, Anima land Human*

- Systems, Task Force Report No. 139, (Ames, IA: CAST), 58–79.
- Dalié, D. K. D., Deschamps, A. M. and Richard-Forget, F. (2010). Lactic acid bacteria– potential for control of mould growth and mycotoxins: A review. *Food Control*, 21(4): 370–380.
- Diao, E., Li, X., Zhang, Z., Ma, W., Ji, N. and Dong, H. (2015). Ultraviolet irradiation detoxification of aflatoxins. *Trends in Food Science & Technology*, 42(1): 64–69.
- Diella, G., Caggiano, G., Ferrieri, F., Ventrella, A., Palma, M., Napoli, C., Rutigliano, S., Lopuzzo, M., Lovero, G. and Montagna, M.T. (2018). Aflatoxin contamination in nuts marketed in Italy: preliminary results. *Ann Ig*, 30(5): 401–9.
- Ding, N., Xing, F., Liu, X., Selvaraj, J. N., Wang, L., Zhao, Y. and Liu, Y. (2015). Variation in the fungal microbiome (mycobiome) and aflatoxin in stored in-shell peanuts at four different areas of China. *Frontiers in Microbiology*, 6: 1055.
- Dixit, P. (2009). Moulds and mycotoxin contamination of fenugreek (*Trigonella foenum-graecum* L.) seeds during storage. Ph.D. thesis, DR. B.R. Ambedkar University, Agra.
- Drusch, S. and Ragab, W. (2003). Mycotoxins in fruits, fruit juices and dried fruits. *J. Food Prot*, 66 (8):1514–1527.
- EC (2006). Commission regulation (EC) no 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. *Off J Eur Union*.
- Ediage, E. N., Di Mavungu, J. D., Monbaliu, S., Peteghem, C. V. and De Saeger, S. (2011). A validated multianalyte LC–MS/MS method for quantification of 25 mycotoxins in cassava flour, peanut cake and maize samples. *J. Agric. Food Chem.* 59:5173–5180.
- EL Khoury, A., Rizk, T., Lteif, R., Azouri, H., Delia, M.L. and Lebrhi, A. (2008). Fungal contamination and aflatoxin B1 and ochratoxin A in Lebanese wine-grapes and musts. *Food Chem. Toxicol*, 46 (6): 2244–2250.
- El-Nagerabi, S. A. E., Elshafie, A. E., AlKhanjari, S. S., Al-Bahry, S. N. and Elamin, M. R. (2013). The potential of baobab (*Adansonia digitata* L.) extracts as biocontrol on the growth and aflatoxin production by *Aspergillus flavus* and *A. parasiticus*. *J. Food Res*, 2: 93–103.
- El-Nagerabi, S. A. F., Al-Bahry, S. N., Elshafie, A. E. and AlHilali, S. (2012). Effect of Hibiscus sabdariffa extract and Nigella sativa oil on the growth and aflatoxin B1 production of *Aspergillus flavus* and *Aspergillus parasiticus* strains. *Food Control*, 25: 59–63.
- Elzupir, A. O., Suliman, M. A., Ibrahim, I. A., Fadul, M. H. and Elhussein, A. M. (2010). Aflatoxins levels in vegetable oils in Khartoum State, Sudan. *Mycotoxin Research*, 26: 69–73.
- Embaby, E. and Hassan, M. K. (2015). The decay of guava fruit (*Psidium guajava* Linn.) quality caused by some mould fungi. *International Journal of Agricultural Technology*, 11(3): 713–730.
- Embaby, E. M., Reda, M., Abdel-Wahhab, M. A., Omara, H. and Mokabel, A. M. (2013). Occurrence of toxigenic fungi and mycotoxins in some legume seeds. *J. Agric. Technol*, 9: 151–164.
- Ezekiel, C. N., Sulyok, M., Somorin, Y., Odutayo, F. I., Nwabekee, S. U., Balogun, A. T. and Krska, R. (2016). Mould and mycotoxin exposure assessment of melon and bush mango seeds, two common soup thickeners consumed in Nigeria. *International Journal of Food Microbiology*, 237: 83–91.
- Ezekiel, C. N., Sulyok, M., Warth, B., Odebo, A. C. and Krska, R. (2012). Natural occurrence of mycotoxins in peanut cake from Nigeria. *Food Control*, 27: 338–342.
- Farzaneh, M., Shi, Z. Q., Ghassempour, A., Sedaghat, N., Ahmadzadeh, M., Mirabolfathy, M. and Javan-Nikkhah, M. (2012). Aflatoxin B1 degradation by *Bacillus subtilis* UTBSP1 isolated from pistachio nuts of Iran. *Food Control*, 23:100–106.
- Ferracane, R., Tafuri, A., Logieco, A., Galvano, F., Balzano, D. and Ritieni, A. (2007). Simultaneous determination of aflatoxin B1 and ochratoxin A and their natural occurrence in Mediterranean virgin olive oil. *Food Additives and Contaminants*, 24:173–180.
- Gandomi, H., Misaghi, A., Basti, A. A., Bokaei, S., Khosravi, A., Abbasifar, A. and Javan, A.J. (2009). Effect of *Zataria multiflora* Boiss. essential oil on growth and aflatoxin formation by *Aspergillus flavus* in culture media and cheese. *Food Chem. Toxicol*, 47: 2397–2400.
- Gbashi, S., Madala, N. E., De Saeger, S., De Boevre, M. and Njobeh, P. B. (2019). Numerical optimization of temperature-time degradation of multiple mycotoxins. *Food Chem. Toxicol.* 125: 289–304.
- Gemeda, N., Woldeamanuel, Y., Asrat, D. and Debella, A. (2014). Effect of *Cymbopogon martinii*, *Foeniculum vulgare*, and *Trachyspermum ammi* essential oils on the growth and mycotoxins production by *Aspergillus* species. *Int. J. Food Sci*, 874135: 1–9.
- Ghanghro, A. B., Channa, M. J., Sheikh, S. A., Nizamani, S. M. and Ghanghro, I. H. (2016). Assessment of aflatoxin level in stored wheat of godowns of Hyderabad division and decontamination by UV radiation. *Int. J. Biosci*, 8(1): 8–16.
- Ghasemi-Kebria, F., Joshaghani, H., Taheri, N. S., Semnani, S., Aarabi, M., Salamat, F. and Roshandel, G. (2013). Aflatoxin contamination of wheat flour and the risk of esophageal cancer in a high-risk area in Iran. *Cancer Epidemiology*, 37(3): 290–293.
- Giray, B., Atasayar, S. and Sahin, G. (2009). Determination of ochratoxin A and total aflatoxin levels in corn samples from Turkey by enzyme-linked immunosorbent assay. *Mycotoxin Res.* 25: 113–116.
- Giray, B., Girgin, G., Engin, A. B., Aydın, S. and Sahin, G. (2007). Aflatoxin levels in wheat samples consumed in some regions of Turkey. *Food Control*, 18: 23–29.
- Golge, O., Hepsag, F. and Kabak, B. (2013). Incidence and level of aflatoxin contamination in chili commercialized in Turkey. *Food Control*, 33(2): 514–520.
- Gonçalez, E., Nogueira, J. H. C., Fonseca, H., Felicio, J. D., Pino, F. A. and Correa, B. (2008). Mycobiota and mycotoxins in Brazilian peanut kernels from sowing to harvest. *Int. J. Food Microbiol*, 123: 184–190.
- Hartley, R.D., Nesbitt, B.F. and Kelley, J.O. (1963). Toxic metabolites of *Aspergillus flavus*. *Nature*, 198:1056–1058.
- Hassan, F. F., Al-Jibouri, M. H. and Hashim, A. K. J. (2014). Isolation and identification of fungal propagation in stored maize and detection of aflatoxin B1, using TLC and ELISA technique. *Iraqi Journal of science*, 55(2):634–642.
- Hassan, R., El-Kadi, S. and Sand, M. (2015). Effect of some organic acids on some fungal growth and the production

- of their toxins. *International Journal of Advances in Biology*, 2(1): 1–11.
- Hell, K., Cardwell, K. F. and Poehling, H. M. (2003). Distribution of fungal species and aflatoxin contamination in stored maize in four agroecological zones in Benin, West-Africa. *J. Phytopathol*, 151: 690–698.
- Hidalgo-Ruiz, J. L., Romero-González, R., Vidal, J. L. M. and Frenich, A. G. (2019). A rapid method for the determination of mycotoxins in edible vegetable oils by ultra-high performance liquid chromatography-tandem mass spectrometry. *Food Chemistry*, 288: 22–28.
- Houissa, H., Lasram, S., Sulyok, M., Šarkanj, B., Fontana, A., Strub, C., Krska, R., Schorr-Galindo, S. and Ghorbel, A. (2019). Multimycotoxin LC-MS/MS analysis in pearl millet (*Pennisetum glaucum*) from Tunisia. *Food Control* 106:106738.
- Hussaini, A. M., Timothy, A. G., Olufunmilayo, H. A., Akanya, H., Ezekiel, A. S. and Ogbadu, G. H. (2009a). Fungi and some mycotoxins contaminating rice (*Oryza sativa*) in Niger State, Nigeria. *Afr. J. Biotechnol*, 6: 099–108.
- Iqbal, S. Z., Asi, M. R., Ariño, A., Akram, N. and Zuber, M. (2012). Aflatoxin contamination in different fractions of rice from Pakistan and estimation of dietary intakes. *Mycotoxin research*, 28: 175–180.
- Iqbal, S. Z., Asi, M. R., Hanif, U., Zuber, M. and Jinap, S. (2016). The presence of aflatoxins and ochratoxin A in rice and rice products; and evaluation of dietary intake. *Food Chem*, 210: 135–140.
- Rakli, M. N., Skendi, A., and Papageorgiou, M. D. (2017). HPLC-DAD-FLD method for simultaneous determination of mycotoxins in wheat bran. *J. Chromatogr. Sci*, 55: 690–696.
- Jalili, M. (2016). A review of aflatoxins reduction in food. *Iranian Journal of Health, Safety, and Environment*, 3(1): 445–459.
- James, B., Adda, C., Cardwell, K., Annang, D., Hell, K., Korie, S., Edorg, M., Gbeassor, M., Nagatey, K. and Houenou, G. (2007). Public information campaign on aflatoxin contamination of maize grains in market stores in Benin, Ghana and Togo. *Food Addit. Contam*, 24: 1283–1291.
- Janardhana, G. R., Raveesha, K. A. and Shetty, H. S. (1999). Mycotoxin contamination of maize grains grown in Karnataka (India). *Food Chem. Toxicol*, 37: 863–868.
- Janik, E., Niemcewicz, M., Podogrocki, M., Ceremuga, M., Gorniak, L., Stela, M. and Bijak, M. (2021). The existing methods and novel approaches in mycotoxins detection. *Molecules*, 26:3981.
- Jard, G., Liboz, T., Mathieu, F., Guyonvarc'h, A. and Lebrihi, A. (2011). Review of mycotoxin reduction in food and feed: From prevention in the field to detoxification by adsorption or transformation. *Food Additives & Contaminants: Part A*, 28(11): 1590–1609.
- Jayaraman, P. and Kalyanasundaram, I. (1990). Natural occurrence of toxigenic fungi and mycotoxins in rice bran. *Mycopathologia*, 110: 81–85.
- Jermnak, U., Yurayart, C., Poapolathep, A., Poapolathep, S., Imsilp, K., Tanhan, P. and Limsivilai, O. (2020). Evaluation of aflatoxin concentrations and occurrence of potentially toxigenic fungi in imported chia seeds consumed in thailand. *Journal of Food Protection*, 83(3):497-502.
- Ji, F., He, D., Olaniran, A., Mokoena, M., Xu, J. and Shi, J. (2019). Occurrence, toxicity, production and detection of *Fusarium* mycotoxin: A review. *Food Prod. Proc. Nutr*, 1:6.
- Jiang, Y., Ogunade, I.M., Vyas, D. and Adesogan, A.T. (2021). Aflatoxin in Dairy Cows: Toxicity, Occurrence in Feedstuffs and Milk and Dietary Mitigation Strategies. *Toxins*, 13: 283.
- Juan, C., Zinedine, A., Molto, J.C., Idrissi, L. and Manes, J., (2008). Aflatoxins levels in dried fruits and nuts from Rabat-Salé area, Morocco. *Food Control*, 19 (9): 849-853.
- Jurjevic, J., Solfrizzo, M., Cvjetkovic, B., De Girolamo, A. and Visconti, A. (2002). Occurrence of Beauvericin in corn from Croatia. *Food Technol. Biotechnol*, 40: 91–94.
- Kaaya, A. N., Eigel, W. and Harris, C. (2006). Peanut aflatoxin levels on farms and in markets of Uganda. *Peanut Sci*, 33: 68–75.
- Kabak, B. (2016). Aflatoxins in hazelnuts and dried figs: Occurrence and exposure assessment. *Food Chemistry*, 211: 8–16.
- Kakde, U. B. (2012). Fungal bioaerosols: Global diversity, distribution, and its impact on human beings and crops. *Bionano Genomics*, 5: 323–329.
- Karlovsky, P., Suman, M., Berthiller, F., De Meester, J., Eisenbrand, G., Perrin, I., and Dussort, P. (2016). Impact of food processing and detoxification treatments on mycotoxin contamination. *Mycotoxin Research*, 32(4): 179–205.
- Karunarathna, N. B., Fernando, C. J., Munasinghe, D. and Fernando, R. (2019). Occurrence of aflatoxins in edible vegetable oils in Sri Lanka. *Food Control*, 101: 97–103.
- Khodaei, D., Javanmardi, F. and Khaneghah, A. M. (2021). The global overview of the occurrence of mycotoxins in cereals: a three-year survey. *Curr. Opin. Food Sci*, 39: 36–42.
- Kimuli, D., Wang, W., Lawrence, K. C., Yoon, S. C., Ni, X. and Heitschmidt, G. W. (2018). The utilization of visible/near-infrared hyperspectral images to classify aflatoxin B1 contaminated maize kernels. *Biosystems Engineering*, 166: 150–160.
- Kinyungu, S. W. (2019). Efficacy of pre-harvest *Aspergillus flavus* biocontrol treatment on reducing aflatoxin accumulation during drying. Doctoral dissertation, Purdue University Graduate School.
- Kishore, G. K., Pande, S., Manjula, K., Rao, J. N. and Thomas, D. (2002). Occurrence of mycotoxins and toxigenic fungi in groundnut (*Arachis hypogaea* L.) seeds in Andhra Pradesh, India. *Plant Pathol. J*, 18: 204–209.
- Kos, J., JanićHajnal, E., Malachová, A., Steiner, D., Stranska, M., Krska, R., Poschmaier, B. and Sulyok, M. (2020). Mycotoxins in maize harvested in republic of Serbia in the period 2012–2015. Part 1: regulated mycotoxins and its derivatives. *Food Chemistry*, 312:126034.
- Kos, J., Mastilović, J., Hajnal, E. J. and Šarić, B. (2013). Natural occurrence of aflatoxins in maize harvested in Serbia during 2009–2012. *Food Control*, 34(1): 31–34.
- Kumagai, S., Nakajima, M., Tabata, S., Ishikuro, E., Tanaka, T., Norizuki, H., Itoh, Y., Aoyama, K., Fujita, K., Kai, S., Sato, T., Saito, S., Yoshiike, N. and Sugita-Konishi, Y. (2008). Aflatoxin and

- ochratoxin A contamination of retail foods and intake of these mycotoxins in Japan. *Food Addit Contam: Part A Chem Anal Control Expo Risk Assess*, 25:1101–6.
- Kumar, A., Pathak, H., Bhadauria, S. and Sudan, J. (2021). Aflatoxin contamination in food crops: causes, detection, and management: a review. *Food Production, Processing and Nutrition*, 3:17
- Kunz, B. M., Wanko, F., Kemmlin, S., Bahlmann, A., Rohn, S. and Maul, R. (2020). Development of a rapid multi-mycotoxin LC-MS/MS stable isotope dilution analysis for grain legumes and its application on 66 market samples. *Food Control*, 109:106949.
- Lahouar, A., Jedidi, I., Sanchis, V. and Saïd, S. (2018). Aflatoxin B1, ochratoxin A and zearalenone in sorghum grains marketed in Tunisia. *Food Additives & Contaminants: Part B*, 11(2): 103–110.
- Le, V. T., Vasseghian, Y., Dragoi, E. N., Moradi, M. and Mousavi Khaneghah, A. (2021). A review on graphene-based electrochemical sensor for mycotoxins detection. *Food Chem. Toxicol*, 148:11931.
- Leger, R. J. S., Screen, S. E. and Shams-Pirzadeh, B. (2000). Lack of host specialization in *Aspergillus flavus*. *Applied and Environmental Microbiology*, 66(1): 320–324.
- Leong, Y. H., Ismail, N., Latif, A. A. and Ahmad, R. (2010). Aflatoxin occurrence in nuts and commercial nutty products in Malaysia. *Food Control*, 21(3): 334–338.
- Liu, J., Sun, L., Zhang, N., Zhang, J., Guo, J., Li, C. and Qi, D. (2016). Effects of nutrients in substrates of different grains on aflatoxin B1 production by *Aspergillus flavus*. *BioMed Research International*. 7232858:1-10.
- Liu, X., Liu, X., Huang, P., Wei, F., Ying, G., Zhang, S., Lu, J., Zhou, L. and Kong, W. (2018). Regeneration and reuse of immunoaffinity column for highly efficient clean-up and economic detection of ochratoxin a in malt and ginger. *Toxins*, 10:462.
- Liu, Z., Gao, J. and Yu, J. (2006). Aflatoxins in stored maize and rice grains in Liaoning province, China. *J. Stored Prod. Res*, 42: 468–479.
- Lu, Z., Chen, X., Wang, Y., Zheng, X. and Li, C. M. (2015). Aptamer based fluorescence recovery assay for aflatoxin B1 using a quencher system composed of quantum dots and graphene oxide. *Microchimica Acta*, 182: 571–578.
- Ma, F., Chen, R., Li, P., Zhang, Q., Zhang, W. and Hu, X. (2013). Preparation of an immunoaffinity column with amino-silica gel microparticles and its application in sample cleanup for aflatoxin detection in agri-products. *Molecules*, 18: 2222–2235.
- Ma, X., Wang, W., Chen, X., Xia, Y., Duan, N., Wu, S. and Wang, Z. (2015). Selection, characterization and application of aptamers targeted to Aflatoxin B2. *Food Control*, 47: 545–551.
- Ma, X., Wang, W., Chen, X., Xia, Y., Wu, S., Duan, N. and Wang, Z., 2014. Selection, identification, and application of Aflatoxin B1 aptamer. *European Food Research and Technology*, 238(6): 919-925.
- Magembe, K. S., Mwatawala, M. W., Mamiro, D. P. and Chingonikaya, E. E. (2016). Assessment of awareness of mycotoxins infections in stored maize (*Zea mays* L.) and groundnut (*Arachis hypogea* L.) in Kilosa District, Tanzania. *International Journal of Food Contamination*, 3(1): 12.
- Magnoli, C., Violante, M., Combina, M., Palacio, G. and Dalcero, A. (2003). Mycoflora and ochratoxin-producing strains of *Aspergillus* section *Nigri* in wine grapes in Argentina. *Lett Appl Microbiol*, 37(2):179-84.
- Mahbobinejad, Z., Aminian, H., Ebrahimi, L., and Vahdati, K. (2019). Reduction of aflatoxin production by exposing *Aspergillus flavus* to CO₂. *Journal of Crop Protection*, 8(4): 441–448.
- Majeed, S., Boevre, M. D., Saeger, S. D., Rauf, W., Tawab, A., Habib, F., Rahman, M. and Iqbal, M. (2018). Multiple mycotoxins in rice: occurrence and health risk assessment in children and adults of Punjab, Pakistan. *Toxins*, 10:77.
- Majeed, S., Iqbal, M., Asi, M. R. and Iqbal, S. Z. (2013). Aflatoxins and ochratoxin A contamination in rice, corn and corn products from Punjab, Pakistan. *J. Cereal Sci*, 58: 446–450.
- Majid, I. (2007). Studying the mycotoxins found in wheat and maize under conditions of storage. Ph.D. Dissertation. Damascus University, Syria.
- Malu, S. P., Donatus, R. B., Ugye, J. T., Imarenezor, E. P. K. and Leubem, A. (2017). Determination of aflatoxin in some edible oils obtained from Makurdi Metropolis, North Central Nigeria. *American Journal of Chemistry and Application*, 4: 36–40.
- Manjunath, K., and Mohana, D. C. (2018). Assessment of contamination levels and characterization of Aflatoxin B1 producing *Aspergillus flavus* strain from food and feed samples from local markets of South India. *International Journal of Life Sciences*, 6(1): 326–334.
- Mannaa, M., and Kim, K. D. (2017). Influence of temperature and water activity on deleterious fungi and mycotoxin production during grain storage. *Mycobiology*, 45(4): 240–254.
- Maraqa, A., Alsharao, N. F., Farah, H., Albjeirami, W. M., Shakya, A. K. and Sallal, A. J. (2007). Effect of *Nigella sativa* extract and oil on aflatoxin production by *Aspergillus flavus*. *Turk. J. Biol*, 31: 155–159.
- Maringe, D. T., Chidewe, C., Benhura, M. A., Mvumi, B. M., Murashiki, T. C., Dembedza, M. P., Siziba, L. and Nyanga, L. K. (2017). Natural postharvest aflatoxin occurrence in food legumes in the small holder farming sector of Zimbabwe. *Journal Food Additives and Contaminants: part B surveillance*, 10(1):21-26.
- Marroquín-Cardona, A. G., Johnson, N. M., Phillips, T. D. and Hayes, A. W. (2014). Mycotoxins in a changing global environment—a review. *Food and Chemical Toxicology*, 69: 220–230.
- Mateo, E. M., Gómez, J. V., Gimeno-Adelantado, J. V., Romera, D., Mateo-Castro, R. and Jiménez, M. (2017). Assessment of azole fungicides as a tool to control growth of *Aspergillus flavus* and aflatoxin B1 and B2 production in maize. *Food Additives & Contaminants: Part A*, 34(6): 1039–1051.
- Mateus, A. R. S., Barros, S., Pena, A. and Sanches Silva, A. (2021). Mycotoxins in pistachios (*Pistacia vera* L.): methods for determination, occurrence, decontamination. *Toxins*, 13:682.
- Matumba, L., Sulyok, M., Njoroge, S. M., Ediage, E. N., Van Poucke, C., De Saeger, S. and Krska, R. (2015). Uncommon occurrence ratios of aflatoxin B1, B2, G1, and G2 in maize and groundnuts from Malawi. *Mycotoxin Research*, 31(1): 57–62.

- Mazumder, P. M. and Sasmal, D. (2001). Mycotoxins—limits and regulations. *Anc. Sci. Life*, 20:1.
- Meissonnier, G. M., Pinton, P., Laffitte, J., Cossalter, A., Gong, Y. Y. and Wild, C. P. (2008). Immunotoxicity of aflatoxin B1: impairment of the cell-mediated response to vaccine antigen and modulation of cytokine expression. *Toxicology and Applied Pharmacology*, 231:142–149.
- Mendez-Albores, A., Arambula-Villa, G., Loarca-Pina, M. G. F., Castano-Tostado, E. and Moreno-Martínez, E. (2005). Safety and efficacy evaluation of aqueous citric acid to degrade B-aflatoxins in maize. *Food Chem. Toxicol*, 43: 233–238.
- Milhome, M. A. L., Lima, C. G., De Lima, L. K., Lima, F. A. F., Sousa, D. O. B. and Nascimento, R. F. (2014). Occurrence of aflatoxins in cashew nuts produced in northeastern Brazil. *Food Control*, 42: 34–37.
- Mir, S. A., Dar, B. N., Shah, M. A., Sofi, S. A., Hamdani, A. M., Oliveira, C. A. F. (2021). Application of new technologies in decontamination of mycotoxins in cereal grains: challenges and perspectives. *Food Chem. Toxicol*, 148: 111976.
- Mmongoyo, J. A., Wu, F., Linz, J. E., Nair, M. G., Mugula, J. K., Tempelman, R. J. and Strasburg, G. M. (2017). Aflatoxin levels in sunflower seeds and cakes collected from micro-and small-scale sunflower oil processors in Tanzania. *PLOS One*, 12(4): e0175801.
- Mohamed, N. F., El-Dine, R. S. S., Kotb, M. A. M. and Saber, A. (2015). Assessing the possible effect of gamma irradiation on the reduction of aflatoxin B1 and on the moisture content in some cereal grains. *Am. J. Biomed. Sci*, 7:33–39.
- Mohammed, A., Chala, A., Dejene, M., Fininsa, C., Hoisington, D. A., Sobolev, V. S. and Arias, R. S. (2016). *Aspergillus* and aflatoxin in groundnut (*Arachis hypogaea* L.) and groundnut cake in Eastern Ethiopia. *Journal Food Additives and Contaminants: part B surveillance*, 4(9):290-298.
- Mohana, D. C., Thippeswamy, S., Abhishek, R. U., Shobha, B. and Mamatha, M. G. (2017). Studies on seed-borne mycoflora and aflatoxin B1 contaminations in food-based seed samples: molecular detection of mycotoxigenic *Aspergillus flavus* and their management. *Int. Food Res. J.* 24: 422–427.
- Motawe, H. F. A., Salam, A. A. and El-Meleigy, K. M. (2014). Reducing the toxicity of aflatoxin in broiler chickens' diet by using probiotics and yeast. *International Journal of Poultry Science*, 13(7): 397–407.
- Mwakinyali, S. E., Ding, X., Ming, Z., Tong, W., Zhang, Q. and Li, P. (2019). The recent development of aflatoxin contamination biocontrol in agricultural products. *Biological Control*, 128: 31–39.
- Nabizadeh, S., Shariatifar, N., Shokoohi, E., Shoeibi, S., Gavahian, M., Fakhri, Y., Azari, A. and Khaneghah, A.M. (2018). Prevalence and probabilistic health risk assessment of aflatoxins B1, B2, G1, and G2 in Iranian edible oils. *Environmental Science and Pollution Research*, 25: 35562–35570.
- Nakai, V. K., Rocha, L. D. O., Goncalvez, E., Fonseca, H., Ortega, E. M. M. and Correa, B. (2008). Distribution of fungi and aflatoxin in a stored peanut variety. *Food Chemistry*, 106(1):285-290.
- Nazir, A., Kalim, I., Sajjad, M., Usman, M. and Iqbal, M. (2019). Prevalence of aflatoxin contamination in pulses and spices in different regions of Punjab. *Chemical International*, 5(4): 274–280.
- Nesbitt, B.F., O'Kelly, J., Sargeant, K. and Sheridan, A. (1962). Toxic metabolites of *Aspergillus flavus*. *Nature*, 195:1062-1063.
- Njeri, V., Mburu, M. and Koskei, K. (2019). Mould Characterization and Mycotoxin Quantification of Chia Seeds (*Salvia hispanica* L.) Grown in Kenya. *Journal of Food Research*, 8(6):119.
- Nsabiymva, G., Mutegi, C.K., Wagacha, J.M., Mohamed, A.B., Njeru, N.K., Ndayihanzamaso, P., Niyuhire, M.C., Atehnkeng, J., Njukwe, E., Callicott, K.A., Cotty, P.J., Ortega-Beltran, A. and Bandyopadhyay, R. (2023). Aflatoxin contamination of maize and groundnut in Burundi: Distribution of contamination, identification of causal agents and potential biocontrol genotypes of *Aspergillus flavus*. *Frontiers in Microbiology*, 14:1106543.
- O'zay, G. and I. Alperden. (1991). Aflatoxin and ochratoxin—a contamination of dried figs. *Mycotoxin Res*, 7:85–91.
- Odongo, G. A., Schlotz, N., Baldermann, S., Neugart, S., Ngwene, B., Schreiner, M. and Lamy, E. (2018). Effects of *Amaranthus cruentus* L. on aflatoxin B1 and oxidative stress induced DNA damage in human liver (HepG2) cells. *Food Bioscience*, 26:42–48.
- Olatunde, O. O., Shiekh, K. A. and Benjakul, S. (2021). Pros and cons of cold plasma technology as an alternative non-thermal processing technology in seafood industry. *Trends Food Sci. Technol*, 111: 617–627.
- Opoku, G. F. (2013). Process and product optimization and storage characteristics of canned Peanut Soup Base. Doctoral dissertation, University of Ghana.
- Oswald, I. P., Marin, D. E., Bouhet, S., Pinton, P., Taranu, I. and Accensi, F. (2005). Immunotoxicological risk of mycotoxins for domestic animals. *Food Additives and Contaminants*, 22:354–360.
- Pallarés, N., Carballo, D., Ferrer, E., Fernández-Franzón, M. and Berrada, H. (2019). Mycotoxin dietary exposure assessment through fruit juices consumption in children and adult population. *Toxins*, 11(12): 684.
- Pande, N., Saxena, J. and Pandey, H. (1990). Natural occurrence of mycotoxins in some cereals. *Mycoses*, 33: 126–128.
- Pandey, A. K., Samota, M. K. and Silva, A. S. (2022). Mycotoxins along the tea supply chain: a dark side of an ancient and high valued aromatic beverage. *Crit. Rev. Food Sci. Nutr*, 63(27):8672-8697.
- Pandey, A.K., Samota, M.K., Kumar, A., Silva, A.S. and Dubey, N.K. (2023). Fungal mycotoxins in food commodities: present status and future concerns. *Front. Sustain. Food Syst.* 7:1162595.
- Pandey, A. K., Sonker, N., and Singh, P. (2016). Efficacy of some essential oils against *Aspergillus flavus* with special reference to Lippia alba oil an inhibitor of fungal proliferation and aflatoxin B1 production in green gram seeds during storage. *J. Food Sci. Technol*, 81: M928–M934.
- Park, J.W., Kim, E.K. and Kim, Y.B. (2004). Estimation of the daily exposure of Koreans to aflatoxin B1 through food consumption. *Food Addit Contam*, 21:70–5.

- Peng, W. X., Marchal, J. L. M. and Van der Poel, A. F. B. (2018). Strategies to prevent and reduce mycotoxins for compound feed manufacturing. *Animal Feed Science and Technology*, 237:129–153.
- Pietri, A., Bertuzzi, T., Pallaroni, L. and Piva, G. (2004). Occurrence of mycotoxins and ergosterol in maize harvested over 5 years in the northern Italy. *Food Addit. Contam.*, 21: 479–487.
- Pildain, M. B., Vaamonde, G. and Cabral, D. (2004). Analysis of population structure of *Aspergillus flavus* from peanut based on vegetative compatibility, geographic origin, mycotoxin and sclerotia production. *Int. J. Food Microbiol.* 93:31–40.
- Prakash, B., Shukla, S., Singh, P., Mishra, P. K., Dubey, N. K. and Kharwar, R. N. (2011). Efficacy of chemically characterized *Ocimum gratissimum* L. essential oil as an antioxidant and a safe plant-based antimicrobial against fungal and aflatoxin B1 contamination of spices. *Food Res. Int.*, 44:385–390.
- Pratiwi, C., Rahayu, W. P., Lioe, H. N., Herawati, D., Broto, W. and Ambarwati, S. (2015). The effect of temperature and relative humidity for *Aspergillus flavus* BIO 2237 growth and aflatoxin production on soybeans. *International Food Research Journal*, 22(1): 82.
- Qi, N., Yu, H., Yang, C., Gong, X., Liu, Y. and Zhu, Y. (2019). Aflatoxin B1 in peanut oil from Western Guangdong, China, during 2016–2017. *Food Additives and Contaminants: Part B*, 12: 45–51.
- Qureshi, H., Hamid, S. S., Ali, S. S., Anwar, J., Siddiqui, A. A. and Khan, N. A. (2015). Cytotoxic effects of aflatoxin B1 on human brain microvascular endothelial cells of the blood-brain barrier. *Medical Mycology*, 53(4): 409–416.
- Rajarajan, P. N., Rajasekaran, K. M. and Devi, N. K. (2013). Aflatoxin contamination in agricultural commodities. *Indian Journal of Pharmaceutical and Biological Research*, 1(4): 148–151.
- Reddy, K. R. N., Reddy, C. S., and Muralidharan, K. (2009a). Potential of botanicals and biocontrol agents on growth and aflatoxin production by *Aspergillus flavus* infecting rice grains. *Food Control*, 20: 173–178.
- Reddy, K.R.N., Farhana, N.I. and Salleh, B. (2011). Occurrence of *Aspergillus* spp. and Aflatoxin B1 in Malaysian foods used for human consumption. *J Food Sci*, 76:99–104.
- Rejeb, I. B., Arduini, F., Arvinte, A., Amine, A., Gargouri, M., Micheli, L., Bala, C., Moscone, D. and Palleschi, G. (2009). Development of a bio-electrochemical assay for AFB1 detection in olive oil. *Biosensors and Bioelectronics*, 24: 1962–1968
- Rotariu, L., Lagarde, F., Jaffrezic-Renault, N, and Bala, C. (2016). Electrochemical biosensors for fast detection of food contaminants—trends and perspective. *TrAC Trends in Analytical Chemistry*, 79: 80–87.
- Rushing, B. R., and Selim, M. I. (2019). Aflatoxin B1: A review on metabolism, toxicity, occurrence in food, occupational exposure, and detoxification methods. *Food and Chemical Toxicology*, 124: 81–100.
- Saleem, A. R. (2017). Mycobiota and molecular detection of *Aspergillus flavus* and *A. parasiticus* aflatoxin contamination of strawberry (*Fragaria ananassa* Duch.) fruits. *Archives of Phytopathology and Plant Protection*, 50(19–20): 982–996.
- Savi, G. D., Piacentini, K. C., Bittencourt, K. O. and Scussel, V. M. (2014). Ozone treatment efficiency on *Fusarium graminearum* and deoxynivalenol degradation and its effects on whole wheat grains (*Triticum aestivum* L.) quality and germination. *J. Stored Prod. Res.*, 59:245–253.
- Saxena, J. and Mehrotra, B.S. (1990). The occurrence of mycotoxins in some dry fruits retail marketed in Nainital district of India. *Acta Aliment*, 19: 221-224.
- Schabo, D. C., Martins, L. M., Maciel, J. F., Iamanaka, B. T., Taniwaki, M. H., Schaffner, D. W. and Magnani, M. (2020). Production of aflatoxin B1 and B2 by *Aspergillus flavus* in inoculated wheat using typical craft beer malting conditions. *Food Microbiology*, 89:103456.
- Schmidt-Heydt, M., Rüfer, C.E., Abdel-Hadi, A., Magan, N. and Geisen, R. (2010). The production of aflatoxin B1 or G1 by *Aspergillus parasiticus* at various combinations of temperature and water activity is related to the ratio of aflS to aflR expression. *Mycotox Res*, 26: 241–246.
- Segvic, M., Cvetnic, Z., Pepeljnjak, S. and Kosalec, I. (2009). Co-occurrence of aflatoxins, ochratoxin A, fumonisins, and zearalenone in cereals and feed, determined by competitive direct enzyme-linked immunosorbent assay and thin-layer chromatography. *Arch. Ind. Hyg. Toxicol.*, 60: 427–434.
- Selvolini, G., Lettieri, M., Tassoni, L., Gastaldello, S., Grillo, M., Maran, C., and Marrazza, G. (2019). Electrochemical enzyme-linked oligonucleotide array for aflatoxin B1 detection. *Talanta*, 203: 49–57.
- Sen, Y., Onal-Ulusoy, B. and Mutlu, M. (2019). Detoxification of hazelnuts by different cold plasmas and gamma irradiation treatments. *Innov. Food Sci. Emerg. Technol.*, 54: 252–259.
- Senthilkumar, R. P., Natarajan, A. and Kavitha, R. (2021). Co-occurrence of mycotoxins in pearl millet. *Pharma Innovation Journal*, 10:253–255.
- Serra, R., Bragab, A. and Venancio, A. (2005). Mycotoxin-producing and other fungi isolated from grapes for wine production, with particular emphasis on ochratoxin A. *Res. Microbiol.*, 156: 515–521.
- Shah, H. U., Simpson, T. J., Alam, S., Khattak, K. F. and Perveen, S. (2010). Mould incidence and mycotoxin contamination in maize kernels from Swat valley, North West frontier province of Pakistan. *Food and Chemical Toxicology*, 48:1111-1116.
- Sharma, S., Gupta, D. and Sharma, Y. P. (2013). Aflatoxin contamination in chilgoza pine nuts (*Pinus gerardiana* Wall.) commercially available in retail markets of Jammu, India. *International Journal of Pharma and Bioscience*, 4(2):751-759.
- Shetty, P. H. and Bhatt, R. V. (1997). Natural occurrence of fumonisin B1 and its co-occurrence with aflatoxin B1 in Indian sorghum, maize, and poultry feeds. *J. Agric. Food Chem.*, 45: 2170–2173.
- Shu, X., Wang, Y., Zhou, Q., Li, M., Hu, H., Ma, Y. and Wu, L. (2018). Biological degradation of aflatoxin B1 by cell-free extracts of *Bacillus velezensis* DY3108 with broad pH stability and excellent thermostability. *Toxins*, 10(8): 330.
- Siciliano, I., Berta, F., Bosio, P., Gullino, M. L., and Garibaldi, A. (2017). Effect of different temperatures and CO2 levels on *Alternaria* toxins produced on the

- cultivated rocket, cabbage, and cauliflower. *World Mycotoxin Journal*, 10(1): 63–71.
- Sindhu, S., Chempakam, B., Leela, N. K., and Suseela Bhai, R. (2011). Chemoprevention by essential oil of turmeric leaves (*Curcuma longa* L.) on the growth of *Aspergillus flavus* and aflatoxin production. *Food Chem. Toxicol*, 49: 1188–1192.
- Singh, J. and Mehta, A. (2020). Rapid and sensitive detection of mycotoxins by advanced and emerging analytical methods: A review. *Food Sci. Nutr.* 8:2183–2204.
- Singh, P. and Cotty, P.J. (2017). Aflatoxin contamination of dried red chilies: contrast between the United States and Nigeria, two markets differing in regulation enforcement. *Food Control*, 80: 374–379.
- Sirma, A. J., Ouko, E. O., Murithi, G., Mburugu, C., Mapenay, I., Ombui, J. N. and Korhonen, H. (2015). Prevalence of aflatoxin contamination in cereals from Nandi County, Kenya. *International Journal of Agricultural Sciences and Veterinary*, 3: 3.
- Siruguri, V., Kumar, U. P., Raghu, P., Rao, V. V. M., Sesikeran, B., Toteja, G. S., *et al.* (2012). Aflatoxin contamination in stored rice variety PAU 201 collected from Punjab, India. *Ind. J. Med. Res.* 136: 89–97.
- Spanjer, M.C., Rensen, P.M. and Scholten, J.M. (2008). LC–MS/MS multi-method for mycotoxins after single extraction, with validation data for peanut, pistachio, wheat, maize, cornflakes, raisins and figs. *Food Addit. Contam.- Part A Chem. Anal. Control. Expo. Risk Assess*, 25: 472–489.
- Srianujata, S. (2011). “Regulatory update and control measures for prevention and reduction of mycotoxins contamination in foods and feeds.” in Proceedings of FFTC-KU 2011 Conference: International Seminar on Risk Assessment and Risk Management of Mycotoxins for Food Safety in Asia. Kasetsart University, Bangkok, Thailand.
- Sumon, A.H., Islam, F., Mohanto, N.C., Kathak, R.R., Molla, N.H., Rana, S., Degen, G.H. and Ali, N. (2021). The Presence of aflatoxin M1 in Milk and Milk Products in Bangladesh. *Toxins*, 13:440.
- Sun, G., Wang, S., Hu, X., Su, J., Zhang, Y., Xie, Y., Zhang, H., Tang, L. and Wang, J-S. (2011). Co-contamination of aflatoxin B1 and fumonisin B1 in food and human dietary exposure in three areas of China. *Food Addit Contamin* 28:461–70.
- Taheri, N., Semnani, S., Roshandel, G., Namjoo, M., Keshavarzian, H., Chogan, A., Kebria, F.G. and Joshaghani, H. (2012). aflatoxin contamination in wheat flour samples from Golestan province, northeast of Iran. *Iran J Public Health*, 41(9):42-7.
- Toteja, G.S., Mukherjee, A., Diwakar, S, *et al.* (2006). Aflatoxin B1 contamination of parboiled rice samples collected from different states of India: a multi-centre study. *Food Addit Contamin*, 4:411–14.
- Trombete, F. M., Porto, Y. D., Freitas-Silva, O., Pereira, R. V., Direito, G. M., Saldanha, T., *et al.* (2017). Efficacy of ozone treatment on mycotoxins and fungal reduction in artificially contaminated soft wheat grains. *J. Food Process. Preserv*, 41: e12927.
- Trombete, F.M., Moraes, D.D.A., Porto, Y.D., Santos, T.B., Direito, G.M., Fraga, M.E. and Saldanha, T. (2014). “Determination of Aflatoxins in Wheat and Wheat by-products Intended for Human Consumption, Marketed in Rio de Janeiro, Brazil.” *Journal of Food and Nutrition Research*, 2(10): 671-674.
- Trucksess, M.W. and Scott, P.M. (2008). Mycotoxins in botanicals and dried fruits: a review. *Food Addit. Contam*, 25(2): 181-192.
- Turner, N. W., Bramhmbhatt, H., Szabo-Vezse, M., Poma, A., Coker, R. and Piletsky, S. A. (2015). Analytical methods for determination of mycotoxins: An update (2009–2014). *Analytica Chimica Acta*, 901: 12–33.
- Verma, R. K., Bedi, P. S. and Agarwal, R. K. (2000). Inhibitive effect of organic acids on aflatoxin production in groundnut cake. *Indian Journal of Toxicology*, 7(2): 117–119.
- Wang, B., Han, X., Bai, Y., Lin, Z., Qiu, M., Nie, X., and Wang, S. (2017). Effects of nitrogen metabolism on growth and aflatoxin biosynthesis in *Aspergillus flavus*. *Journal of Hazardous Materials*, 324: 691–700.
- Wang, B., Mahoney, N. E., Pan, Z., Khir, R., Wu, B. and Ma, H. (2016). Effectiveness of pulsed light treatment for degradation and detoxification of aflatoxin B1 and B2 in rough rice and rice bran. *Food Control*, 59: 461–467.
- Wang, J. and Liu, X. (2007). Contamination of aflatoxins in different kinds of foods in China. *Biomed Environ Sci*, 20:483–7.
- Wang, N., Duan, C., Geng, X., Li, S., Ding, K. and Guan, Y. (2019). One step rapid dispersive liquid-liquid micro-extraction with in-situ derivatization for determination of aflatoxins in vegetable oils based on high performance liquid chromatography fluorescence detection. *Food Chemistry*, 287: 333–337.
- Wang, T., Li, P., Zhang, Q., Zhang, W., Zhang, Z., Wang, T. and He, T. (2017). Determination of *Aspergillus* pathogens in agricultural products by a specific nanobody-polyclonal antibody sandwich ELISA. *Scientific Reports*, 7(1):1–11.
- Wang, Y., Zhao, C., Zhang, D., Zhao, M., Zheng, D., Lyu, Y., Cheng, W., Guo, P. and Cui, Z. (2017). Effective degradation of aflatoxin B1 using a novel thermophilic microbial consortium TADC7. *Bioresource Technology*, 224: 166–173.
- Wielogorska, E., Ahmed, Y., Meneely, J., Graham, W. G., Elliott, C. T. and Gilmore, B. F. (2019a). A holistic study to understand the detoxification of mycotoxins in maize and impact on its molecular integrity using cold atmospheric plasma treatment. *Food Chem.* 301:125281.
- Xia, X., Wang, H., Yang, H., Deng, S., Deng, R., Dong, Y. and He, Q. (2018). Dual-terminal stemmed aptamer beacon for label-free detection of aflatoxin B1 in broad bean paste and peanut oil via aggregation-induced emission. *Journal of Agricultural and Food Chemistry*, 66: 12431–12438.
- Xue, Z., Zhang, Y., Yu, W., Zhang, J., Wang, J., Wan, F. and Kou, X. (2019). Recent advances in aflatoxin B1 detection based on nanotechnology and nanomaterials-a review. *Analytica Chimica Acta*, 1069: 1–27.
- Yang, X., Zhang, Q., Chen, Z. Y., Liu, H. and Li, P. (2017). Investigation of *Pseudomonas fluorescens* strain 3JW1 on preventing and reducing aflatoxin contaminations in peanuts. *PLOS One*, 12(6): e0178810.
- Yang, Y., Li, G., Wu, D., Liu, J., Li, X., Luo, P., Hu, N., Wang, H. and Wu, Y. (2020). Recent advances on toxicity and determination methods of mycotoxins in foodstuffs. *Trends Food Sci. Technol*, 96: 233–252.

- Yoshinari, T., Noda, Y., Yoda, K., Sezaki, H., Nagasawa, H., and Sakuda, S. (2010). Inhibitory activity of blasticidin a, a strong aflatoxin production inhibitor, on protein synthesis of yeast: Selective inhibition of aflatoxin production by protein synthesis inhibitors. *The Journal of Antibiotics*, 63(6): 309–314.
- Zhao, Y., Wan, L.-H., Bai, X.-L., Liu, Y.-M., Zhang, F.-P., Liu, Y.-M. and Liao, X. (2017). Quantification of mycotoxins in vegetable oil by UPLC-MS/MS after magnetic solid-phase extraction. *Food Additives & Contaminants: Part A*, 34:1201–1210.
- Zhu, Z., Feng, M., Zuo, L., Zhu, Z., Wang, F., Chen, L., Li, J., Shan, G. and Luo, S-Z. (2015). An Aptamer based surface plasmon resonance biosensor for the detection of ochratoxin A in wine and peanut oil. *Biosensors and Bioelectronics*, 65: 320–326.
- Zinedine, A., Brera, C., Elakhdari, S., Catano, C., Debegnach, F., Angelini, S., De Santis, B., Faid, M., Benlemlih, M., Minardi, V. and Miraglia, M. (2006). Natural occurrence of mycotoxins in cereals and spices commercialized in Morocco. *Food Control*, 17(11): 868–874.
- Lippolis, V., Irurhe, O., Porricelli, A. C. R., Cortese, M., Schena, R., Imafidon, T. and Pascale, M. (2017). Natural co-occurrence of aflatoxins and ochratoxin a in ginger (*Zingiber officinale*) from Nigeria. *Food Control*, 73: 1061–1067

Cite this article:

Avinash Jain and Shyam Govind Singh, 2023, “From field to forks: A deep dive into aflatoxin contamination in food items” *Journal of Science Innovations and Nature of Earth*, Vol. 3(4), page-04-21

[www.doi.org/10.59436/https://jsiane.com/archives3/4/105](https://doi.org/10.59436/https://jsiane.com/archives3/4/105)