



REVIEW ARTICLE

Extenuating mycotoxin contamination in spices: detection, regulatory frameworks and preventive strategies

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Abstract

Mycotoxins are secondary metabolites produced by fungi, primarily from the genera *Aspergillus*, *Fusarium*, *Penicillium* and *Alternaria*. The attention is on the existence of mycotoxin compounds in food substances that jeopardize public health and it is directed to systematic regulation to overcome these issues. Pathogenic fungi, including *Aspergillus*, *Penicillium* and *Fusarium* species, infiltrate spice crops during the pre-harvest, postharvest and storage stages. These fungi create toxic secondary metabolites called mycotoxin. The reviews' intend to examine the prevalence, types and levels of mycotoxins commonly found in spices, including aflatoxins, ochratoxin A and fumonisins. The study highlights the factors that influence mycotoxin contamination, such as environmental conditions, agricultural practices and storage methods. Analytical techniques for detecting mycotoxins, including chromatography and immunoassays, are evaluated for efficacy and sensitivity. It also discusses the regulatory frameworks and safety standards established by international bodies like the Codex Alimentarius Commission to mitigate mycotoxin risks. In addition to these regulatory measures, mycotoxin detection needs to be addressed before framing the standards. The preventive strategies and mitigation measures, including good agricultural practices (GAP), proper drying, storage conditions and biocontrol agents, were explored based on previous research conducted earlier. This comprehensive review underscores the critical importance of implementing integrated approaches combining advanced detection methods, harmonized regulatory standards and preventive strategies to ensure the safety and quality of spices in the global food supply chain.

Keywords

detection methods; fungal contaminants; mycotoxin; spices

Introduction

Spices refer to the parts of plants like leaves, bark, seeds, fruit, or roots that enhance colour and flavour and even preserve food (1). Spices are widely used in everyday cooking and are essential for improving the flavour of food in many different cuisines worldwide. However, there is a risk as these ingredients get contaminated by harmful fungi, leading to mycotoxins that remain unaffected by cooking processes (2). Commonly utilized worldwide and integral to Persian cuisine, it includes cinnamon, turmeric, black pepper and chilli powder in various dishes. The

most inexpensive and widely used spice in food is black pepper, which is grown in tropical climates. In addition to being used as a spice in meals, meat items, soups, vegetables and marinades, black pepper is also used as a preservative in the pharmaceutical and perfumery industries (3). Mycotoxin contamination in spices represents a significant global food safety concern, affecting food security and international trade. Spices, essential components of culinary traditions worldwide, are particularly susceptible to mycotoxin contamination due to their cultivation, harvesting, processing and storage conditions in predominantly tropical and subtropical regions (4). The presence of mycotoxins, primarily produced by *Aspergillus*, *Penicillium* and *Fusarium* species, poses substantial health risks to consumers, ranging from acute toxicity to chronic diseases, including carcinogenic, immunosuppressive and teratogenic effects (5).

Mycotoxins, toxins generated by fungi, are byproducts of toxigenic fungi. The presence of mycotoxins in food products is a primary worldwide health concern, affecting both economies and public health. These substances can pose severe risks to human and animal health, potentially leading to illnesses or even deaths (6). Due to the lack of a protein structure, mycotoxins resist heat and can persist through cooking processes (80-121 °C) (7). Specific types of mould fungi with toxigenic properties are responsible for producing these substances. Environmental factors such as temperature and moisture play a significant role in promoting fungal growth and, consequently, the production of mycotoxins in food items (8). Currently, over 300 identified mycotoxins, primarily focusing on those known to be carcinogenic and toxic. Ochratoxin A (OTA) and aflatoxins (AFTs) are among the numerous mycotoxins that have gained attention due to their harmful effects and economic significance. Mycotoxins cause significant economic losses globally in human and animal health and products every year (9).

Aflatoxins (AFTs) and ochratoxin A (OTA) are the most prevalent and hazardous mycotoxins. Aflatoxin, a significant mycotoxin, is primarily produced by species within the *Aspergillus* section Flavi, like *A. flavus*, *A. parasiticus* and *A. nomius*, under suitable environmental conditions. The main AFTs, including B₁, B₂, G₁ and G₂, are identifiable under fluorescent or violet light (appearing green or blue) (10). Aflatoxin B₁, a well-known toxin within the AFTs group, is recognized for its harmful effects, such as mutagenicity and carcinogenicity in humans and animals (11). OTA is another mycotoxin produced by specific species of *Aspergillus* and *Penicillium*, such as *A. ochraceus*, *A. carbonarius* and *P. verrucosum* (12). The United Nations Food and Agriculture Organization (FAO) estimates that up to 25% of agricultural and food products worldwide are contaminated with mycotoxins (13). Mycotoxin contamination is often linked to drying spices on the ground, creating ideal conditions for fungal growth. According to the Rapid Alert System for Food and Feed (RASFF), the most reported border rejection notifications in the European Union in 2016 were the products contaminated with mycotoxins (14). Mycotoxin contamination has emerged as a critical threat to food security over the past twenty years, with fumonisins being particularly widespread in essential crops. This prevalent contamination by fumonisins necessitates further research into the toxin-producing capabilities of *Fusarium* species. (15).

Analytical techniques like enzyme-linked immunosorbent

assay (ELISA) and high-performance liquid chromatography (HPLC) can measure mycotoxins. HPLC is mainly useful for simultaneous mycotoxin analysis owing to its specificity and sensitivity. Nevertheless, ELISA may exhibit cross-reactivity with similar compounds and lower sensitivity compared to chromatographic methods (16). Acceptable levels of mycotoxin contamination differ among various countries, including the USA, India, Spain and Iran (2,17,18). Additionally, recent advances in rapid detection methods, including biosensors and portable analytical devices, have enhanced the capability for early detection and monitoring of mycotoxin contamination in spices (19). This review aims to provide an in-depth analysis of current challenges and recent developments in mycotoxin detection, examine existing regulatory frameworks and evaluate preventive measures for ensuring the safety and quality of spices in the global food supply chain.

Economically important spices

Spices are unique botanical substances that enhance food scent, flavour and appearance. Since ancient Vedic times, various herbs and plants have been recognized for their therapeutic benefits. The medicinal properties of spices and their ability to combat microbes and inflammation have been documented since the Rigveda era (4500-1600 BCE). Not only do spices enhance the taste of food, but they also promote human health due to their antimicrobial, anti-inflammatory and medicinal qualities. Additionally, they prolong the shelf life of food and serve as natural preservatives (20).

Sold in whole, ground, or blended forms, spices like turmeric, paprika, chili, cloves, star anise, coriander seed, cardamom, cumin and fennel are commonly featured in Asian cuisines. However, geographical location, soil quality and postharvest techniques can influence the attributes of spices. Despite many countries cultivating spices, India stands as the largest producer globally. FAOSTAT data from 2019 reveals that spice production reached 2.8 million tonnes from 1.4 million hectares of harvested land, with Asia accounting for 86% of the total output. Specifically, India produced 1.4 million tonnes of spices in 2019, indicating its dominant position in the market. The top chilli producers in 2016 were China, Mexico and Turkey, underscoring the significance of this crop, especially for emerging economies.

Chilli

Chilli is one of the most commonly used spices worldwide (*Capsicum annum* L.). Chillies are the fruits of *Capsicum* plants from the *Solanaceae* family, originating in America. In Sindh, the most cultivated chilli types are Longi and Sanam. These cultivars are widely used as seasonings in various Sindhi dishes and are profitable in domestic and foreign markets. Chilli products come in multiple forms, such as dried, fresh, powdered, pastes and flakes. Although fresh chillies can be consumed immediately after harvest, most chilli production focuses on processing and dehydration and it is often used in creating spice mixes. Studies suggest that most fungi found in chilli are likely contaminants or pathogens rather than native to the plant (21-23). Among the various spices, *A. flavus* and *A. niger* are the primary sources of fungal contamination in chillies (24). Analysis of OTA contamination in chilli samples from multiple regions revealed predominant fungal species, including *Aspergillus niger*, *A. carbonarius* and *A. ochraceus* (12).

Additionally, recent surveillance studies have demonstrated the co-occurrence of these mycotoxins in dried chilli samples, with AFB1 showing a higher prevalence (82%) compared to OTA (65%) in market samples (25). The Guntur Sannam chilli is renowned worldwide for its distinctive characteristics. Known as an S4 type chilli in trade, it is primarily valued for its strong spice and as a source of *capsaicin*, the active component in chillies responsible for their heat (26). The combination of leaf blight and fruit rot represents a severe threat to chilli production, possibly destroying entire crops (27). Anthracnose (*Colletotrichum capsici*), the most devastating disease in Longi chillies, manifests as dark sunken fruit lesions, leading to significant crop losses (28).

Cinnamon

There are four main types of cinnamon popularly used in various products: Indonesian cinnamon (*C. burmannii*), Chinese cinnamon (*C. cassia*), Vietnamese cinnamon (*C. loureirii*) and Sri Lankan cinnamon (*C. zeylanicum*), although over 250 cinnamon varieties have been identified (29). Throughout history, people have incorporated cinnamon into their culinary practices as a flavour enhancer and aromatic seasoning across diverse cultures. Besides its culinary uses, cinnamon plays a significant role in medicine due to its antibacterial and antioxidant characteristics (30, 31). In a related study conducted in Saudi Arabia, *Aspergillus flavus* and *Aspergillus niger* were identified in cinnamon samples at frequencies of 33% and 75%, respectively (32).

Coriander seeds

Coriander seeds, from the plant *Coriandrum sativum* of the Apiace family, are commonly used as a spice. Among fungal pathogens isolated from coriander samples in Bihar, India, *P. verrucosum* showed the highest prevalence (63%), followed by *A. niger* (10.6%) and *A. flavus* (8%) (31). Southeastern Asian countries, which are famous. Fungal pathogens constantly infect them for their reputation in coriander production. Coriander samples from Medan and Indonesia had minimal toxic *Aspergillus* (33).

Pepper

Peppers are widely used as a popular table spice globally. Black pepper is known as the "king of spices" and "black gold. In various regions, including Malaysia and Southeast Asia, peppers are commonly used in curries, soups and meat and poultry marinades. Numerous studies have highlighted the prevalence of fungi in black pepper samples. Black and white peppers are predominately infected with *Aspergillus* species, among other fungal pathogens (33). Black pepper samples from Brazil are highly contaminated with *Aspergillus* spp, such as *A. ochraceus*, *A. parssiticus*, *A. carbonarius*, *A. flavus*, *A. nomius* and *A. niger* (32). Black pepper from Tanzania was found to include AF-producing fungi, including *A. parasiticus*, *A. flavus* and *A. nomius* (34).

Similarly, white pepper exhibited lower-level contamination with only *Rhizopus* spp and *Aspergillus*. Black pepper samples from Bahrain showed contamination by *A. flavus* species, with 1.12×10^3 CFU/g of fungi at 78% (24).

Fennel

Multiple fennel varieties exist, sweet fennel (*F. vulgare* var.) and bitter fennel (*F. vulgare* Mill) are the most commonly used. The distinction between these lies in the volatile oil content of their seeds, ranging from 1% to 6%. In bitter fennel, about 10% to 6%

of the volatile oil consists predominantly of anethole, comprising half of the oil contents of *A. ochraceus* (5.0%), *A. niger* (5.3%) and *A. flavus* (12.3%), were identified in moderately contaminated fennel samples from India (31). Fungal contaminations such as *A. niger* in fennel were reported with the potential to produce OTA in significant amounts (32). Fennel is widely used to flavour soups, sauces, pastries, confectioneries, bread rolls, liquors, meat dishes and pickled seasonings. Its fruit is often chewed as a masticatory, while its seeds and oil possess various medicinal properties. Fennel leaves are known for their digestive, appetizing and stimulating effects, helping to increase urine secretion and discharge. Additionally, aqueous ethanol extracts from the roots of *F. vulgare* var. dulce have been tested for diuretic activity in rats (35). In fennel ochratoxin A, contamination is less than the permissible limit (31).

Cumin

Cumin is widely used in dishes such as Indian pickles and spice blends like sambar powder. *A. niger* is the major fungal pathogen identified to be contaminated at 4.6×10^2 CFU /g of cumin samples in Bahrain (24). *A. niger* was the predominant fungus at 60%, followed by *A. flavus* at 40% and *A. fumigatus* at 20%, all known to produce OTA and AFT. AFB1 and total AFTs were uncommon, with mean amounts of 0.03 µg/kg and 0.05 µg/kg in 57% of Moroccan cumin samples from public markets (36). Studies showed that there was no contamination of cumin samples with *A. niger* with a 0.2 µg/kg detection limit (37).

Mycotoxins in Fungi

Mycotoxins, which are secondary compounds produced by fungi such as *Aspergillus*, *Penicillium*, *Alternaria* and *Fusarium*, are known to be present in spices (38). The primary mycotoxins found in spices were OTA and Afs, along with other mycotoxins detected in food products that include fumonisins (FBs), deoxynivalenol (DON), trichothecenes, zearalenone (ZEN) (8,20). Spices are particularly susceptible to mycotoxin contamination due to cultivation, storage and processing conditions in tropical/subtropical regions (14). Ochratoxin A's dual threat as a potent kidney toxin and potential carcinogen is particularly concerning in spices. Their frequent consumption as food ingredients enables chronic low-dose exposure that can accumulate harmful effects over time, even at concentrations below regulatory limits (39). It is described below in (Table 1-2).

Aflatoxins (AFTs)

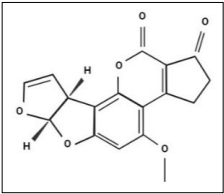
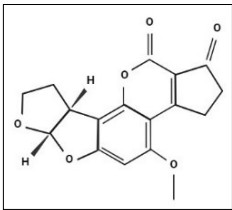
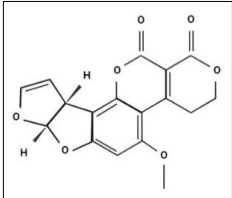
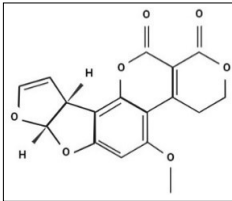
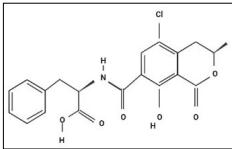
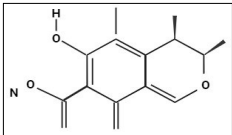
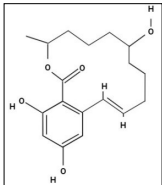
AFs exhibit mutagenic solid, carcinogenic and immunosuppressive characteristics, notably more harmful than other mycotoxins (46). AFT represents a significant mycotoxin produced by fungi within the *Aspergillus* genus. *A. flavus*, *A. parasiticus* and *A. nomius* are the primary AFT producers among various *Aspergillus* species (8). AFTs are commonly found in peanuts contaminated with *A. flavus* or *A. parasiticus* in other substances such as dried fruits, nuts, rice, spices, figs and corn (56). There are four main types of aflatoxin: B1, B2, G1 and G2. Research indicates that *A. flavus* primarily releases B toxins, with B1 being the most commonly occurring toxin known for its cancer-causing and genetic-mutating characteristics (57, 58). Cotton and maize stand first in identifying AFTs produced by *A. flavus* (59). Aflatoxins are particularly dangerous in spices because these ingredients are often stored in warm, humid conditions that promote mould growth, are resistant to typical household cooking temperatures and can concentrate in spice

Table 1. List of important mycotoxin and toxin-producing fungal organisms

Mycotoxin	Fungal organisms	Mode of action	Reference
Aflatoxins B1, B2, G1, G2	<i>A. parasiticus</i> , <i>Aspergillus flavus</i> , <i>A. nomius</i>	DNA adduct formation, Inhibition of protein synthesis, Lipid peroxidation, Immunosuppression, Carcinogenic (primarily targets liver), P53 mutation induction	(8, 40)
Ochratoxin A	<i>Penicillium verrucosum</i> , <i>Aspergillus ochraceus</i> , <i>A. carbonarius</i>	Inhibition of protein synthesis, Disruption of calcium homeostasis, Mitochondrial dysfunction, Competitive inhibition of Phe-tRNA synthetase, Nephrotoxic effects, DNA damage through oxidative stress	(41-44).
Fumonisin B1, B2, B3	<i>Fusarium verticillioides</i> , <i>F. proliferatum</i>	Disruption of sphingolipid metabolism, inhibition of ceramide synthase, Cell membrane damage, Alteration of sphinganine/ sphingosine ratio, Neural tube defect induction	(45-47)
Zearalenone	<i>F.culmorum</i> , <i>F.verticillioides</i> , <i>Fusarium graminearum</i> , <i>F. semitectum</i> , <i>F.cerealis</i> , <i>F. crookwellense</i> , <i>F.pseudograminearum</i> and <i>F.equiseti</i>	Estrogenic activity, Binding to estrogen receptors, Disruption of hormonal balance, Reproductive system effects, Competitive binding with 17 β -estradiol	(20, 45, 46, 48, 49)
Citrinin	<i>P. viridicatum</i> , <i>P. expansum</i> , <i>Penicillium citrinum</i> , <i>Monascus purpureus</i> , <i>M. ruber</i> , <i>A. niveus</i> , <i>A. terreus</i>	Nephrotoxicity, Mitochondrial dysfunction, Oxidative stress induction, Disruption of ion transport, Inhibition of RNA/ protein synthesis	(20, 50-52)

Table 2. Chemical structure of mycotoxins

Source: Biorender

Mycotoxins	Chemical structure	Reference
Aflatoxin B ₁		(55)
Aflatoxin B ₂		
Aflatoxin G ₁		
Aflatoxin G ₂		
Ochratoxin A (OTA)		(43)
Citrinin		(20)
Zearalenone (ZEA)		(45)

matrices - a key food safety concern since even small amounts of contaminated spices can introduce significant AFT exposure through regular consumption patterns (45, 60).

Ochratoxin A (OTA)

Out of these, OTA is the most prevalent mycotoxin in food, originating from *P. verrucosum* and various *Aspergillus* species, namely *A. ochraceus* and *A. carbonarius* (8). *A. ochraceus* and *A. carbonarius* dominate OTA production in tropical regions, commonly contaminating spices and crops during both the cultivation phase and postharvest storage under warm, humid conditions. The ochratoxin A (OTA) is primarily produced by four key fungal species: *A. ochraceus*, *A. niger*, *A. carbonarius* and *P. verrucosum* (41-33). Fungi-producing OTAs are well favoured in regions with tropical climates, promoting the synthesis of OTA (61).

Citrinin

Citrinin (CIT) is a mycotoxin produced by several *Penicillium* spp (50). Although CIT was discovered for the first time in 1931 from *Penicillium citrinum*, several other fungi were also found to produce the mycotoxin, such as *A. terreus*, *A. niveus*, *Monascus ruber*, *M. purpureus*, *P. viridicatum* and *P. expansum* (20). Studies have confirmed that citrinin is toxic to kidneys, as shown in a prior investigation with chickens contaminated by *P. citrinum* (62). However, it is classified under group 3 carcinogen, indicating their low lethality by the International Agency for Research on Cancer (IARC).

Fumonisin

The primary producers of fumonisins are *Fusarium* species, particularly *F. verticillioides* (63-65). Twenty-eight fumonisins, which have been identified, were sorted into four different groups (46), among which fumonisin B (FB) was found to be the most common group, comprising FB1, FB2 and FB3. Necrotic lesions identify the syndrome with a liquid consistency in the white matter region of horses' brains (8). There has been an increasing interest among researchers in exploring the presence of FBs in spices. Spices and herb samples collected in China were identified with the presence of FB1 and FB2 (66).

The research demonstrated that mouldy samples, accounting for 42.5%, were tainted with FB2 and FB1 and averaged concentrations of 165.9 and 129.0 µg/kg, respectively. In contrast, usual samples, comprising 8.6%, exhibited contamination levels of 165.9 and 256.8 µg/kg for FB1 and FB2, respectively. Additionally, assessed herbs and spices were obtained from Polish markets, where FBs were identified in the samples at levels ranging from 5.29 to 62.78 µg/kg for total FBs (67).

Trichothecene (TC)

F. graminearum and *F. culmorum* are among the common species in agricultural goods, besides other species capable of producing TCs, including *Cephalosporium*, *Cylindrocarpon*, *Dendrodochium*, *Myrothecium*, *Trichoderma*, *Trichothecium* and various *Stachybotrys* species (51, 53). Field crops such as Paddy, Barley, oats, corn, rye and wheat are frequently tainted with TCs (69).

Zearalenone (ZEA)

Zearalenone (ZEA), previously referred to as F-2 toxin, is categorized as a non-steroidal estrogenic mycotoxin (37). ZEA is synthesized by certain *Fusarium* species, primarily *F. graminearum* and *F. semitectum* (45). Additional producers of ZEA include *F. culmorum*,

F. verticillioides, *F. cerealis*, *F. crookwellense*, *F. pseudograminearum* and *F. equiseti* (48, 69).

Impact of Environmental and Agricultural Factors on Mycotoxin Production

The aflatoxin biosynthesis pathway is modelled by non-biological factors such as temperature, water activity, pH and carbon/nitrogen availability (70). These environmental factors serve a dual role: enhancing *A. flavus* colonization while simultaneously inducing the transcription of genes involved in aflatoxin production (71-72). Fungal growth and toxin production are favoured by higher water activity, specifically with aflatoxin synthesis reaching optimal levels at 0.99 aw when combined with temperatures of 29-30°C (73-74).

Aflatoxin biosynthesis and fungal growth are inhibited at temperatures outside the 25-37°C range, while water activity below 0.85 aw reduces toxin production, with complete cessation occurring at 0.70-0.75 aw (74). Mycotoxin contamination in spices is significantly influenced by poor soil management practices, particularly inadequate crop rotation, improper field preparation and contaminated soil conditions (75). Improper irrigation practices, such as over-irrigation, water stress and the use of contaminated water, can adversely affect crop health and soil quality (76). Delayed harvesting, such as leaving crops in the field too long or harvesting under wet conditions, can increase the risk of spoilage and contamination (14). Inadequate drying, including slow or improper methods and incomplete drying, can lead to the growth of spoilage organisms and reduce crop quality (77). Poor storage conditions like high humidity, inadequate ventilation, temperature abuse and pest infestation can lead to contamination, spoilage and product degradation (78). In the agricultural sector, proper sanitation and hygiene practices are absent throughout the process, from harvesting to storage and transportation (79-80). The most suitable temperature range for the survival of *A. flavus* is around 30°C, with the most effective production occurring between 25°C and 30°C (81, 82). Even with their low water activity levels, spices are at risk of fungal contamination, influenced by the cultivation location, harvesting procedures and processing techniques (61). Fungal contaminations and mycotoxin production are significantly promoted in warm and humid tropical regions, which are also ideal conditions for spice cultivation (83).

The mycotoxins contaminating the spices are viable from the point of infection through the storage unit and can show their impact when consuming the food products containing the spices (84).

Among storage fungi, *Aspergillus* species, especially *A. flavus* and *A. niger*, are commonly isolated from spices due to their tolerance to low moisture conditions and ability to produce mycotoxins (85, 86). *Penicillium* is another common storage fungi that can produce and secrete mycotoxins, especially in tropical regions (87). Southeast Asia's climate is predominantly tropical, making it one of the world's most climate-vulnerable regions. Predicted changes in temperature, CO₂ levels and rainfall patterns are expected to intensify in this region due to climate change (88). The hot and humid conditions present for much of the year promote the growth of mycotoxin-producing fungi, which release toxic metabolites, leading to contamination in food and feed (89). The tropical zone, between 23.5° North and 23.5° South, has high temperatures year-round because the

Sun's rays fall directly here. This direct sunlight is concentrated over a smaller area, causing more heat per unit and making it the hottest climate zone (90). Spices, valued for their unique flavours and aromatic compounds, are inherently vulnerable to fungal contamination due to their hygroscopic nature, which allows moisture absorption from the environment, creating ideal conditions for fungal proliferation (91). Container transportation and temperature abuse during maritime shipping significantly increase spice contamination levels during transit (92) (Fig. 1.).

Impact of mycotoxin

Ochratoxin A (OTA) exhibits nephrotoxic and reproductive toxicity, with demonstrated transplacental transmission and documented hepatotoxic, neurotoxic and immunosuppressive effects. At the same time, OTA and aflatoxins contaminate diverse food matrices, including cereals, nuts, dried fruits, spices, legumes, alcoholic beverages and herbs at varying concentrations (37) (Fig. 2.).

Mycotoxins can enter the body through various pathways, including contact, inhalation and ingestion. A primary concern among these toxic components is AFTs; consistent consumption of mycotoxin at a level ranging from 10 to 50 µg/kg or above can reflect negatively on human health due to their teratogenic, immunosuppressive, carcinogenic and mutagenic effects (93). Approximately five billion people worldwide are exposed to mycotoxins daily through conventional food sources and unidentified pathways (94). Excessive consumption of mycotoxin results in intoxication, a condition referred to as mycotoxicosis (95). Mycotoxin accumulation causes acute or chronic toxicity and temporary or long-term adverse effects such as neurotoxicity, teratogenicity, cytotoxicity, mutation, hepatotoxicity and carcinogenicity. OTA is also nephrotoxic and its target organ is the kidney. Overdose of ochratoxin can cause kidney failure and death also (31). Mycotoxins (particularly

aflatoxins, ochratoxin A and trichothecenes) disrupt cellular bioenergetics by inhibiting mitochondrial electron transport chain complexes I-IV, resulting in decreased ATP production and increased reactive oxygen species (ROS) generation, which collectively leads to cellular energy depletion and oxidative damage (96-97). Aflatoxin B1 and ochratoxin A disrupt glucose homeostasis by inhibiting GLUT4 transporter expression and IRS-1 phosphorylation in the insulin signalling cascade, resulting in impaired glucose uptake, insulin resistance and reduced glycogen synthesis in muscle and liver cells (98).

Mycotoxins prevent the replication of RNA and DNA by interacting with nucleic acids at the cellular level (99). Acute toxicity is reflected in rapid allergic changes and symptomatic effects, which can be diagnosed using drugs. Chronic toxicity is the result of prolonged consumption of toxins, leading to irreversible conditions such as cancer and severe fatality(8). In Gambia, children consuming AFT-contaminated food had a lower secretory immunoglobulin A(IgA) rate (43). Moreover, Contamination with AFT has also led to changes in lymphocyte subsets and distribution among Ghanaian adults, indicating that AFTs may weaken cellular immunity and reduce infection resistance (100).

Techniques involving mycotoxin detection

Early detection of mycotoxins is paramount for ensuring food safety and minimizing public health risks, with recent research demonstrating its vital role in preventing acute and chronic toxicity exposures, protecting vulnerable populations like children and the immunocompromised and identifying contamination sources before widespread distribution (19). Early detection strengthens food security by enabling screening of raw materials before processing, preventing contaminated products from entering the food chain and supporting sustainable

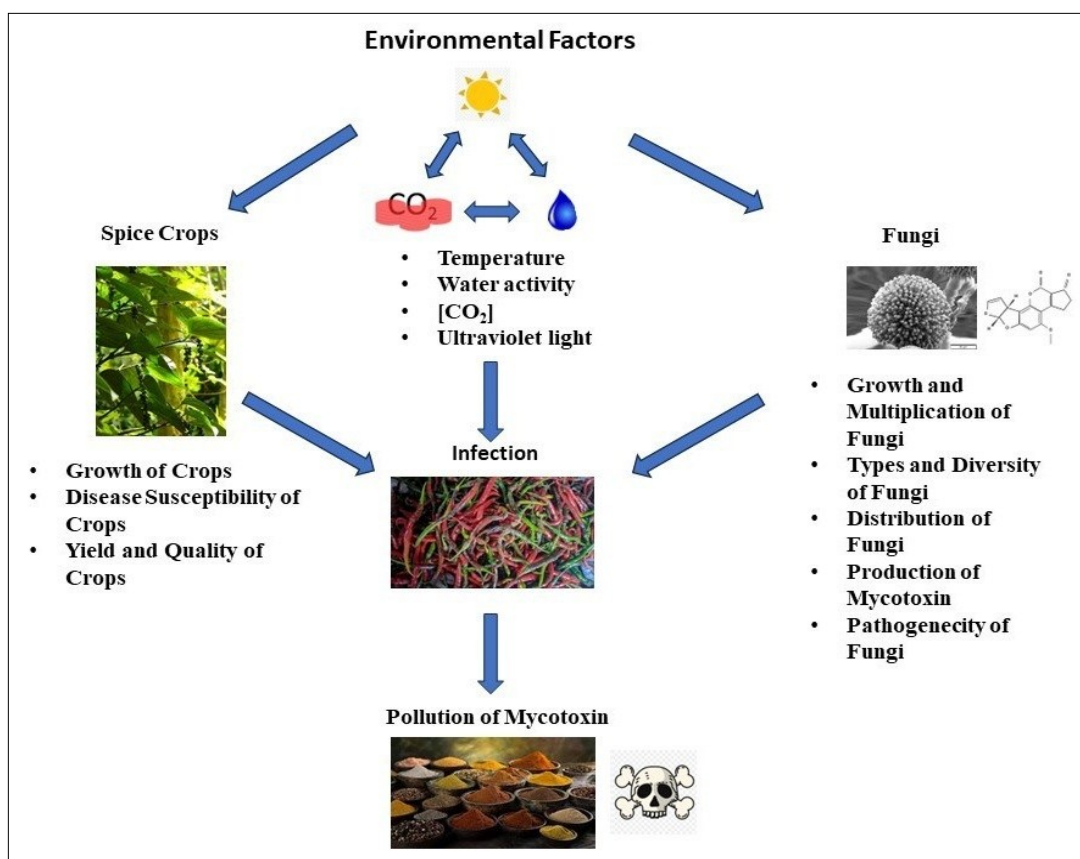


Fig. 1. Impact of environmental factors on toxin contamination

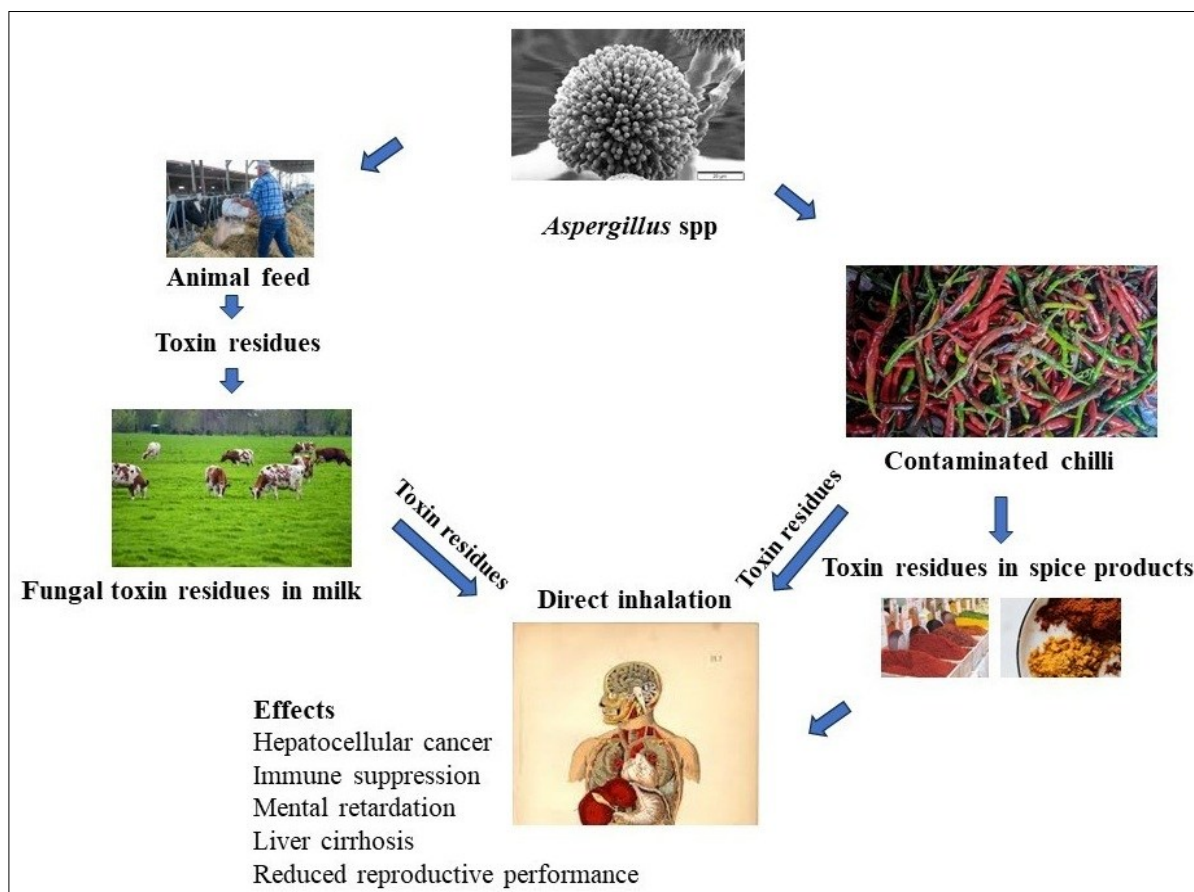


Fig. 2. Impacts of mycotoxin on human health from a toxicological perspective agriculture practices (101). Since the discovery of mycotoxins, a variety of approaches have been utilized for their analysis, with chromatographic methods, immunoassays and rapid strip screening tests being the predominant methods for mycotoxin detection and analysis (102-103) (Table 3).

Chromatographic methods

In chromatographic analysis, separation occurs through physical interactions when the liquid mobile phase permeates through or moves along the solid stationary phase, causing a differential distribution of components between these phases (108-109). Commonly utilized chromatography methods include high-performance liquid chromatography (HPLC) integrated with diode array, fluorescence and UV detectors, thin-layer chromatography (TLC), gas chromatography-tandem mass spectrometry (GC-MS/MS) and liquid chromatography-tandem mass spectrometry (LC-MS/MS), (102-103). Methods belonging to the chromatographic classification have been developed explicitly for the precise quantification of mycotoxins because they can effectively ascertain, recognize and measure various toxic substances (110).

Thin-layer chromatography

Thin-layer chromatography (TLC) has demonstrated its cost-effectiveness and simplicity as a method suitable for the quantitative and qualitative detection and analysis of multiple mycotoxins. This is mainly due to its cost efficiency, simplicity and the presence of UV light fluorescent spots. However, it is essential to note that TLC exhibits lower sensitivity and accuracy levels, which present challenges in achieving precise quantification (102, 111). Conversely, liquid chromatography (LC) is known for its reliable separation capacity, particularly when combined with the sensitivity of tandem mass spectrometry. This combination has solidified LC as a powerful technique capable of detecting and quantifying mycotoxins in various circumstances (112, 113). The detection limit for aflatoxins using fluorescence detection after derivatization was reported to be 0.1-0.5 ng per spot (114). The detection limit for fumonisins using fluorescence detection after derivatization was reported to be between 100-500 ng per spot (115).

Table 3. Comparison of Analytical Techniques: TLC, HPLC and LC-MS/MS in Terms of Cost, Sensitivity, Accuracy and Applications

Techniques	Cost	Sensitivity	Accuracy	Application	References
TLC	Low (inexpensive setup and materials)	Low to moderate sensitivity	Moderate accuracy; qualitative/semi-quantitative	Qualitative analysis, preliminary compound identification, purity checks	(102)
HPLC	Moderate to High (equipment and solvents are costly)	Higher sensitivity than TLC in the ng/mL range	High accuracy for quantitative analysis, but can be impacted by matrix complexity.	Quantitative analysis, pharmaceutical testing, complex mixture separation	(104)
LC-MS/MS	Very High (expensive setup and operation costs)	Very high sensitivity, capable of detecting low ng/mL or even pg/mL concentrations	Extremely high accuracy, especially for complex mixtures due to MS specificity	Used in biopharmaceuticals, proteomics, metabolomics, clinical diagnostics and drug development	(105-107)

High-performance liquid chromatography (HPLC)

The concurrent analysis of multiple mycotoxins is achieved using HPLC due to its high sensitivity and specificity as a chromatographic technique (19, 44). HPLC uses diverse discoverers and adsorbents, including fluorescent (FLD) and UV-visible (UV), which are contingent upon the presence of chromophores employed for mycotoxin examination. Occasionally, mycotoxins are detectable directly in HPLC-FLD owing to inherent fluorescence (37). Detection limits are approximately 50 ng g⁻¹ for FB1 and 100 ng/g for FB2 (115). Fluorescence detection (FLD) with post-column derivatization is widely used for detecting aflatoxins in food and feed due to its high sensitivity. For aflatoxins B1 (AFTB1) and B2 (AFTB2), the method can detect levels as low as 0.1-0.5 ng/g, while for G1 (AFTG1) and G2 (AFTG2), detection limits range from 0.2-0.6 ng/g. (116). The limits of detection (LOD) for aflatoxins (AFTs), ochratoxin A (OTA) and zearalenone (ZEA) were 0.004-0.012 ng/g, 0.05 ng/g and 0.5 ng/g, respectively, while the limits of quantification (LOQ) were 0.015-0.05 ng/g, 0.2 ng/g and 2 ng/g, respectively (117). HPLC provides excellent resolution for complex mycotoxin mixtures, mainly using advanced columns with sub-2 µm particle sizes (118). Modern UHPLC systems achieve faster analysis times while maintaining high separation efficiency (44). The development of comprehensive HPLC methods capable of simultaneously detecting multiple mycotoxin classes, integrating novel stationary phases for improved separation and implementing gradient elution programs optimized for complex matrices has been demonstrated (119). Enhanced sample cleanup protocols using immunoaffinity columns and QuEChERS (101). Matrix-matched calibration strategies for accurate quantification (120).

Liquid chromatography (LC)

Using liquid chromatography combined with tandem mass spectrometry (LC-MS/MS) is currently the predominant method for detecting mycotoxin. This method is renowned for its exceptional selectivity and sensitivity, eliminating the necessity for derivatization or purification steps (121). The integration of LC with MS/MS (LC-MS/MS) presents a robust diagnostic technique known for its high sensitivity, selectivity and dependability (106-107). LC-MS/MS-based multi-methods have become increasingly important as they facilitate the quick detection and sometimes quantification of various mycotoxins in diverse food categories and animal feeds (99). LC-MS/MS has extended its application in detecting several mycotoxins such as DON, T-2 toxin, AFTB1, B2, G1, G2, HT-2 toxin and OTA in grains of legume (122). LC-MS/MS can detect multiple toxins at deficient concentrations (ppb or lower). The tandem mass spectrometry (MS/MS) process allows for high specificity, reducing interference from other substances in complex matrices (106-107). This instrumentation makes it suitable for automation, allowing labs to handle large sample volumes efficiently and with consistent results. This is particularly useful in regulatory and quality control settings (123). It can detect toxins, including those with different chemical structures (e.g., polar and non-polar compounds), providing flexibility in multi-toxin analysis (124). It is a faster analysis compared to traditional methods, allowing for detecting multiple toxins in one analytical run, saving time and resources (125). The aflatoxin detection limits were reported as 0.005-0.01 µg/kg for AFTB1 and AFTB2 and 0.008-0.015 µg/kg for AFTG1 and AFTG2

(126). The detection limits for ochratoxins were reported as 0.01-0.05 µg/kg for OTA and 0.02-0.06 µg/kg for OTB (127). LC-MS/MS enables simultaneous detection of multiple mycotoxin classes with high specificity and sensitivity, achieving detection limits of 0.01-0.5 µg/kg across diverse mycotoxins, including masked and emerging forms (4). Tandem MS/MS analysis offers enhanced specificity and sensitivity (5). The simultaneous detection of regulated, emerging and masked mycotoxins, which can analyze over 50 mycotoxins in a single run and reduce sample preparation requirements compared to conventional methods, has been achieved (4).

Immunochemical Methods

Immunochemical methodology obviates the need for proficient and extensively trained personnel to address potential issues during the separation process, thereby reducing labour intensity and time consumption and establishing superiority over chromatographic and spectrophotometric methodologies. The most prevalent immunochemical techniques utilized in the examination of aflatoxins include enzyme-linked immunosorbent assay (ELISA), immunosensors, Radioimmunoassay (RIA) and immunoaffinity column assay (ICA) (8,128).

The detection process depends on specific polyclonal and monoclonal antibodies designed for these toxins (75). Recently, biosensors, including piezoelectric, electrochemical, optical and variants, have been integrated to quantify mycotoxins in food items (129). Nanoparticle-based Biosensor and Surface Plasmon Resonance (SPR) techniques function by detecting refractive index changes, earning their classification as 'label-free' detection systems (4, 5). The SPR method allows for the real-time optical recognition of multiple analytes involving fluorescence polarization and near-infrared fluorescence sensors, displaying promising fluorescence detection and quantification capabilities. By utilizing this technique, a fluorescence-labelled PT derivative bound to antibodies exhibits increased emission of fluorescence polarization. This technique's detection range for PT in food products extends from 6 to 102 µg/L (130).

Biosensors, particularly PT ones, could prove valuable in real-time mycotoxin monitoring in the food sector. However, the short stability of the bio-recognition elements in effect with the long-term self-life of biosensors, insufficient selectivity, in particular with enzyme inhibition-based biosensors and the relatively high cost of antibodies in comparison with artificial recognition elements are various challenges faced in executing detection methods using biosensors. The realm of nanotechnology is evolving in mycotoxin detection. Nanoprobes that include nano-silver, graphene and magnetic nanoparticles are utilized to detect different mycotoxins (36). Another rapid technique, the electronic nose, relies on food aromas and odours.

Fungal contaminations in food leave a trail of volatile byproducts that can be detected using GC-MS, whose properties are correlated with fungal activities during infection(8). The fungal-contaminated samples are differentiated from healthy samples utilizing the integration of NIR hyper-spectral imaging and spectroscopy ranging from 700 to 2500 nm. Various alternative approaches have surfaced alongside conventional methods, including aggregation-induced emission, molecularly imprinted polymers, electronic noses and fluorescent polarization.

The utilization of the electronic nose has been documented in the identification of various mycotoxins, such as FBs and Afs, DON in maize and wheat and wheat bran, respectively (131, 132). Detection of AFTB1 in broad bean sauce, peanut oil and OTA in coffee and wine by developing an Aggregation-Induced Emission (AIE) dye-based sensor (133-134). Chronic exposure to sub-ppb levels of aflatoxins can lead to liver damage and immunosuppression (70). Improved detection methods help enforce strict regulatory limits(134). Enhanced sensitivity was reported using quantum dot-labeled antibodies (4). The strict regulatory limits for AFTM1 in milk, set at 0.05 ppb by the EU and 0.5 ppb by the FDA, preclude the use of sample dilution or reduced injection volumes in analysis, as these techniques can raise detection limits above these critical threshold values (135, 136). A novel immunoassay system utilizing microfluidic and protein microarray technologies was developed for rapid mycotoxin screening, demonstrating high sensitivity with detection limits between 0.03 and 1.24 ng/mL (137).

Regulatory limits

Implementing preventive measures and regulations is crucial to shield consumers from exposure to mycotoxins. The primary goal is establishing upper limits for mycotoxins in food products to promote fair trade and protect public health. Regulatory thresholds have been set by more than a hundred nations across the globe (13). It is described below in (Table 4).

Management of mycotoxins

The global spice industry, particularly in tropical regions, faces a prevalent issue of mycotoxin contamination. It is imperative to enforce stringent pre and postharvest measures to mitigate the escalation of mycotoxin levels (139-140). Furthermore, the adoption of practices such as adherence to good manufacturing practices (GMP), good storage practices (GSP) and good agricultural practices (GAP) can significantly contribute to the reduction of mycotoxin production (141) (Fig. 3).

Table 4. Maximum levels of aflatoxins in spices under EU legislation reported (138).

Toxin	Spices	Maximum level ($\mu\text{g/kg}$)	
		B	Sum of B ₁ , B ₂ , G ₁ and G ₂
Aflatoxin	Dried spices include fruits from <i>Capsicum</i> spp. (whether whole or ground, such as chillies, cayenne, paprika, chilli powder), <i>Piper</i> spp. (comprising white and black pepper), <i>Myristica fragrans</i> (commonly known as nutmeg) and <i>Curcuma longa</i> (known as turmeric). Additionally, mixed dried spices that contain any combination of the spices as mentioned above are also considered.	5,0	10,0
	Ginger (<i>Zingiber officinale</i>) (dried)	5,0 10,0	5,0 10,0
Ochratoxin	Dried spices (including whole or ground chillies, chilli powder, cayenne, or paprika) other than capsicum species		15
	<i>Capsicum</i> spp. (dried fruits thereof, whole or ground, including chillies, chilli powder, cayenne or paprika)		20

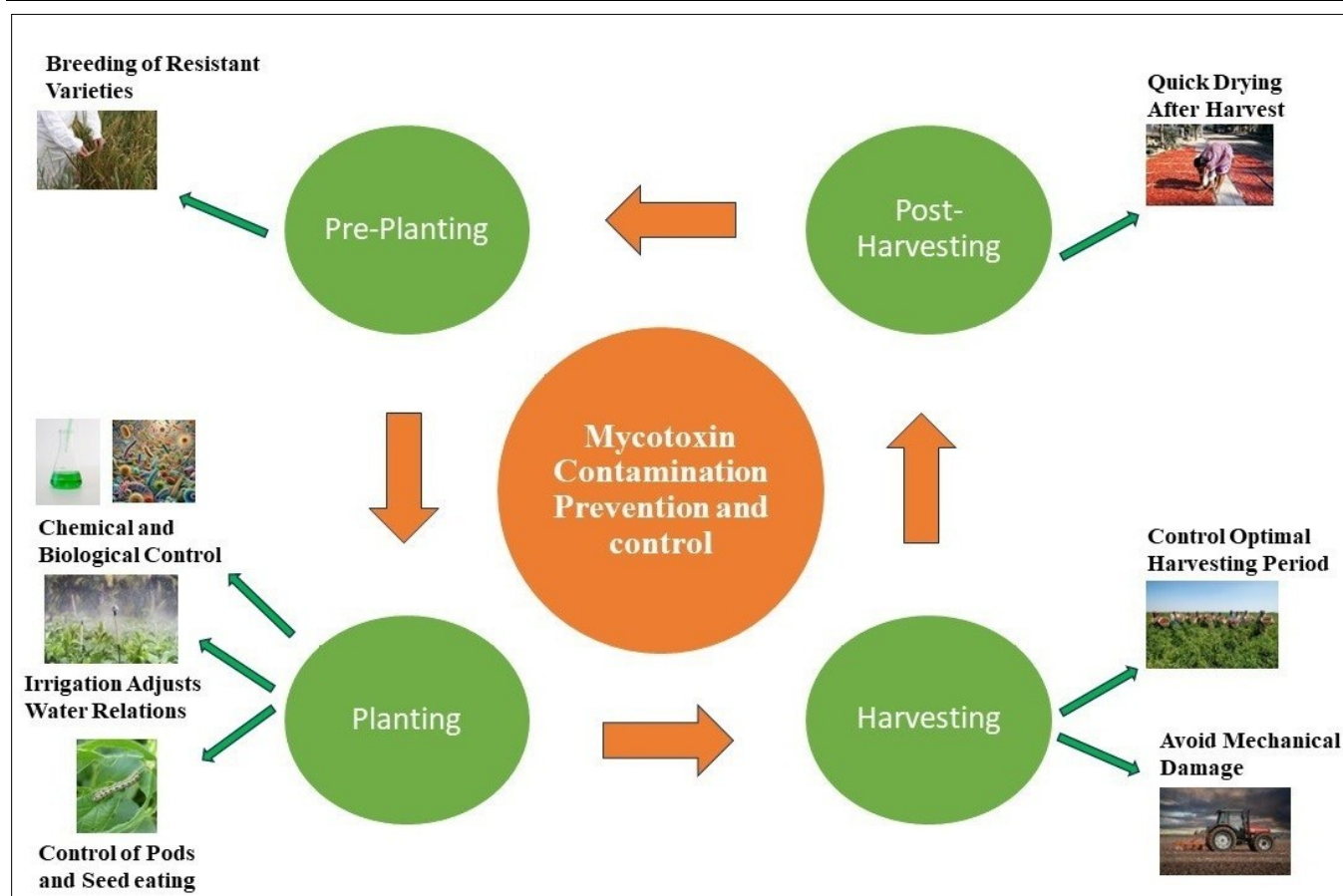


Fig. 3. Methods for preventing mycotoxin contamination in spices

Preharvest

Crop rotation strategies in spices, such as rotating pepper with ginger and turmeric with pulses, help manage pests, improve soil health and reduce disease incidence (142-143) demonstrate the effectiveness of these practices in spice cultivation. When applied appropriately, organic soil amendments such as compost, green manure, biochar and animal manure enhance soil fertility and structure (4). Microorganisms like lactic acid bacteria, *Bacillus licheniformis*, *B. subtilis* and *Saccharomyces cerevisiae* have effectively detoxified mycotoxin in pre- and postharvest stages (144). The extract from neem leaves has been reported to reduce AFT contamination in cereals during storage (145). Amid growing concerns over synthetic preservatives, there is increasing interest in natural food protection methods to enhance food quality, extend shelf life and safeguard against biodegradation by mycotoxigenic microbes (146). Integrated management combines cultural practices, biological control and soil management to enhance agricultural sustainability (147).

The choice of genetically modified seeds or fungal-resistant crop varieties with antifungal attributes presents favourable strategies. Moreover, pesticides, fertilizers and appropriate irrigation practices can be advantageous.

Utilizing native, suitable toxigenic *A. flavus*, the biological management of aflatoxins has recently become a viable method for reducing crop contamination (148). Application of pre-harvest fungicide can reduce the production of mycotoxins by specific *A. flavus* strain in Capsicum powder, growth of fungal strains that produce aflatoxin, identified and isolated from chilli, paprika and smoked paprika significantly inhibited *in vitro* when grown in 3% extract agar supplemented with 80% mancozeb and 25% tebuconazole, administered at a concentration of 3.5 and 0.75g/L respectively, regardless of strain or environmental conditions (149).

An ideal fungicide should effectively concurrently hinder both mould growth and AFT production. Chilli was evaluated with bioagents, plant extracts and fungicides for contamination with aflatoxin in *in-vitro* and *in vivo* conditions. The development of mould was significantly reduced by 0.3% mancozeb (91.1%), followed by captan (85.2%) and carbendazim (73%). Suppression of (100%) *A. flavus* was recorded with the application of nimbecidin, Pongamia oil and neem seed kernel extract (NSKE) at a concentration of 5%. *A. flavus* was inhibited by an indigenous isolate of *Pseudomonas fluorescens* with a suppression rate of 74.9% exceeding *Trichoderma harzianum* with a recorded inhibition rate of 70.4% *in vitro*. The supplements performed exceptionally *in vitro* were selected for real-time challenges against *A. flavus* in the agricultural field. Among these, fruits treated with captan displayed the lowest infection rate by *A. flavus* (1.6%), followed by those treated with NSKE (2.2%), *P. fluorescens* (2.0%) and nimbecidin (7.8%), in comparison to the control (38.3%). In terms of field assessment, the lowest incidence was observed in the chilli plot treated with NSKE spray (1.6%), which was similar to *T. harzianum* (2.6%), captan (2.2%) and *P. fluorescens* (2.4%) treatments, contrasting with the control (7.4%). It is advisable to utilize mancozeb (0.3%), NSKE (5%) or *P. fluorescens* (1×10^8 CFU/mL) through preharvest spraying on chilli plants ten days before harvest to effectively manage aflatoxins (AFTs) at the agricultural level (150).

Harvest and Postharvest

Efficient management practices during harvesting and postharvest stages can mitigate the escalating levels of mycotoxin in spices. It is essential to prevent physical harm to the bark of cinnamon, seeds of cumin, pods of peppers, roots of ginger and turmeric and leaves of bay plants caused by insect infestations or harvesting tools. Fruits damaged by physical means or fungal contamination must be eliminated. Appropriate hygienic washing techniques to eliminate dirt or soil from the plant surfaces. Extreme hygiene must be employed when separating dirt or soil from plant surfaces. After the cleaning process is completed, promptly initiating the drying phase is imperative. Since moisture provides a favourable environment for mould growth, it is essential to dry spices quickly to prevent the proliferation of mould. The moisture content should be decreased to approximately 10%, with the water activity level below 0.7. The effects of drying red peppers on concrete and soil surfaces were explored in a study. The red peppers were halved and dried outdoors, with one group placed on soil and the other on concrete. After drying, the pepper halves were left to incubate for a week. Interestingly, the peppers dried on concrete surfaces did not exhibit a significant production of aflatoxins; however, six samples out of 10 produced high levels of aflatoxin contamination when dried on soil surfaces.

The predominant fungi present in the soil were found to be *A. flavus* and *A. parasiticus*, indicating that the contact of chilli with soil during soil drying of chilli might be the significant factor contributing to the contamination of aflatoxin in ground-dried red peppers. It is crucial to ensure appropriate storage and transportation conditions to uphold the quality of spices. Transport vehicles and storage facilities should be maintained in excellent, dry conditions and protected from insects. Due to their hygroscopic nature, spices can absorb moisture from the surroundings, creating an environment conducive to mould growth and mycotoxin production, especially in warm and humid climates (151).

Similarly, aflatoxin levels and mould growth on hot peppers during a 5-month storage period at 20°C, 25°C and 30°C. The hot peppers were stored in low-density polyethylene bags and jute bags. The findings revealed that storing the peppers at higher temperatures of 25°C and 30°C resulted in a 61% increase in AFT concentrations compared to those stored at 20°C. However, there was no report of AFT contamination during the initial 90-100 days of the storage period in polyethylene bags. In contrast, the contamination was reported in hot peppers when stored in jute bags during the same period. The results showed the advantage of storing hot pepper in polyethylene bags compared to jute bags. The prolonged storage of hot pepper combined with a gradual increase in temperature and aeration permeability in jute bags over polyethylene bags contributed to the rise in fungal growth and aflatoxin contamination (152). Cold plasma is a novel non-thermal technology that utilizes reactive species (e.g., O, O₃, OH, NO, NO₂) to degrade mycotoxins, converting them into less toxic compounds while preserving food quality (153). An alternative to traditional open-air Sun drying is solar driers, which require lower investments compared to advanced fossil fuel drying techniques. This is particularly beneficial for most developing countries in climatic zones with significantly higher insolation than the global average of 3.82

kWh/m² per day (154). Preserving food materials like meat, vegetables, fruits, spices and herbs through open-air sun drying is considered one of humankind's earliest systematic technological activities (155). A survey conducted in several countries in the Asia-Pacific region identified the most promising and popular solar driers as (i) natural convection cabinet type, (ii) forced convection indirect type and (iii) greenhouse type (156).

Conclusions and Future Perspectives

Current challenges

Current detection methods face significant constraints, including high costs, time-intensive processes, limited field sensitivity, challenges in multi-mycotoxin detection, complex sample preparation requirements and dependence on specialized expertise and laboratory facilities. The management of mycotoxins faces critical challenges due to climate change-induced proliferation, emerging fungal resistance to treatments and inadequate storage infrastructure in developing nations, creating significant obstacles to effective control and prevention. The substantial financial burden on small-scale farmers and the complexity of meeting diverse regulatory requirements across different geographical regions further compound these challenges, making comprehensive mycotoxin management increasingly complex.

Emerging technologies

Modern mycotoxin detection is evolving through innovative technologies, including highly specific biosensors with aptamers and antibodies, accessible smartphone-based platforms, sensitive, rapid test kits, machine learning-driven automated analysis systems and portable spectroscopic devices, all aimed at improving detection accuracy and accessibility.

Microbial biocontrol represents a sustainable approach to mycotoxin management through the strategic use of non-toxigenic fungal strains, antagonistic *Bacillus* and *Pseudomonas* species, advanced formulations for enhanced efficacy, integrated control methods for synergistic effects and field-validated biocontrol agents, as supported by extensive research.

Gene-editing technologies, particularly CRISPR-Cas9, are transforming mycotoxin resistance in crops through targeted applications in developing resistant varieties, modifying mycotoxin biosynthesis pathways, enhancing plant defence mechanisms, creating fungal-resistant crops and ensuring safety through rigorous assessments, as demonstrated by recent research advances.

Future directions

By combining IoT-based environmental monitoring systems, modified atmosphere packaging, real-time sensor technologies for moisture and temperature control, blockchain-enabled supply chain traceability and automated intelligent warehousing systems, modern storage solutions are revolutionizing mycotoxin management and creating a more efficient and reliable storage ecosystem, bolstered by recent research advances. Producers, processors, regulatory agencies, the scientific community and consumers are responsible for maintaining a safe and high-quality spice supply. Contaminants like mycotoxins are inevitable and impossible to eradicate. However, effective monitoring programs and regulatory limits can significantly reduce the levels of mycotoxins in consumer products.

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Authors' contributions

SV and TM conceived the idea and wrote the manuscript. TM gave ideas and SV designed the diagrams and tables. SV and TM revised the manuscript. MJ, PV, KP, JH and KD finalized the manuscript. All authors read and approved the final manuscript.

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References

- Diniz do Nascimento L, Barbosa de Moraes AA, Santana da Costa K, Pereira Galúcio JM, Taube PS, Leal Costa CM, et al. Bioactive natural compounds and antioxidant activity of essential oils from spice plants: New findings and potential applications. *Biomolecules*. 2020;10(7):988. <https://doi.org/10.3390/biom10070988>
- Zareshahrabadi Z, Bahmyari R, Nouraei H, Khodadadi H, Mehryar P, Asadian F, Zomorodian K. Detection of aflatoxin and ochratoxin A in spices by high-performance liquid chromatography. *J Food Qual*. 2020;2020(1):8858889. <https://doi.org/10.1155/2020/8858889>
- Shityakov S, Bigdelian E, Hussein AA, Hussain MB, Tripathi YC, Khan MU, Shariati MA. Phytochemical and pharmacological attributes of piperine: A bioactive ingredient of black pepper. *European Journal of Medicinal Chemistry*. 2019;176:149-61. <https://doi.org/10.1016/j.ejmech.2019.04.002>
- Zhang J, Tang X, Cai Y, Zhou WW. Mycotoxin contamination status of cereals in China and potential microbial decontamination methods. *Metabolites*. 2023;13(4):551. <https://doi.org/10.3390/metabo13040551>
- Wang L, Su D, Yuan Q, Xiao C, Hu M, Guo L, et al. Simultaneous detection of multiple mycotoxins in *Radix Dipsaci* and estimation of exposure risk for consumers. *Sci Rep*. 2024;14(1):22762. <https://doi.org/10.1038/s41598-024-73597-0>
- Aiko V, Mehta A. Prevalence of toxigenic fungi in common medicinal herbs and spices in India. *3 Biotech*. 2016;6(2):159. <https://doi.org/10.1007/s13205-016-0476-9>
- Estiarte N, Crespo-Sempere A, Marín S, Ramos AJ, Worobo RW. Stability of alternariol and alternariol monomethyl ether during food processing of tomato products. *Food Chem*. 2018;245:951-57. <https://doi.org/10.1016/j.foodchem.2017.11.078>
- Al-Anati L, Petzinger E. Immunotoxic activity of ochratoxin A. *J Veter Pharma therape*. 2006;29(2):79-90. <https://doi.org/10.1111/j.1365-2885.2006.00718.x>
- El Darra N, Gambacorta L, Solfrizzo M. Multimycotoxins occurrence in spices and herbs commercialized in Lebanon. *Food Con*. 2019;95:63-70. <https://doi.org/10.1016/j.foodcont.2018.07.033>

10. Campos WE, Rosas LB, Neto AP, Mello RA, Vasconcelos AA. Extended validation of a sensitive and robust method for simultaneous quantification of aflatoxins B1, B2, G1 and G2 in Brazil nuts by HPLC-FLD. *J Food Comp Anal*. 2017;60:90-96. <https://doi.org/10.1016/j.jfca.2017.03.014>
11. Marchese S, Polo A, Ariano A, Velotto S, Costantini S, Severino L. Aflatoxin B1 and M1: Biological properties and their involvement in cancer development. *Toxins*. 2018;10(6):214. <https://doi.org/10.3390/toxins10060214>
12. Chuaysrinule C, Maneeboon T, Roopkham C, Mahakarnchanakul W. Occurrence of aflatoxin-and ochratoxin A-producing *Aspergillus* species in Thai dried chilli. *Journal of Agriculture and Food Research*. 2020;2:100054. <https://doi.org/10.1016/j.jafr.2020.100054>
13. Van Egmond HP, Jonker MA. Worldwide regulations for mycotoxins in food and feed in 2003. https://doi.org/10.2520/myco1975.2003.Suppl3_1
14. Kabak B, Dobson AD. Mycotoxins in spices and herbs-An update. *Critical reviews in food Science and Nutrition*. 2017;57(1):18-34. <https://doi.org/10.1080/10408398.2013.772891>
15. JM JJ, Zhang M, Thiruvengadam M. Determination of mycotoxins by HPLC, LC-ESI-MS/MS and MALDI-TOF MS in *Fusarium* species-infected sugarcane. *Microbial Pathogenesis*. 2018;123:98-110. <https://doi.org/10.1016/j.micpath.2018.06.045>
16. Beyene AM, Du X, Schunk DE, Ensley S, Rumbeih WK. High-performance liquid chromatography and Enzyme-Linked Immunosorbent Assay techniques for detection and quantification of aflatoxin B 1 in feed samples: A comparative study. *BMC Research Notes*. 2019;12:1-6. <https://doi.org/10.1186/s13104-019-4538-z>
17. Hendel E, Ramirez S, Gott P, Raj MG, Hofstetter U. PSII-22 trends in mycotoxin contamination in United States corn. *Journal of Animal Science*. 2020;98(Supplement_3):172-73. <https://doi.org/10.1093/jas/skaa054.306>
18. Tarazona A, Gómez JV, Mateo F, Jimenez M, Romera D, Mateo EM. Study on mycotoxin contamination of maize kernels in Spain. *Food Control*. 2020;118:107370. <https://doi.org/10.1016/j.foodcont.2020.107370>
19. Chen M, Qileng A, Liang H, Lei H, Liu W, Liu Y. Advances in immunoassay-based strategies for mycotoxin detection in food: From single-mode immunosensors to dual-mode immunosensors. *Comprehensive Reviews in Food Science and Food Safety*. 2023 Mar;22(2):1285-311. <https://doi.org/10.1111/1541-4337.13111>
20. Pickova D, Ostry V, Malir J, Toman J, Malir F. A review on mycotoxins and microfungi in spices in the light of the last five years. *Toxins*. 2020;12(12):789. <https://doi.org/10.3390/toxins12120789>
21. Gambacorta L, Magistà D, Perrone G, Murgolo S, Logrieco AF, Solfrizzo M. Co-occurrence of toxigenic moulds, aflatoxins, ochratoxin A, *Fusarium* and *Alternaria* mycotoxins in fresh sweet peppers (*Capsicum annuum*) and their processed products. *World Mycotoxin Journal*. 2018;11(1):159-74. <https://doi.org/10.3920/wmj2017.2271>
22. Khan MI, Asgher M, Khan NA. Alleviation of salt-induced photosynthesis and growth inhibition by salicylic acid involves glycinebetaine and ethylene in mungbean (*Vigna radiata* L.). *Plant Physiology and Biochemistry*. 2014;80:67-74. <https://doi.org/10.1016/j.plaphy.2014.03.026>
23. Singh P, Cotty PJ. Aflatoxin contamination of dried red chillies: Contrasts between the United States and Nigeria, two markets differing in regulation enforcement. *Food Control*. 2017;80:374-79. <https://doi.org/10.1016/j.foodcont.2017.05.014>
24. Mandeel QA. Fungal contamination of some imported spices. *Mycopathologia*. 2005;159:291-98. <https://doi.org/10.1007/s11046-004-5496-z>
25. Yogendrarajah P, Jaxsens L, De Saeger S, De Meulenaer B. Co-occurrence of multiple mycotoxins in dry chilli (*Capsicum annum* L.) samples from the markets of Sri Lanka and Belgium. *Food Control*. 2014;46:26-34. <https://doi.org/10.1016/j.foodcont.2014.04.043>
26. Agropedia. Area and production of chilli in world 2008-09. 2017 [updated 2024 Jun 23; cited 2024 Jun 30]. Available from: agropedia.iitk.ac.in
27. Vysali P, Subramanyam K, Kasi IK. A study on the management of biotic and abiotic threats in chilli crop cultivation. *Pharma Innovation Journal*. 2021;10(12):1741-48.
28. Thangiam B, Chanu WT, Mayanglambam B. Fungal diseases of chili and their management.
29. Rao PV, Gan SH. Cinnamon: a multifaceted medicinal plant. *Evidence-Based Complementary and Alternative Medicine*. 2014;2014(1):642942. <https://doi.org/10.1155/2014/642942>
30. Nabavi SF, Di Lorenzo A, Izadi M, Sobarzo-Sánchez E, Daglia M, Nabavi SM. Antibacterial effects of cinnamon: From farm to food, cosmetic and pharmaceutical industries. *Nutrients*. 2015;7(9):7729-48. <https://doi.org/10.3390/nu7095359>
31. Jeswal P, Kumar D. Natural occurrence of toxigenic mycoflora and ochratoxin A and aflatoxins in commonly used spices from Bihar state (India). *Journal of Environmental Science Toxicology and Food Technology*. 2015;9(2):50-55. <https://doi.org/10.1155/2015/242486>
32. Garcia MV, Parussolo G, Moro CB, Bernardi AO, Copetti MV. Fungi in spices and mycotoxigenic potential of some *Aspergilli* isolated. *Food Microbiology*. 2018;73:93-98. <https://doi.org/10.1016/j.fm.2018.01.013>
33. Nurtjahja K, Zuhra CF, Sembiring H, Bungsu A, Simanullang J, Silalahi JE, et al. Fungal contamination spices from Indonesia with emphasis on *Aspergillus flavus*. *Czech Journal of Food Sciences*. 2019;37(5). <https://doi.org/10.17221/18/2019-CJFS>
34. Temu TB, Masenga G, Obure J, Mosha D, Mahande MJ. Maternal and obstetric risk factors associated with preterm delivery at a referral hospital in northern-eastern Tanzania. *Asian Pacific Journal of Reproduction*. 2016;5(5):365-70. <https://doi.org/10.1016/j.apjr.2016.07.009>
35. Zafar S, Khan MK, Perveen S, Iqbal M, AL-Huqail AA. In: Zia-Ul-Haq M, AL-Huqail AA, Riaz M, Gohar UF, editors. *Essentials of medicinal and aromatic crops*. Cham: Springer International Publishing; 2023. p. 483-514 https://doi.org/10.1007/978-3-031-35403-8_19
36. Zinedine A, Soriano JM, Juan C, Mojemmi B, Molto JC, Bouklouze A, et al. Incidence of ochratoxin A in rice and dried fruits from Rabat and Salé area, Morocco. *Food Additives and Contaminants*. 2007;24(3):285-91. <https://doi.org/10.1080/02652030600967230>
37. Bircan C. The determination of aflatoxins in spices by immunoaffinity column extraction using HPLC. *International Journal of Food Science and Technology*. 2005;40(9):929-34. <https://doi.org/10.1111/j.1365-2621.2005.01025.x>
38. Syamilah N, Nurul AS, Effarizah ME, Norlia M. Mycotoxins and mycotoxigenic fungi in spices and mixed spices: A review. *Food Res*. 2022;6:30-46. [https://doi.org/10.26656/fr.2017.6\(4\).971](https://doi.org/10.26656/fr.2017.6(4).971)
39. Duarte SC, Pena A, Lino CM. Human ochratoxin A biomarkers-From exposure to effect. *Critical Reviews in Toxicology*. 2011;41(3):187-212. <https://doi.org/10.3109/10408444.2010.529103>
40. Benkerroum N. Chronic and acute toxicities of aflatoxins: Mechanisms of action. *International Journal of Environmental Research and Public Health*. 2020;17(2):423. <https://doi.org/10.3390/ijerph17020423>
41. Richard JL. Some major mycotoxins and their mycotoxicoses-An overview. *International Journal of Food Microbiology*. 2007;119(1-2):3-10. <https://doi.org/10.1016/j.jfoodmicro.2007.07.019>
42. Steyn PS. Mycotoxins, general view, chemistry and structure. *Toxicology Letters*. 1995;82:843-51. [https://doi.org/10.1016/0378-4274\(95\)03525-7](https://doi.org/10.1016/0378-4274(95)03525-7)
43. Turner NW, Subrahmanyam S, Piletsky SA. Analytical methods for determination of mycotoxins: a review. *Analytica Chimica Acta*. 2009;632(2):168-80. <https://doi.org/10.1016/j.aca.2008.11.010>
44. Kumar A, Rana R, Saklani R, Kumar M, Yadav PK, Tiwari A, Chourasia MK. Technology transfer of a validated RP-HPLC method for the simultaneous estimation of andrographolide and paclitaxel in application to pharmaceutical nanoformulation. *Journal of Chromatographic Science*. 2024;62(4):356-63. <https://doi.org/10.1093/chromsci/bmad070>

45. Mahato DK, Devi S, Pandhi S, Sharma B, Maurya KK, Mishra S, et al. Occurrence, impact on agriculture, human health and management strategies of zearalenone in food and feed: A review. *Toxins*. 2021;13(2):92. <https://doi.org/10.3390/toxins13020092>
46. Rheeder JP, Marasas WF, Vismer HF. Production of fumonisin analogs by *Fusarium* species. *Applied and Environmental Microbiology*. 2002;68(5):2101-05. <https://doi.org/10.1128/AEM.68.5.2101-2105.2002>
47. Qu L, Wang L, Ji H, Fang Y, Lei P, Zhang X, et al. Toxic mechanism and biological detoxification of fumonisins. *Toxins*. 2022;14(3):182. <https://doi.org/10.3390/toxins14030182>
48. Afsah-Hejri L, Jinap S, Hajeb P, Radu S, Shakibzadeh SH. A review on mycotoxins in food and feed: Malaysia case study. *Comprehensive Reviews in Food Science and Food Safety*. 2013;12(6):629-51. <https://doi.org/10.1111/1541-4337.12029>
49. Balló A, Busznyákné SK, Czétány P, Márk L, Török A, Szántó Á, Máté G. Estrogenic and non-estrogenic disruptor effect of zearalenone on male reproduction: a review. *International Journal of Molecular Sciences*. 2023;24(2):1578. <https://doi.org/10.3390/ijms24021578>
50. Silva LJ, Pereira AM, Pena A, Lino CM. Citrinin in foods and supplements: A review of occurrence and analytical methodologies. *Foods*. 2020;10(1):14. <https://doi.org/10.3390/foods10010014>
51. Alshannaq A, Yu JH. Occurrence, toxicity and analysis of major mycotoxins in food. *Inter J Environ Res Public Health*. 2017;14(6):632. <https://doi.org/10.3390/ijerph14060632>
52. Li Y, Wang Y, Jiang Z, Yang C, Wu Y, Wu A, et al. Apoptosis mediated by crosstalk between mitochondria and endoplasmic reticulum: A possible cause of citrinin disruption of the intestinal barrier. *Ecotoxicology and Environmental Safety*. 2024;284:116877. <https://doi.org/10.1016/j.ecoenv.2024.116877>
53. Bottalico A, Perrone G. Toxigenic *Fusarium* species and mycotoxins associated with head blight in small-grain cereals in Europe: mycotoxins in plant disease: under the aegis of COST Action 835 'agriculturally important toxigenic fungi 1998-2003. EU project (QLK1-CT-1998-01380) and ISPP' *Fusarium* Committee'. 2002:611-24. https://doi.org/10.1007/978-94-010-0001-7_2
54. Beal MA, Habauzit D, Khoury L, Audebert M. Human next-generation risk assessment of trichothecene toxicity. *Food and Chemical Toxicology*. 2024;192:114916. <https://doi.org/10.1016/j.fct.2024.114916>
55. Ali N, Hashim NH, Shuib NS. Natural occurrence of aflatoxins and ochratoxin A in processed spices marketed in Malaysia. *Food Additives and Contaminants: Part A*. 2015;32(4):518-32. <https://doi.org/10.1080/19440049.2015.1011712>
56. Martinez-Miranda MM, Rosero-Moreano M, Taborda-Ocampo G. Occurrence, dietary exposure and risk assessment of aflatoxins in arepa, bread and rice. *Food Control*. 2019;98:359-66. <https://doi.org/10.1016/j.foodcont.2018.11.046>
57. Payne GA, Brown MP. Genetics and physiology of aflatoxin biosynthesis. *Annual Review of Phytopathology*. 1998;36(1):329-62. <https://doi.org/10.1146/annurev.phyto.36.1.329>
58. Abbas H, Zablotowicz R, Bruns H. Modelling the colonization of maize by toxigenic and non-toxigenic *Aspergillus flavus* strains: implications for biological control. *World Mycotoxin Journal*. 2008;1(3):333-40. <https://doi.org/10.3920/WMJ2008.x036>
59. Hell K, Cardwell KF, Setamou M, Poehling HM. The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *Journal of Stored Products Research*. 2000;36(4):365-82. [https://doi.org/10.1016/S0022-474X\(99\)00056-9](https://doi.org/10.1016/S0022-474X(99)00056-9)
60. Wei Y, Yin X, Zhao M, Zhang J, Li T, Zhang Y, et al. Metabolomics analysis reveals the mechanism underlying the improvement in the color and taste of yellow tea after optimized yellowing. *Food Chemistry*. 2023;428:136785. <https://doi.org/10.1016/j.foodchem.2023.136785>
61. Nguégwouo E, Sone LE, Tchuenchieu A, Tene HM, Mounchigam E, Njajou NF, Nama GM. Ochratoxin A in black pepper, white pepper and clove sold in Yaoundé (Cameroon) markets: contamination levels and consumers' practices increasing health risk. *International Journal of Food Contamination*. 2018;5:1-7. <https://doi.org/10.1186/s40550-017-0063-9>
62. Bhatnagar D, Yu J, Ehrlich KC. Toxins of filamentous fungi. *Fungal Allergy and Pathogenicity*. 2002;81:167-206. <https://doi.org/10.1159/000058867>
63. Desjardins AE. *Fusarium* mycotoxins: chemistry, genetics and biology; APS Press: St. Paul, MN, USA; 2006.
64. Logrieco A, Visconti A. An overview on toxigenic fungi and mycotoxins in Europe; Springer: New York, NY, USA; 2004. <https://doi.org/10.1007/978-1-4020-2646-1>
65. Medina Á, Valle-Algarra FM, Mateo R, Gimeno-Adelantado JV, Mateo F, Jiménez M. Survey of the mycobiota of spanish malting barley and evaluation of the mycotoxin producing potential of species of *Alternaria*, *Aspergillus* and *Fusarium*. *International Journal of Food Microbiology*. 2006;108(2):196-203. <https://doi.org/10.1016/j.ijfoodmicro.2005.12.003>
66. Kong W, Xie T, Li J, Wei J, Qiu F, Qi A, et al. Analysis of fumonisins B1 and B2 in spices and aromatic and medicinal herbs by HPLC-FLD with on-line post-column derivatization and positive confirmation by LC-MS/MS. *Analyst*. 2012;137(13):3166-74. <https://doi.org/10.1039/c2an35164a>
67. Waśkiewicz A, Beszterda M, Bocianowski J, Goliński P. Natural occurrence of fumonisins and ochratoxin A in some herbs and spices commercialized in Poland analyzed by UPLC-MS/MS method. *Food Microbiology*. 2013;36(2):426-31. <https://doi.org/10.1016/j.fm.2013.07.006>
68. Yazar S, Omurtag GZ. Fumonisin, trichothecenes and zearalenone in cereals. *International Journal of Molecular Sciences*. 2008;9(11):2062-90. <https://doi.org/10.3390/ijms9112062>
69. Glenn AE. Mycotoxigenic *Fusarium* species in animal feed. *Animal Feed Science and Technology*. 2007;137(3-4):213-40. <https://doi.org/10.1016/j.anifeeds.2007.06.003>
70. Liu X, Guan X, Xing F, Lv C, Dai X, Liu Y. Effect of water activity and temperature on the growth of *Aspergillus flavus*, the expression of aflatoxin biosynthetic genes and aflatoxin production in shelled peanuts. *Food Control* 2017;82:325-32. <https://doi.org/10.1016/j.foodcont.2017.07.012>
71. Abdel-Hadi A, Schmidt-Heydt M, Parra R, Geisen R, Magan N. A systems approach to model the relationship between aflatoxin gene cluster expression, environmental factors, growth and toxin production by *Aspergillus flavus*. *J R Soc Interface*. 2012;9:757-67. <https://doi.org/10.1098/rsif.2011.0482>
72. Bernáldez V, Córdoba JJ, Magan N, Peromingo B, Rodríguez A. The influence of ecophysiological factors on growth, aflR gene expression and aflatoxin B1 production by a type of strain of *Aspergillus flavus*. *LWT Food Sci Technol*. 2017;83:283-91. <https://doi.org/10.1016/j.lwt.2017.05.030>
73. Tejero P, Martín A, Rodríguez A, Galván AI, Ruiz-Moyano S, Hernández A. *In vitro* biological control of *Aspergillus flavus* by *Hanseniaspora opuntiae* L479 and *Hanseniaspora uvarum* L793, producers of antifungal volatile organic compounds. *Toxins*. 2021;13:663. <https://doi.org/10.3390/toxins13090663>
74. Bhatnagar D, Cary JW, Ehrlich K, Yu J, Cleveland TE. Understanding the genetics of regulation of aflatoxin production and *Aspergillus flavus* development. *Mycopathologia*. 2006;162:155. <https://doi.org/10.1007/s11046-006-0050-9>
75. Thanushree MP, Sailendri D, Yoha KS, Moses JA, Anandharamakrishnan C. Mycotoxin contamination in food: An exposition on spices. *Trends in Food Science and Technology*. 2019;93:69-80. <https://doi.org/10.1016/j.tifs.2019.08.010>
76. Kumar V, Basu MS, Rajendran TP. Mycotoxin research and mycoflora in some commercially important agricultural commodities. *Crop Protection*. 2008 Jun 1;27(6):891-905. <https://doi.org/10.1016/j.cropro.2007.12.011>

77. Rodríguez EC, Fiueroa IP, Mercado CAR. Feasibility analysis of drying process habanero chili using a hybrid-solar-fluidized bed dryer in Yucatan Mexico. *J Energy Power Eng*. 2013;7:1898-1908.
78. Yu Q, Romagnoli A, Al-Duri B, Xie D, Ding Y, Li Y. Heat storage performance analysis and parameter design for encapsulated phase change materials. *Energy Conversion and Management*. 2018 Feb 1;157:619-30. <https://doi.org/10.1016/j.enconman.2017.12.040>
79. Hammami W, Fiori S, Al Thani R, Kali NA, Balmas V, Migheli Q, Jaoua S. Fungal and aflatoxin contamination of marketed spices. *Food Control*. 2014;37:177-81. <https://doi.org/10.1016/j.foodcont.2013.09.027>
80. Pakshir K, Farazmand F, Ghasemi F, Mirhendi H, Zomorodian K, Kharazi M, et al. Translation elongation factor 1-alpha gene as a marker for diagnosing of candidal onychomycosis. *Current Medical Mycology*. 2020;6(1):15. <https://doi.org/10.18502/cmm.6.1.2503>
81. Pitt JI, Hocking AD. *Fungi and food spoilage*. Springer United States; 2009. <https://doi.org/10.1007/978-0-387-92207-2>
82. Yogendrarajah P, Deschuyffeleer N, Jaxsens L, Sneyers PJ, Maene P, De Saeger S, et al. Mycological quality and mycotoxin contamination of Sri Lankan peppers (*Piper nigrum* L.) and subsequent exposure assessment. *Food Control*. 2014;41:219-30. <https://doi.org/10.1016/j.foodcont.2014.01.025>
83. Vyhnánek T, Hanáček P, Šafránková I, Djordjević B, Beranová H, Trojan V, Havel L. Molecular detection of fungi in paprika, chili powder and black pepper. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*. 2018. <https://doi.org/10.11118/actaun201866040927>
84. Reddy KR, Salleh B, Saad B, Abbas HK, Abel CA, Shier WT. An overview of mycotoxin contamination in foods and its implications for human health. *Toxin Reviews*. 2010;29(1):3-26. <https://doi.org/10.3109/15569541003598553>
85. Singh P, Cotty PJ. Characterization of *Aspergilli* from dried red chilies (*Capsicum spp.*): insights into the etiology of aflatoxin contamination. *International Journal of Food Microbiology*. 2019;289:145-53. <https://doi.org/10.1016/j.ijfoodmicro.2018.08.025>
86. Adetunji MC, Aroyeun SO, Osho MB, Sulyok M, Krska R, Mwanza M. Fungal metabolite and mycotoxins profile of cashew nut from selected locations in two African countries. *Food Additives and Contaminants Part A*. 2019;36(12):1847-59. <https://doi.org/10.1080/19440049.2019.1662951>
87. Pardo E, Marin S, Ramos AJ, Sanchis V. Ecophysiology of ochratoxigenic *Aspergillus ochraceus* and *Penicillium verrucosum* isolates. Predictive models for fungal spoilage prevention—a review. *Food Additives and Contaminants*. 2006;23(4):398-410. <https://doi.org/10.1080/02652030500376102>
88. Kompas T, Pham VH, Che TN. The effects of climate change on GDP by country and the global economic gains from complying with the Paris climate accord. *Earths Future*. 2018;6:1153-73. <https://doi.org/10.1029/2018EF000922>
89. Bhat R, Rai RV, Karim AA. Mycotoxins in food and feed: Present status and future concerns. *Comp Rev Food Sci Food Saf*. 2010;9:57-81. <https://doi.org/10.1111/j.1541-4337.2009.00094.x>
90. Kricher JC. *Tropical ecology*. Princeton University Press; 2011 Feb 28.
91. Prakash V. *Spices: Leafy spices*. CRC Press; 2019. <https://doi.org/10.1201/9781351073967>
92. García-López MT. Biocontrol agents to reduce aflatoxins in nuts: inoculum dynamic studies, varietal resistance to the pathogen and characterization of the population of *Aspergillus* spp. section Flavi in Spain. PhD [dissertation]. Cordoba: University of Cordoba; 2022. Available from: <https://helvia.uco.es/bitstream/handle/10396/24032/2022000002556.pdf?sequence=1&isAllowed=y>
93. Barac A. Mycotoxins and human disease. Clinically relevant mycoses: a practical approach. 2019;213-25. https://doi.org/10.1007/978-3-319-92300-0_14
94. Khodaei D, Javanmardi F, Khaneghah AM. The global overview of the occurrence of mycotoxins in cereals: A three-year survey. *Current Opinion in Food Science*. 2021;39:36-42. <https://doi.org/10.1016/j.cofs.2020.12.012>
95. Tanaka K, Sago Y, Zheng Y, Nakagawa H, Kushiro M. Mycotoxins in rice. *International Journal of Food Microbiology*. 2007;119(1-2):59-66. <https://doi.org/10.1016/j.ijfoodmicro.2007.08.002>
96. Kumar P, Kamle M, Mahato DK, editors. *Mycotoxins in food and feed: detection and management strategies*. CRC Press; 2023. <https://doi.org/10.1201/9781003242208>
97. Jačević V, Dumanović J, Alomar SY, Resanović R, Milovanović Z, Nepovimova E, et al. Research update on aflatoxins toxicity, metabolism, distribution and detection: A concise overview. *Toxicology*. 2023;492:153549. <https://doi.org/10.1016/j.tox.2023.153549>
98. Martins IJ. Overnutrition determines LPS regulation of mycotoxin induced neurotoxicity in neurodegenerative diseases. *International Journal of Molecular Sciences*. 2015;16(12):29554-73. <https://doi.org/10.3390/ijms161226190>
99. Zhang K, Schaab MR, Southwood G, Tor ER, Aston LS, Song W, et al. A collaborative study: Determination of mycotoxins in corn, peanut butter and wheat flour using stable isotope dilution assay (SIDA) and liquid chromatography–tandem mass spectrometry (LC-MS/MS). *Journal of Agricultural and Food Chemistry*. 2017 Aug 23;65(33):7138-52. <https://doi.org/10.1021/acs.jafc.6b04872>
100. Jiang YI, Jolly PE, Ellis WO, Wang JS, Phillips TD, Williams JH. Aflatoxin B1 albumin adduct levels and cellular immune status in Ghanaians. *International Immunology*. 2005;17(6):807-14. <https://doi.org/10.1093/intimm/dxh262>
101. Rodríguez-Vargas A, Franco-Vásquez AM, Triana-Cerón M, Alam-Rojas SN, Escobar-Wilches DC, Corzo G, et al. Immunological cross-reactivity and preclinical assessment of a colombian anticorall antivenom against the venoms of three *Micrurus* species. *Toxins*. 2024;16(2):104. <https://doi.org/10.3390/toxins16020104>
102. Janik E, Niemcewicz M, Podogrocki M, Ceremuga M, Gorniak L, Stela M, Bijak M. The existing methods and novel approaches in mycotoxins' detection. *Molecules*. 2021;26(13):3981. <https://doi.org/10.3390/molecules26133981>
103. Zhang L, Dou XW, Zhang C, Logrieco AF, Yang MH. A review of current methods for analysis of mycotoxins in herbal medicines. *Toxins*. 2018;10(2):65. <https://doi.org/10.3390/toxins10020065>
104. Gurav NP, Medhe S. Analysis of aflatoxins B1, B2, G1 and G2 in peanuts: validation study. *Analytical Chemistry An Indian Journal*. 2018;17(2):126.
105. Miklós G, Angeli C, Ambrus Á, Nagy A, Kardos V, Zentai A, et al. Detection of aflatoxins in different matrices and food-chain positions. *Frontiers in Microbiology*. 2020;11:1916. <https://doi.org/10.3389/fmicb.2020.01916>
106. Malachová A, Stránská M, Václavíková M, Elliott CT, Black C, Meneely J, et al. Advanced LC–MS-based methods to study the co-occurrence and metabolism of multiple mycotoxins in cereals and cereal-based food. *Analytical and Bioanalytical Chemistry*. 2018;410:801-25. <https://doi.org/10.1007/s00216-017-0750-7>
107. Pascale M, De Girolamo A, Lippolis V, Stroka J, Mol HG, Lattanzio VM. Performance evaluation of LC-MS methods for multimycotoxin determination. *Journal of AOAC International*. 2019;102(6):1708-20. <https://doi.org/10.5740/jaoacint.19-0068>
108. Dongare MV, Kohale NB, Rathod SB. A review of chromatograph: Principal, classification, application. *Int J Humanit Soc Sci Manag*. 2023;3(2):367-73.
109. Kumar P, Mahato DK, Gupta A, Pandey S, Paul V, Saurabh V, et al. Nivalenol mycotoxin concerns in foods: an overview on occurrence, impact on human and animal health and its detection and management strategies. *Toxins*. 2022;14(8):527. <https://doi.org/10.3390/toxins14080527>

110. Agriopoulou S, Stamatelopoulou E, Varzakas T. Advances in analysis and detection of major mycotoxins in foods. *Foods*. 2020;9(4):518. <https://doi.org/10.3390/foods9040518>
111. Mehta M. A comparative qualitative and quantitative estimation of catechin by HPTLC in Arjunarishta—an ayurvedic formulation. *IJRAR*. 2020;7(2):112-19.
112. Adebo OA, Njobeh PB, Adebisi JA, Kayitesi E. 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 Bioscience*. 2018;25:118-27. <https://doi.org/10.1016/j.fbio.2018.08.007>
113. Gbashi S, Madala NE, De Saeger S, De Boevre M, Njobeh PB. Numerical optimization of temperature-time degradation of multiple mycotoxins. *Food and Chemical Toxicology*. 2019;125:289-304. <https://doi.org/10.1016/j.fct.2019.01.009>
114. Lin L, Zhang J, Wang P, Wang Y, Chen J. Thin-layer chromatography of mycotoxins and comparison with other chromatographic methods. *Journal of Chromatography A*. 1998 Jul 31;815(1):3-20. [https://doi.org/10.1016/S0021-9673\(98\)00204-0](https://doi.org/10.1016/S0021-9673(98)00204-0)
115. Shephard GS, Sydenham EW, Thiel PG, Gelderblom WCA. Quantitative determination of fumonisins B₁ and B₂ by high-performance liquid chromatography with fluorescence detection. *Journal of Liquid Chromatography*. 1990;13(10):2077-87. <https://doi.org/10.1080/01483919008049014>
116. Trucksess MW, Stack ME, Nesheim S, Albert RH, Romer TR. Multifunctional column coupled with liquid chromatography for determination of aflatoxins B₁, B₂, G₁ and G₂ in corn, almonds, brazil nuts, peanuts and pistachio nuts: collaborative study. *Journal of AOAC International*. 1994;77(6):1512-21. <https://doi.org/10.1093/jaoac/77.6.1512>
117. Rahmani A, Jinap S, Khatib A, Tan CP. Simultaneous determination of aflatoxins, ochratoxin A and zearalenone in cereals using a validated RP-HPLC method and PHRED derivatization system. *Journal of Liquid Chromatography and Related Technologies*. 2013;36(5):600-17. <https://doi.org/10.1080/10826076.2012.670182>
118. Wang Y, Xing L, Zhang J, Ma X, Weng R. Determination of endogenous phenolic compounds in honey by HPLC-MS/MS. *LWT*. 2023;183:114951. <https://doi.org/10.1016/j.lwt.2023.114951>
119. Lu Q, Guo MY, Tian J, Luo JY, Yang MH. A comprehensive study on multi-mycotoxin screening, changes of mycotoxin residues and fungal community analysis from barley germination to malt. *International Journal of Food Microbiology*. 2022;372:109678. <https://doi.org/10.1016/j.jfoodmicro.2022.109678>
120. Andersson JA, Andersson CA, Frandsen RJ. Applying parallel factor analysis models to HPLC diode array detector datasets reveals strain dependent relation of polyketide biosynthesis in *Fusarium graminearum*, *Fusarium culmorum* and *Fusarium pseudograminearum*. *Analytica Chimica Acta*. 2009;647(2):243-48. <https://doi.org/10.1016/j.aca.2009.06.025>
121. Soleimany F, Jinap S, Abas FJ. Determination of mycotoxins in cereals by liquid chromatography tandem mass spectrometry. *Food Chemistry*. 2012;130(4):1055-60. <https://doi.org/10.1016/j.foodchem.2011.07.131>
122. Kunz BM, Wanko F, Kemmlein S, Bahlmann A, Rohn S, Maul R. 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*. 2020;109:106949. <https://doi.org/10.1016/j.foodcont.2019.106949>
123. Zhao X, Wang S, Wu Q, et al. Development of a multi-mycotoxin detection method based on LC-MS/MS and its application in fungal-contaminated food samples. *Food Control*. 2017.
124. Rodríguez-Carrasco Y, Moltó JC, Mañes J, Berrada H. Development of microextraction techniques in combination with GC-MS/MS for the determination of mycotoxins and metabolites in human urine. *Journal of Separation Science*. 2017;40(7):1572-82. <https://doi.org/10.1002/jssc.201601131>
125. Anfossi C, Giovannoli L, Baggiani C. Mycotoxin detection. *Curr Opin Biotechnol*. 2016;37:120-26. <https://doi.org/10.1016/j.copbio.2015.11.005>
126. Sulyok M, Krska R, Schuhmacher R. Application of an LC-MS/MS based multi-mycotoxin method for the semi-quantitative determination of mycotoxins occurring in different types of food infected by moulds. *Food Chemistry*. 2010;119(1):408-16. <https://doi.org/10.1016/j.foodchem.2009.07.042>
127. Ren Y, Zhang Y, Shao S, Cai Z, Feng L, Pan H, Wang Z. Simultaneous determination of multi-component mycotoxin contaminants in foods and feeds by ultra-performance liquid chromatography-tandem mass spectrometry. *J Chromatogr A*. 2007;1143(1-2):48-64. <https://doi.org/10.1016/j.chroma.2006.12.064>
128. Younis MR, Wang C, Younis MA, Xia XH. Use of biosensors for mycotoxins analysis in foodstuff. *Nanobiosensors: From Design to Applications*. 2020:171-201. <https://doi.org/10.1002/9783527345137.ch8>
129. Melinte G, Hosu O, Cristea C, Marrazza G. DNA sensing technology a useful food scanning tool. *TrAC Trends in Analytical Chemistry*. 2022;154:116679. <https://doi.org/10.1016/j.trac.2022.116679>
130. Ottoboni M, Pinotti L, Tretola M, Giromini C, Fusi E, Rebucci R, et al. Combining E-nose and lateral flow immunoassays (LFIs) for rapid occurrence/co-occurrence aflatoxin and fumonisin detection in maize. *Toxins*. 2018;10(10):416. <https://doi.org/10.3390/toxins10100416>
131. Lippolis V, Cervellieri S, Damascelli A, Pascale M, Di Gioia A, Longobardi F, De Girolamo A. Rapid prediction of deoxynivalenol contamination in wheat bran by MOS-based electronic nose and characterization of the relevant pattern of volatile compounds. *Journal of the Science of Food and Agriculture*. 2018;98(13):4955-62. <https://doi.org/10.1002/jsfa.9028>
132. Xia X, Wang H, Yang H, Deng S, Deng R, Dong Y, He Q. 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*. 2018;66(46):12431-38. <https://doi.org/10.1021/acs.jafc.8b05217>
133. Zhu Y, Xia X, Deng S, Yan B, Dong Y, Zhang K, et al. Label-free fluorescent autosensing of mycotoxins via aggregation-induced emission dye. *Dyes and Pigments*. 2019;170:107572. <https://doi.org/10.1016/j.dyepig.2019.107572>
134. González-Jartín JM, de Castro Alves L, Piñeiro Y, Alfonso A, Alvarinho R, Gomez MG, et al. Magnetic nanostructured agents for the mitigation of mycotoxins and cyanotoxins in the food chain. *Food Chemistry*. 2024;140004. <https://doi.org/10.1016/j.foodchem.2024.140004>
135. Guidance for industry: Action levels for poisonous or deleterious substances in human food and animal feed. FDA. (accessed on 28 Aug 2022). Available online: <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-action-levels-poisonous-or-deleterious-substances-human-food-and-animal-feed>
136. EUR-Lex-32006R1881-EN-EUR-Lex. (accessed on 27 Aug 2022) Available online: <https://eur-lex.europa.eu/eli/reg/2006/1881/oj>
137. Chen Y, Meng X, Zhu Y, Shen M, Lu Y, Cheng J, Xu Y. Rapid detection of four mycotoxins in corn using a microfluidics and microarray-based immunoassay system. *Talanta*. 2018;186:299-305. <https://doi.org/10.1016/j.talanta.2018.04.064>
138. Commission Regulation (EU). 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006. *Off J Eur Union*. 2023;119:103-57.
139. Iha MH, Trucksess MW. Management of mycotoxins in spices. *Journal of AOAC International*. 2019;102(6):1732-39. <https://doi.org/10.5740/jaoacint.19-0117>
140. Moses JA, Alagusundaram K, Kavitha CV. Curing and drying of cardamom. *Processed Food Industry*. 2014;10:21-28.
141. Kamle M, Mahato DK, Devi S, Lee KE, Kang SG, Kumar P. Fumonisin: Impact on agriculture, food and human health and their management strategies. *Toxins*. 2019;11(6):328. <https://doi.org/10.3390/toxins11060328>

142. Sharma G, Shrestha S, Kunwar S, Tseng TM. Crop diversification for improved weed management: A review. *Agriculture*. 2021;11(5):461. <https://doi.org/10.3390/agriculture11050461>
143. Gupta N, Mahajan M, Jawandha SJ. Influence of pre-harvest spray of putrescine on postharvest quality of indian jujube. *Indian Journal of Horticulture*. 2022;79(3):305-10. <https://doi.org/10.5958/0974-0112.2022.00041.X>
144. Ansari MW, Tuteja N. Postharvest quality risks by stress/ethylene: management to mitigate. *Protoplasma*. 2015;252:21-32. <https://doi.org/10.1007/s00709-014-0678-0>
145. Sultana B, Naseer R, Nigam P. Utilization of agro-wastes to inhibit aflatoxins synthesis by *Aspergillus parasiticus*: A biotreatment of three cereals for safe long-term storage. *Bioresource Technology*. 2015;197:443-50. <https://doi.org/10.1016/j.biortech.2015.08.113>
146. Pandey P, Lejeune M, Biswas S, Morash D, Weimer B, Young G. A new method for converting food waste into pathogen free soil amendment for enhancing agricultural sustainability. *Journal of Cleaner Production*. 2016;112:205-13. <https://doi.org/10.1016/j.jclepro.2015.09.045>
147. Tang X. Integrated approaches to managing *Fusarium* and other fungal pathogens in maize. *Molecular Pathogens*. 2024;15. <https://doi.org/10.5376/mp.2024.15.0010>
148. Atehnkeng J, Donner M, Ojiambo PS, Ikotun B, Augusto J, Cotty PJ, Bandyopadhyay R. Environmental distribution and genetic diversity of vegetative compatibility groups determine biocontrol strategies to mitigate aflatoxin contamination of maize by *Aspergillus flavus*. *Microbial Biotechnology*. 2016;9(1):75-88. <https://doi.org/10.1111/1751-7915.12324>
149. Santos L, Marín S, Sanchis V, Ramos AJ. *In vitro* effect of some fungicides on growth and aflatoxins production by *Aspergillus flavus* isolated from *Capsicum* powder. *Food Add Cont: Part A*. 2011;28(1):98-106. <https://doi.org/10.1080/19440049.2010.529622>
150. Sudha S, Naik MK, Ajithkumar K. An integrated approach for the reduction of aflatoxin contamination in chilli (*Capsicum annuum* L.). *J Food Sci Techno*. 2013;50:159-64. <https://doi.org/10.1007/s13197-011-0471-4>
151. Karaaslan M, Arslanğray Y. Aflatoxins B₁, B₂, G₁ and G₂ contamination in ground red peppers commercialized in Sanliurfa, Turkey. *Environ Monitoring Assess*. 2015;187:1-9. <https://doi.org/10.1007/s10661-015-4402-0>
152. Iqbal Q, Amjad M, Asi MR, Arino A. Assessment of hot peppers for aflatoxin and mold proliferation during storage. *J Food Protect*. 2011;74(5):830-35. <https://doi.org/10.4315/0362-028X.JFP-10-449>
153. Mir SA, Dar BN, Shah MA, Sofi SA, Hamdani AM, Oliveira CA, et al. Application of new technologies in decontamination of mycotoxins in cereal grains: challenges and perspectives. *Food Chem Toxicol*. 2021;148:111976. <https://doi.org/10.1016/j.fct.2021.111976>
154. Imre L. Solar drying. In: Mujumdar AS, editor. *Handbook of industrial drying*. CRC Press, Taylor and Francis Group, Florida; 2007. p. 307-61. <https://doi.org/10.1201/9781420017618.ch13>
155. Imre L. Solar driers. In: Baker L, editor. *Industrial drying of food*. Blackie Academic and Professional, London;1997. pp. 210-38.
156. Murthy MVR. A review of new technologies, models and experimental investigations of solar driers. *Renewable and Sustainable Energy Reviews*. 2009;13(4):835-44. <https://doi.org/10.1016/j.rser.2008.02.010>