Review Article

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AN OVERVIEW OF MYCOTOXIN IN CEREALS

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ABSTRACT

Mycotoxins pose an increasing threat to cereal grain production, processing, marketing, and storage. These toxic substances, produced by various fungal species, can cause significant damage to small grains. Mycotoxin contamination in cereals leads to economic losses at multiple stages, including crop production, distribution, processing, and animal feed production. Human consumption of these contaminated grains can result in a range of health issues, such as nausea, vomiting, diarrhea, abdominal pain, aflatoxicosis, liver toxicity, bloody stools, weight loss, weakened immunity, and kidney damage. Several methods have been developed to detect mycotoxin levels, including chromatographic and immunochemical techniques. Cereal grains such as rice, wheat, maize, barley, oats, rye, and sorghum are susceptible to mycotoxin contamination. Effective management practices, such as proper field preparation, crop rotation, timely fungicide application, accurate sowing schedules, weeding, and careful handling during harvest, drying, and storage, can help reduce mycotoxin production and benefit the processing industry.

Keywords: Mycotoxin, Cereal, DON, ZEN, *Fusarium*, Aflatoxin, *Aspergillus*

INTRODUCTION

Whole grains, or cereals in their original state, are a great source of protein, lipids, oils, carbs, vitamins, and minerals. According to estimates, mycotoxin contamination may affect as much as 25% of the world's food and feed crops (Hamad *et al.* 2015). Mycotoxins not only pose health dangers but also negatively impact wheat quality and processing efficiency (Fedorica *et al*. 2017). Maize was found to have a high prevalence of 37% and a high level of aflatoxin contamination (280 ug/kg) (Manna and Kim 2017a). Aflatoxin was not found to be prevalent in Bangladeshi wheat or rice. Additionally, it was discovered that the three samples—rice, wheat, and maize—collected in July had a high occurrence rate of mycotoxin occurrence and a high moisture content (Bhuiyan *et al*. 2013). Depending on the crop type, geographic location, and environmental factors, different *Fusarium* species can infect maize and small grain cereals including wheat, barley, and oats (Logrieco *et al.* 2018).

Fusarium toxins, including deoxynivalenol (DON), zearalenone (ZEN), and various trichothecenes, are secondary metabolites produced by *Fusarium* species during growth and storage. A study by Li *et al.* (2015) found that ZEN was the most prevalent toxin in 76 cereal and oil product samples from China's Yangtze Delta, detected in 27.6% of samples—9.2% exceeding the legal limit.

These mycotoxins can cause acute and chronic toxicity in humans and animals (Figure 1), with *Fusarium* outbreaks reported in numerous countries, including Europe, Asia, Africa, New Zealand, and South America (Marin *et al*. 2013). *Fusarium* head blight (FHB) in small-grain cereals is linked to 17 *Fusarium* species, with *Fusarium graminearum* and *Fusarium poae* as the primary species in warm, wet, and relatively warm, dry conditions, respectively (Backhouse 2014). It is estimated that 25–50% of global crops are contaminated with mycotoxins annually (Ricciardi *et al*. 2013), and many *Fusarium* species produce a range of toxins that can reach harmful levels for humans and animals. Implementing multiple management practices can reduce the risk of mycotoxin contamination in wheat and its products (Fedorica *et al*. 2017). This review aims to summarize recent findings on cereal mycotoxins, detailing their types, factors influencing contamination, and mitigation strategies pre and postharvest.

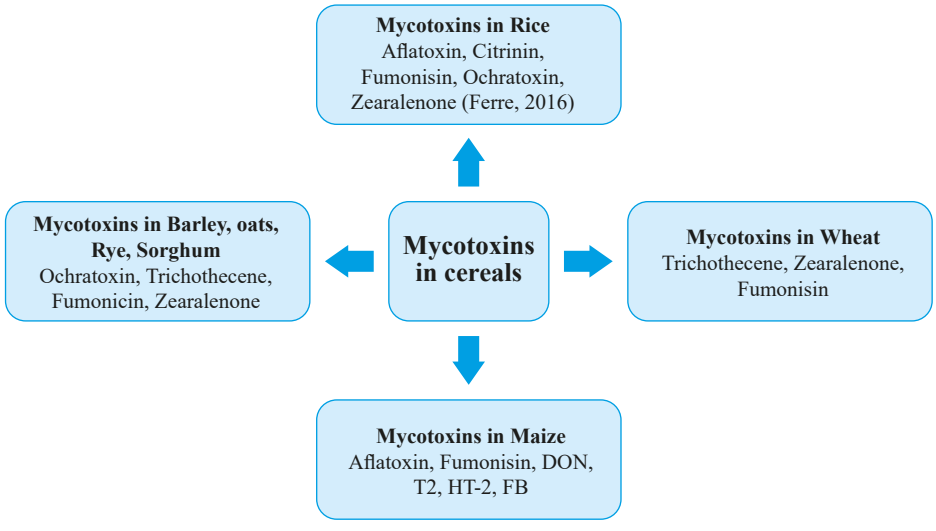

Figure 1. Different mycotoxins in cereals (Marin *et al.* 2013)

Table 1. Major mycotoxins, their producing fungi, and affected food types (Marin *et al*. 2013)

Mycotoxins	Producing fungi	Affected food stuff
Aflatoxin B1, B2, G1, and G2	*Aspergillus parasiticus, Aspergillus nomius, Aspergillus flavus*	Wheat, maize, rice, peanuts, nuts, spices, oilseeds, and cottonseed
Aflatoxin M1	Metabolite of aflatoxin B1	Milk and dairy products
Ochratoxin A	*Aspergillus niger, Aspergillus ochraceus, Penicillium verrucosum, Penicillium nordicum, Penicillium cyclopium, Aspergillus carbonarius,*	Wheat, barley, oats, cocoa beans, coffee beans, fruits and fruit juice, dried fruits, and wine
Patulin	*Penicillium expansum, Byssochlamys nivea, Aspergillus clavatus*	Fruit and fruit juices, cheese, and wheat
Trichothecenes	*Fusarium sporotrichiodes, Fusarium langsethiae Fusarium, graminearum Fusarium culmorum, Fusarium cerealis*	Maize, wheat, barley, oats, grains, and animal feed
Zearalenone	*Fusarium culmorum, Fusarium cerealis, Fusarium equiseti, Fusarium verticilliodes, Fusarium incarnatum, Fusarium graminearum,*	Maize, wheat, barley, rye, and animal feed
Fumonisin B1, B2, B3	*Fusarium verticillioides, Fusarium proliferatum*	Maize, rice, wheat, sorghum, barley, and oats

Mycotoxins

Different fungi produce different mycotoxins (Table 1.) in various cereals. For example, *Aspergillus* produces Aflatoxin and ochratoxin, *Fusarium* produces fumonisin, trichothecenes, etc.

Fusarium mycotoxins

Fusarium species produce the three most important classes of mycotoxins namely: trichothecenes, zearalenone (ZEN), and fumonisins (FBs) (Figure 2.). The most common *Fusarium* mycotoxin groups are trichothecenes, nivalenol, T-2 toxin Deoxynivalenol, zearalenones, and fumonisin B1 (Jestoi 2008).

Trichothecenes

Trichothecenes are a significant class of *Fusarium* mycotoxins and are notable for their wide-ranging chemical diversity (Figure 3). They pose a serious health risk to humans and animals globally due to their high prevalence (Li *et al*. 2011). These mycotoxins are categorized into four main groups where type A toxins include T-2, HT-2, neosolaniol (ENNS), and diacetoxyscirpenol (DAS); type B toxins include deoxynivalenol (DON) and its 3-acetyl and 15-acetyl derivatives, nivalenol (NIV), together with acetylated precursor of NIV; type C trichothecenes contain a C-7/C-8 epoxide, such as crotocin and type D trichothecenes include roridin A, verrucarin A, and satratoxin H (McCormick *et al.* 2011; Pinton and Oswald 2014). The genus *Fusarium* produce different types of mycotoxins (Fig. 2 & Fig. 3)

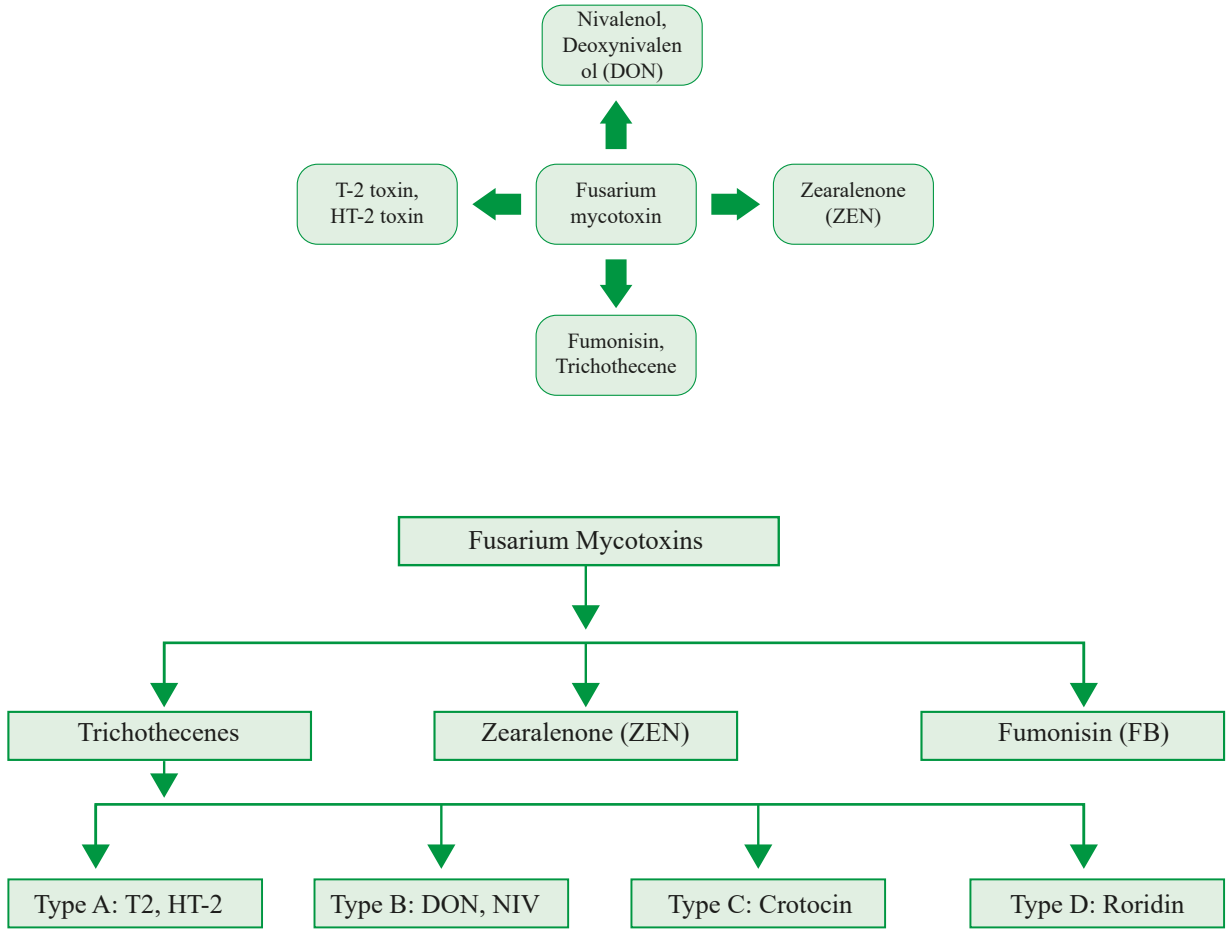

Figure 3. Classification of Fusarium mycotoxins ((McCormick *et al.* 2011)

Deoxynivalenol

Fusarium head blight (FHB) has re-emerged as a significant threat to food security in recent years, spurring renewed interest in trichothecenes such as deoxynivalenol (DON) (Goswami and Kistler, 2004; Van Egmond *et al.* 2007). Primarily produced by *Fusarium graminearum* and *Fusarium culmorum*, DON forms as colorless needle-like crystals that remain stable under extreme heat (120–180 °C) and dissolve in polar organic solvents, including aqueous acetonitrile, chloroform, methanol, ethanol, and ethyl acetate (EFSA 2004). DON causes vomiting, digestive issues, oxidative stress, and reproductive toxicity in humans and animals, though it is not classified as a carcinogen (Berthiller *et al*. 2011). At the cellular level, DON disrupts biological barriers, impacting cell and organ function and viability (Maresca 2013).

Nivalenol

Nivalenol (NIV) frequently co-occurs in crops like wheat, barley, and maize. Recently, NIV has been detected in cereal-based products across Europe, Brazil, Japan, Southeast Asia, and China (Turner 2010). NIV and DON share similar chemical structures and toxicological effects, including nausea, vomiting, diarrhea, and, in severe cases, death.

T-2 toxin and HT-2 toxin

Among *Fusarium* species, *Fusarium langsethiae* is the primary producer of T-2 and HT-2 toxins, followed by *Fusarium poae* and *Fusarium sporotrichioides* (Glenn and Quillin 2007). Symptoms of acute T-2 poisoning include nausea, vomiting, abdominal pain, diarrhea, bloody stools, cartilage damage, weight loss, immunosuppression, decreased plasma glucose, and pathological changes in the liver and stomach (Li *et al.* 2011). The primary action of T-2 is to inhibit protein synthesis, leading to secondary disruptions in DNA and RNA synthesis (Doi *et al*. 2008). T-2 affects the cell cycle and induces apoptosis in various high-proliferation cells, including chondrocytes, human astrocytes, mouse embryonic stem cells, pig hepatocytes, and hematopoietic cells in bone marrow, spleen, and epidermal basal cells (Fang *et al*. 2012).

Zearalenone

Zearalenone (ZEN) is a resorcylic acid lactone primarily produced by certain *Fusarium* species,

including *Fusarium graminearum*, *Fusarium culmorum*, *Fusarium crookwellense*, and *Fusarium equiseti*. These fungi can also produce other toxins such as DON, NIV, and FUX, with ZEN concentrations varying across host plants and regions (Frizzell *et al*. 2011).

ZEN contamination has been detected in corn, barley, oats, wheat, sorghum, millet, rice, flour, malt, soybeans, and beer (Marin *et al*. 2011). It primarily targets the reproductive system, as its structure resembles estrogen, giving it estrogenic properties along with its metabolites α-ZEN and β-ZEN (Schoevers *et al*. 2012). Additionally, ZEN has immunotoxic, hepatotoxic, hematotoxic, and nephrotoxic effects and promotes lipid peroxidation (Choi *et al*. 2012). It can induce liver damage, leading to hepatocarcinoma and altered hepatic function in rabbits, rats, and gilts (Pinton and Oswald 2014). Furthermore, ZEN may stimulate the growth of human breast cancer cells expressing estrogen receptors (Ahamed *et al*. 2001).

The genus *Aspergillus* produce different types of Aflatoxins (Fig. 4 & Table 2)

Fumonisins

Fumonisins (FBs) were first isolated from *Fusarium moniliforme* cultures in corn from South Africa (Gelderblom *et al.* 1988), with their structures later reported by Marasas *et al.* in 1988. Since then, fumonisins have also been identified in other *Fusarium* species, such as *Fusarium verticillioides*, *Fusarium proliferatum*, and *Alternaria alternata* f. sp. *lycopersici* (Bezuidenhout *et al*. 1988). These toxins are classified into three main types—FB1, FB2, and FB3—and commonly contaminate food and animal feed (Soriano 2004). Although fumonisins are not mutagenic, they are known to promote cancer development (Summerell and Leslie 2011). Fumonisins are also linked to apoptosis in humans, esophageal cancer, and neural tube defects (Ahangarkani *et al.* 2014).

Aflatoxins are produced by various *Aspergillus* species, primarily *Aspergillus flavus* and *Aspergillus parasiticus* (Bhuiyan *et al.* 2013). Of the many types of aflatoxins, the four main ones are aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1), and aflatoxin G2 (AFG2), as shown in Figures 4 and 5 (Nadeem and Hadeel 2022).

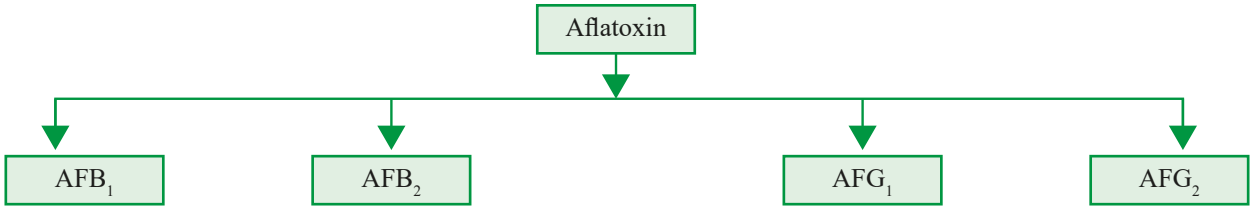

Figure 4. Classification of Aflatoxins (Nadeem and Hadeel 2022)

Table 2. Key properties of Aflatoxins (Nadeem and Hadeel 2022)

Aflatoxin	MW (g/mol)	Formula	Melting point (°C)	Toxicity			Adverse health effects
				LD50 (mg/kg bw)	Test organism	Route	
AFB_1	312.063	$C_{17}H_{12}O_6$	268.5	0.24-6.03	Various animals	Oral	Genotoxicity, carcinotoxicity, immunotoxicity, hepatotoxicty
AFB_2	314.079	$C_{17}H_{14}O_7$	286-289	1.7	Duck, Rat	Oral	Low toxicity
AFG_1	330.074	$C_{17}H_{14}O_7$	237-240	2.5	Duckling	Oral	Low toxicity
AFG_2	346.069	$C_{17}H_{14}O_8$	243.13	NA	Duckling	Oral	Low toxicity

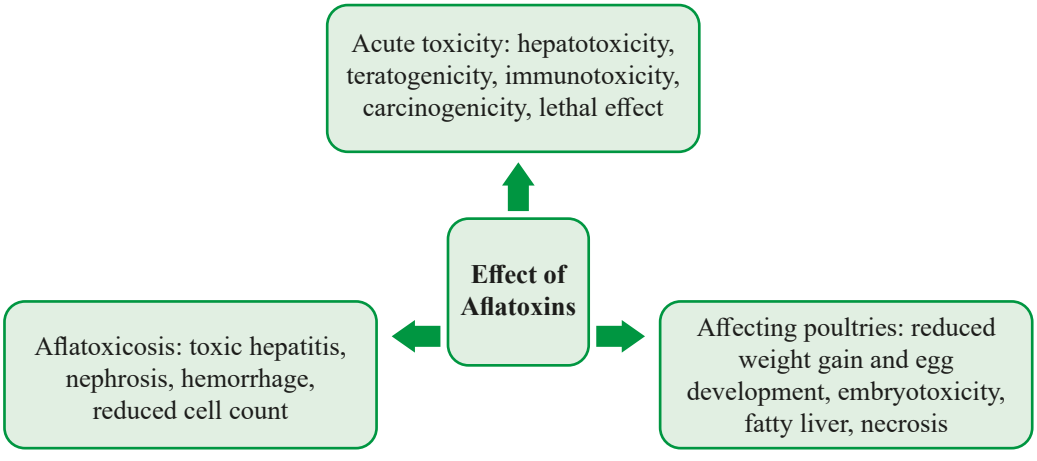

Figure 5. Effects of Aflatoxins on health and productivity (Nadeem and Hadeel 2022)

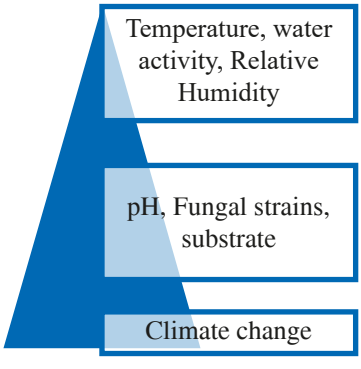

Figure 6. Factors affecting Mycotoxin Production (Vyclova 2017)

Effects of Aflatoxins on health and productivity

The primary exposure to aflatoxins comes from consuming contaminated food, negatively impacting human and animal health (Figure 5). In Kenya, patients with aflatoxin-induced hepatitis also showed tenderness around the liver and, in some cases, developed ascites (Nadeem and Hadeel 2022).

Factors affecting mycotoxin production

The primary factors influencing mycotoxin production include temperature, relative humidity, pH, fungal strain, and the substrate (Figure 6).

Temperature, water activity, and relative humidity

Since *Fusarium* species are hygrophilic fungi that need relative humidity values of 90% or greater to germinate and thrive, they predominate in the field during the pre-harvest phase. Fungal growth and subsequent mycotoxin contamination are generally facilitated by temperatures between 25°C and 30°C, water activity levels above 0.78, and relative humidity between 88% and 95% (Thanushree *et al*. 2019).

pH

Mycotoxin generation and fungal development are influenced by the pH of the medium in which the fungi are found. *Aspergillus* and *Pennicillium* species can acidify their surroundings by releasing citric and gluconic acids (Vylcova 2017).

Fungal strain

The toxicity of different fungal species varies, and the synthesis of mycotoxins is frequently restricted to particular strains within a species and occasionally to unique fungal species (Vyclova 2017). Furthermore, Laubscher *et al.* claim that "strain specificity, variation, and instability" have an impact on mycotoxin production (Greeff-laubscher *et al.* 2019). *Aspergillus flavus*, for instance, may grow between 15 and 44 °C and create AFB1, but *Aspergillus carbonarius* can grow between 8 and 40 °C and produce OTA (Mannaa and Kim 2017b).

Substrate

Mycotoxin production is generally a complex phenomenon, which can be affected by several substrate factors such as pH, temperature, and

especially the composition (Özcelik and Özcelik 2004). Furthermore, fungi have been demonstrated to modify their physiology in response to osmotic stress which appears to aid in adaptation and survival (Duran *et al*. 2010). In contrast, sugars comprise carbon molecules and filamentous fungi generally can hydrolyze various carbon sources for energy production and growth (Hamad *et al*. 2015).

Climate change

Through (1) rising pest and insect population, global spread and invasion, (2) early setting in and maturation of crops, (3) reducing plant homeostasis capacity together with (4) change in host pathology due to CO2 presence on the air, climate change also has a downstream indirect drive on mycotoxin loadings globally (Nadeem and Hadeel 2022).

Production of mycotoxins

The primary producers of mycotoxin are the *Fusarium graminearum* species complex (FGSC) and the *Fusarium fujikuroi* species complex (FFSC). Fumonisins are produced by the FFSC (O'Donnell *et al.* 2000). The genus Aspergillus is a broad family of fungi that occupy various ecological niches. These fungi are more prevalent in warm temperate and subtropical regions (Table 3). Versicolorins, ochratoxins, aflatoxins, gliotoxins, and sterigmatocystin are among the mycotoxins linked to Aspergillus species (Nadeem and Hadeel 2022). Poultry feed has the potential to introduce aflatoxin into the human food chain (Bhuiyan *et al*. 2013).

Table 3. Origins of Aflatoxins and the products most exposed to contamination (Nadeem and Hadeel 2022)

Aflatoxins	Source	Frequently contaminated products
Aflatoxin B_1	*A. pseudotamarii, A. austwickii, A. aflatoxiformans, A. arachidicola, A. cerealis, A. mottae, A. minisclerotigenes, A. luteovirescens (formerly A. bombycis), A. novoparasiticus, A. parasiticus, A. nomius, A. pipericola, A. pseudonomius, A. pseudocaelatus, A. transmontanensis, A. sergii, Section Ochraceorosei: A. ochraceoroseus,A. rambellii Section Nidulantes: A. miraensis, A. astellatus A. venezuelensis,, A. olivicola, A. flavus, A. togoensis*	Cereals (like, rice, sorghum, wheat, barley, maize), oil seeds (like., cotton seeds, rape seeds, seeds of sunflower), seeds of nuts (like, pistachio, groundnut, peanuts), spices (like, black and red pepper, turmeric, allspices, ginger), dairy products, meats, dried fruits, fruit juices, eggs, foods derived from these products
Aflatoxin B_2	*A. aflatoxiformans, A. pseudotamarii, A. cerealis, A. austwickii, A. minisclerotigenes, A. arachidicola, A. luteovirescens, A. mottae, A. novoparasiticus, A. nomius, A. pipericola, A. parasiticus, A. pseudonomius, A. pseudocaelatus, A. flavus, A. transmontanensis, A. sergii Section Ochraceorosei: A. ochraceoroseus and A. rambellii*	Cereals (like, rice, sorghum, barley, wheat, corn,), seeds oil (like, sunflower seed, oilseed rape cotton seed,), nuts (like, groundnut, pistachio, peanuts), Spices (like, black and red pepper, ginger, turmeric), milk products, meats, dried fruit, eggs, fruit juices, and foodstuffs derived from such products.
Aflatoxin G_1	*A. aflatoxiformans, A. flavus, A. cerealis, A. austwickii, A. minisclerotigenes, A. arachidicola, A. luteovirescens, A. mottae, A. novoparasiticus, A. nomius, A. pipericola, A. parasiticus, A. pseudonomius, A. pseudocaelatus, A. transmontanensis, A. sergii*	Cereals (like, rice, sorghum, wheat, barley, and maize), oily seeds (like, cotton seeds, rape seeds, and sunflower seeds), nuts (like, peanuts, groundnuts, pistachio nuts), spices (like ginger, black and red pepper, turmeric), milk products, meats, dried fruits, fruit juices, poultry, and feed and foods extracted from such products.
Aflatoxin G_2	*A. flavus, A. austwickii, A. aflatoxiformans, A. arachidicola, A. cerealis, A. mottae, A. minisclerotigenes, A. nomius, A. luteovirescens, A. transmontanensis, A. parasiticus, A. novoparasiticus, A. pseudocaelatus, A. pipericola, A. sergii, A. pseudonomius*	Cereals (like, rice, sorghum, wheat, barley, maize), oily seeds (like, cotton seeds, rape seeds, sunflower seeds), nuts (like, peanuts, groundnuts, pistachio nuts), spices (like ginger, black and red pepper, turmeric), milk products, meats, dried fruits, fruit juices, poultry, and feed and foods extracted from such products.

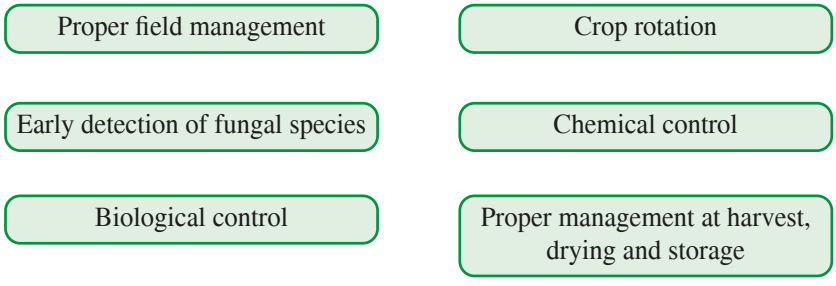

Figure 7. A list of mycotoxin control and management strategies (Marin *et al*. 2011)

Detection of mycotoxins
Numerous methods, which can be roughly categorized as instrumental and bioanalytical procedures, can be used to identify mycotoxins. Each strategy has advantages and disadvantages, though, and the best approach will rely on the needs of the detection.

Chromatographic methods
The technique with the longest history for detecting mycotoxins is thin-layer chromatography (TLC), which can be associated with several detectors. These detectors include mass spectrometry, diode array, ultraviolet (UV), and fluorescence detection. Mass spectrometry (MS) detection, flame ionization detection (FID), or electron capture detection can all be coupled with gas chromatography (Lippolis *et al*. 2008). Both quantitative and qualitative evaluations can be conducted using these techniques, which offer excellent accuracy and precision. However, they cost a lot, need highly qualified staff, and take longer to prepare complex samples (Elliott 2011).

Immunochemical methods
Because antibody-antigen reaction-based immunoassays are straightforward and have been utilized for quick mycotoxin detection, they are highly beneficial for regular analyses (Zherdev 2014). Enzyme-linked immunosorbent assays, time-resolved immunochromatographic assays, enzyme-linked aptamer assays, chemiluminescence immunoassays, fluorescence immunoassays, fluorescence resonance energy transfer immunoassays, and metal-enhanced fluorescence assays are among the immunological techniques that have been developed recently (Chauhan *et al*. 2016). An essential component of these detection methods is the aptamer. With great affinity and specificity, it may bind a wide range of peptides, proteins, amino acids, and chemical or inorganic compounds (Torres-Chavolla and Alocilja 2009). Regular implementation of effective control programs, such as the best possible use of immunoassays, is necessary for risk management.

Mycotoxins control and prevention strategies
Mycotoxin presence in the field can be caused by a variety of circumstances, including heat, insect infestation, drought stress, low soil fertility, and postponed harvesting (Mahuku *et al.* 2019). Mycotoxin contamination can be mitigated in a number of ways (Figure 7). Mycotoxin contamination may be reduced with the use of suitable field management techniques (Fedorica *et al.* 2017).

Proper field practices
Wherever the climate is theoretically conducive to mycotoxin contamination, the degree of contamination is anticipated to be greater (Joubrane *et al.* 2011). Field management and preparation before planting, as well as field and crop management following planting, are examples of proper field practices.

Crop rotation
It has been shown that mycotoxin contamination is higher in plots where the same crops are grown over consecutive years (FAO 2007).

Field preparation and management before planting
Seeds with partial resistance are generally more effective in cooler climates, but this resistance is more critically needed in tropical and subtropical regions, where fungal infections occur more frequently (FAO 2007).

Field and crop management
After planting, promoting healthy plant growth through effective field practices and reducing crop stress can significantly limit fungal growth and mycotoxin production. These practices include using fertilizers, implementing proper irrigation, managing weeds and insects, and applying chemical and biological controls (Mannaa and Kim 2017a; Mahuku *et al*. 2019). When

soil nutrients are insufficient, fertilizers can boost soil fertility; however, they must be applied with precision regarding timing and quantity, as excessive use can stress plants, making them more vulnerable to pests and mold (Nganchamung and Robson 2017). Controlling water splashing through appropriate irrigation methods is essential to limit fungal spread (Food and Agriculture Organization 2007). Excessive moisture in irrigated wheat fields during flowering and early grain fill stages can promote Fusarium infection (Fedorica *et al.* 2017).

Early detection of fungal species

Accurate, rapid, and reliable methods are essential for detecting filamentous fungi. The primary approaches include mycological, proteomic, and genomic techniques (Rodríguez *et al.* 2015). Due to its high sensitivity, PCR can detect specific DNA molecules even within complex mixtures, enabling precise identification of the filamentous fungi present (Atoui *et al*. 2012).

Chemical control

Currently, chemical control using fungicides is one of the most effective methods to manage fungal invasion and the resulting mycotoxin contamination (Magan and Olsen 2004). Fungicides may pose a risk by giving mycotoxin-contaminated crops a healthy appearance, which can be misleading (Simpson *et al*. 2001).

Biological control

Biological control strategies offer a valuable approach to mitigating mycotoxin risks in wheat, especially for organic farming systems where synthetic fungicides are not permitted (Fedorica *et al.* 2017). Mycotoxin production traits could be passed to future generations if non-toxic strains cross with toxic ones, potentially resulting in toxin-producing fungi over time (Kagot *et al*. 2019).

Proper management during harvest

Effective management strategies at harvest include collecting crops at low moisture levels, reducing mechanical seed damage, and employing grain sorting techniques to remove diseased kernels, which are often lighter than healthy ones. Although discarding damaged grains may result in lower yield, it enhances storage conditions and improves grain safety, ultimately balancing out economic losses (Fedorica *et al.* 2017).

Proper management during drying

Drying is a traditional method used to protect crops from fungal infections and thereby prevent economic losses. Mechanical drying, which uses warm, dry air forced through the produce, achieves effective results quickly. For large-scale production, drying can be carried out with methods like superheated steam drying or infrared radiation (Chiewchan *et al.* 2015).

Proper storage practices

Storage fungi can cause significant damage, including mycotoxin production, reduced quality, nutrient losses, and even heat buildup. These fungi can grow in relative humidity levels of 70-90% and thrive at temperatures between 10–40°C, with an optimal range of 25–35°C (Magan *et al.* 2004). Proper drying and secure storage of wheat in pest-free silos, devoid of moldy materials, are essential measures to minimize mycotoxin contamination (Fedorica and Fernandez 2017).

Methods for detoxification and decontamination of mycotoxins

Controlling mycotoxins in the early stages along the food chain and its primary prevention at critical points in the field and during harvest and storage are very crucial (Pankaj *et al.* 2018).

Physical decontamination

Physical decontamination methods, including heat treatment and irradiation, are used to reduce mycotoxins in agricultural products like wheat (Karlovsky *et al*. 2016). Grain sorting, cleaning, debranning, and milling processes all impact how mycotoxins are distributed across different milling fractions entering the food supply chain (Fedorica *et al.* 2017). Innovative thermal decontamination methods, such as steam, infrared, microwave, radiofrequency, and extrusion heating, have been developed (Deng *et al.* 2021). Non-thermal treatments, like irradiation, may partially reduce mycotoxin levels by absorbing radiation energy (Pleadin *et al.* 2019), and are particularly suitable for large-scale industrial applications.

Chemical decontamination

As many of the chemical treatments have proved affordable and effective against mycotoxins, their usage is still banned by the European Union in foods since they can pose some health risks due to possible toxic byproducts generated in the process, and according to European Commission regulation, "foodstuff containing mycotoxins shall not be deliberately detoxified by chemical treatments" (Deng *et al*. 2020).

Biological decontamination

Biological methods are inexpensive and present no risk to the environment since no chemical substances are used. However, their use can be time-consuming and impractical in some cases. Many biological means also proved to be effective only in the laboratory. Another major drawback is the limited ability to decontaminate multiple mycotoxins simultaneously (Patriarca *et al.* 2017).

Effect of processing on mycotoxins

Mycotoxins are influenced by various factors during food processing, as their presence is determined by their high stability (Milani and Maleki 2014

), temperature resistance, and the presence of other factors such as enzymes, pH, moisture content, and temperature of the food product. Strategies to reduce mycotoxin contamination in cereals include both pre- and postharvest approaches. Postharvest decontamination methods serve as a final option. These methods should not compromise crop quality or safety and must adhere to established regulatory standards (Fedorica *et al.* 2017).

CONCLUSION

Mycotoxins in cereals pose a significant health risk to both animal health and food safety, creating substantial challenges within the food supply chain. *Fusarium,* one of the most critical genera of plant-pathogenic fungi, is arguably the leading mycotoxin-producing genus worldwide. *Fusarium* species produce a wide range of toxic metabolites that contribute to plant diseases and mycotoxicoses in humans and animals. Understanding the mycotoxin-producing potential of different *Fusarium* species is essential for assessing the toxicological risks linked to *Fusarium* related diseases. Numerous studies have documented mycotoxin production by various species, and efforts have been made to summarize these findings. It has been shown that animals consuming contaminated feed can transfer mycotoxins, further amplifying the risk. Although mycotoxin contamination in food may not always be avoidable, its presence remains a significant threat to food security, especially in developing countries. Therefore, widespread education about the harmful effects of mycotoxins on human health and the economy, along with proper food preservation techniques, should be shared with the general public, stakeholders, and farmers. Scientific seminars, roundtable discussions, and workshops can be organized to raise awareness. Governments should also set quality control standards for commodities intended for export or import, as diet is the primary route of mycotoxin exposure for both humans and animals. Implementing proper methods throughout the entire food chain—from planting, harvesting, drying, and storage to processing, packaging, and transport—can significantly reduce contamination levels and ensure they stay below the tolerable limits set by various countries.

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