

MYCOTOXINS AS HIDDEN FOOD CONTAMINANTS: A PUBLIC HEALTH CONCERN

Mela Ilu Luka^{1*}, Elkanah Glen², Hosea Stephen Hamafyelto³, Olapeju Omolade Omolehin¹, Gbolabo Odewale¹, Comfort Japhet Philip⁴, Florence Ajis⁵, Esther Okolo¹, Christiana Enemona Idoko¹

¹Microbiology Department, Faculty of Life Sciences, Federal University Lokoja, Kogi State, Nigeria

²Biochemistry Department, Faculty of Life Sciences, Federal University Lokoja, Kogi State, Nigeria

³Microbiology Department, Faculty of Life Sciences, University of Maiduguri, Borno State, Nigeria

⁴North-Central Zonal Centre of Excellence, National Biotechnology Research and Development, Abuja, Nigeria

⁵Department of Medical Microbiology, Faculty of Basic Clinical Sciences, College of Health Sciences, University of Jos, Plateau State, Nigeria

*Corresponding author: ilumela@yahoo.com

Cite this article as: Luka, M.I., Glen, E., Hamafyelto, H.S., Omolehin, O.O., Odewale, G., Philip, C.J., Ajis, F., Okolo, E. and Idoko, C.E. (2026). Mycotoxins as Hidden Food Contaminants: A Public Health Concern. *Journal of Integrative Public Health Research*, pp. 264-278.

Abstract

Mycotoxins are toxic secondary metabolites synthesized by certain filamentous fungi, notably *Aspergillus*, *Fusarium*, and *Penicillium* species, which commonly contaminate food commodities and animal feed. These compounds are aptly described as "hidden" food contaminants because they are colorless, odorless, and resistant to many conventional food processing methods, allowing them to persist undetected in the food supply chain. Staple foods such as cereals, nuts, spices, dairy products, and processed foods are especially vulnerable to contamination, particularly in regions with warm and humid climates. Human exposure occurs primarily through dietary intake but may also result from occupational contact and maternal transfer during pregnancy and lactation. Acute exposure to elevated levels of mycotoxins can cause severe toxicity, while chronic low dose exposure is associated with hepatotoxicity, nephrotoxicity, immunosuppression, growth retardation, and an increased risk of cancer. Children, pregnant women, and immunocompromised individuals are particularly susceptible to these adverse health outcomes. Changing climatic conditions further exacerbate the risk by influencing fungal growth and toxin production. Combating mycotoxin contamination therefore requires integrated public health and food safety strategies focused on early detection, preventive agricultural practices, proper storage, public awareness, and strict regulatory frameworks to reduce exposure and safeguard global health.

Keywords: Mycotoxins; Food contamination; Public health; Aflatoxins; Food safety; Fungal toxins

1. Introduction

Mycotoxins constitute a diverse group of toxic compounds that occur naturally and are produced as secondary metabolites by certain filamentous fungi, particularly species of *Fusarium*, *Penicillium*, and *Aspergillus*. These toxins most commonly contaminate a broad range of agricultural products such as cereals, spices, nuts, dried fruits, and animal feeds, either before or after harvest (Sharma and Parisi, 2017). Contamination occurs predominantly under favorable environmental conditions that promote fungal growth, including elevated humidity and temperature. Given that mycotoxins are ubiquitous in most environments and possess the capacity to withstand conventional food processing (Alam *et al.*, 2022), they have emerged as one of the most significant yet frequently overlooked threats to food safety at the global level.

The distinctive attribute that renders mycotoxins particularly hazardous is their "hidden" nature. They are generally tasteless, odorless, and invisible, making their presence as contaminants in foods difficult to detect without specialized analytical techniques (Maurya, 2025; Janik *et al.*, 2021). Unlike other forms of microbial spoilage, mycotoxin contamination does not alter the flavor or appearance of food, thereby allowing contaminated products to enter the food chain unnoticed. These compounds are also chemically stable and can withstand several methods of food processing, including cooking, pasteurization, and boiling (Kabak, 2009). Consequently, contaminated foods may appear safe for consumption while posing substantial risks to health. Moreover, contamination frequently occurs at low levels over extended periods, resulting in chronic exposure without immediate symptoms yet contributing to long term health complications (Fung and Clark, 2004). This insidious pattern of contamination underscores their classification as hidden food hazards and highlights the considerable challenges encountered during monitoring and control.

The recognition of mycotoxins as a significant health risk began in the early 1960s, following the outbreak of "Turkey X disease" in England, which resulted in the death of over 100,000 turkeys fed on mold contaminated peanut meal (Abdelmotilib *et al.*, 2021). Subsequent investigations identified aflatoxins,

produced by *Aspergillus flavus*, as the causative agents, marking a seminal milestone in food toxicology and public health research. Since that discovery, comprehensive research has identified hundreds of mycotoxins, many of which are now recognized to produce chronic and acute toxic effects with resultant teratogenic, mutagenic, carcinogenic, and sometimes immunosuppressive outcomes (Omotayo *et al.*, 2019).

The public health significance of mycotoxins is reinforced by their global distribution and the disproportionate burden placed on developing countries, where climatic conditions favor fungal growth and food safety infrastructure remains inadequate. International organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) acknowledge mycotoxins as a major food safety concern (Eskola *et al.*, 2020), underscoring the necessity for comprehensive strategies involving agricultural, public health, and regulatory interventions to minimize exposure and protect vulnerable populations. Accordingly, mycotoxins represent a silent yet consequential threat to global food safety and public health.

2. Sources and Types of Mycotoxins

2.1 Fungi Responsible for Mycotoxin Production

Mycotoxins are produced by a limited number of filamentous fungi that predominantly colonize food crops and stored agricultural products. The most significant are fungal species belonging to the genera *Aspergillus*, *Fusarium*, and *Penicillium*, owing to their widespread distribution, ability to contaminate staple foods, and potential for producing toxic compounds (Egbuta *et al.*, 2017). These fungi differ in their ecological niches, growth conditions, and the types of mycotoxins they synthesize, thus influencing contamination patterns along the food supply chain (Perrone *et al.*, 2020).

The genus *Aspergillus* is particularly significant in tropical and subtropical regions where elevated temperatures and humidity favor fungal growth. Important toxigenic species include *A. flavus* and *A. parasiticus*, which are the primary producers of aflatoxins (Klich, 2007). These species primarily contaminate crops such as maize, peanuts, spices, tree

nuts, and oil seeds. Other *Aspergillus* species, including *A. carbonarius* and *A. ochraceus*, are responsible for producing ochratoxin A, a nephrotoxic and potentially carcinogenic compound commonly detected in cereals, coffee, wine, and dried fruits (Banahene *et al.*, 2024). The ability of *Aspergillus* species to grow under conditions of relatively low moisture renders them particularly problematic in poorly stored food products (Guchi, 2015).

Fusarium species are largely field fungi that infect crops during growth, particularly under conditions of moderate temperature and high moisture. Significant toxigenic species within this genus include *F. proliferatum* and *F. verticillioides*, which synthesize fumonisins predominantly found in maize, and *F. graminearum* and *F. culmorum*, which produce zearalenone and trichothecenes such as deoxynivalenol (Munkvold, 2016). These mycotoxins commonly contaminate cereals including maize, barley, wheat, and oats. Contamination by *Fusarium* species is strongly influenced by climatic factors and agricultural practices, and infection occurs most frequently in the field, making prevention challenging. The genus *Penicillium* is principally associated with post harvest contamination during storage, especially in temperate climates. Ochratoxin A is notably produced by *P. verrucosum* and *P. nordicum*, particularly in stored cereal products and cured meat products (Sanchez-Montero *et al.*, 2019). Other *Penicillium* species produce toxins such as patulin, which is most commonly found in apples and apple derived products. *Penicillium* species thrive in cool and damp storage conditions and are frequently associated with inadequate drying and poor storage hygiene (Nishimwe *et al.*, 2020).

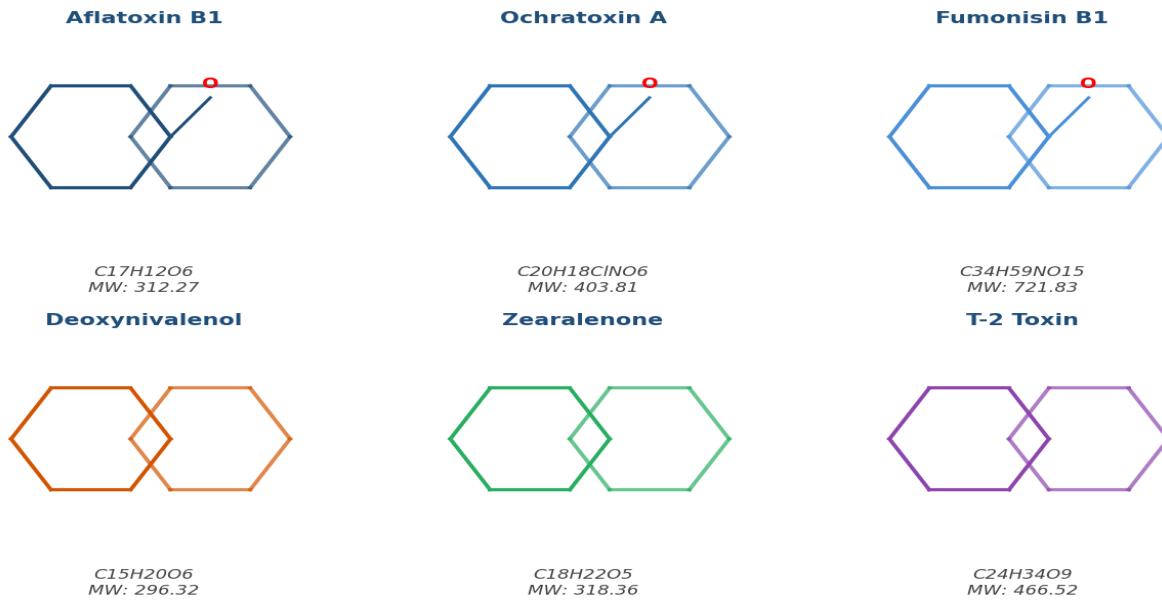


Figure 1: Chemical structures and molecular properties of the six major classes of mycotoxins commonly encountered in food commodities. Each structure reflects distinct functional groups responsible for their toxic properties (Magembe, 2025; Cao *et al.*, 2022).

2.2 Major Types of Mycotoxins

Mycotoxins comprise a distinct group of toxic compounds that vary in their chemical structures, biological sources, and effects on human health. Among the numerous mycotoxins identified to date, aflatoxins, ochratoxins, fumonisins, zearalenone, and trichothecenes are considered the most significant because of their recurrent occurrence in foods and their considerable implications for human and animal health (Magembe, 2025). Aflatoxins are predominantly synthesized by *A. flavus* and *A. parasiticus* and are among the most potent naturally occurring toxins known (Abrar et al., 2013). They contaminate staple foods such as maize, peanuts, groundnuts, spices, tree nuts, and occasionally seed oils, particularly in warm and humid regions. Aflatoxin B₁ has been classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) on account of its extreme toxicity and strong association with hepatocellular carcinoma (Cao et al., 2022). Aflatoxins can also induce acute aflatoxicosis, immunosuppression, and impaired growth in children (Dabuo et al., 2022).

Ochratoxins are synthesized by several species of *Aspergillus* and *Penicillium*. These toxins are most frequently detected in cereals, coffee, dried fruits, spices, wine, and in some cases animal products such as pork, through contaminated feed (Li et al., 2021). Ochratoxin A (OTA) is principally nephrotoxic and has been associated with teratogenic, immunotoxic, and carcinogenic effects. Excessive exposure to OTA raises serious concern because of its long biological half life and its connection with kidney disorders and endemic nephropathies in certain populations (Longobardi et al., 2022). Fumonisin are primarily produced by *F. verticillioides* and *F. proliferatum* and principally contaminate maize and maize based products. Fumonisin B₁ is the most common and most toxic member of the group. Fumonisin exert a wide range of toxic effects through their capacity to disrupt sphingolipid metabolism (Chen et al., 2020). Human exposure to fumonisin B₁ has been associated with neural tube defects and esophageal cancer (Arumugam and Chuturgoon, 2021), while in animals, it causes conditions such as porcine pulmonary edema and equine leukoencephalomalacia (Smith and Gupta, 2025).

Zearalenone is a non steroidal estrogenic mycotoxin synthesized by *F. graminearum* and related species. It most commonly contaminates cereals such as sorghum, wheat, barley, and maize. Owing to its structural similarity to estrogen, zearalenone disrupts hormonal regulation and is associated with reproductive disorders such as precocious puberty, infertility, and other estrogenic effects, predominantly in livestock (Lv et al., 2025; Sajjad et al., 2025). Although it is considered less acutely toxic relative to other mycotoxins, zearalenone poses a significant risk to human reproductive health through prolonged exposure (Sajjad et al., 2025). Trichothecenes are a chemically diverse group of mycotoxins produced primarily by *Fusarium* species. Prominent members include deoxynivalenol (DON, also known as vomitoxin), HT-2 toxin, and T-2 toxin. These toxins contaminate oats, barley, maize, and wheat. Trichothecenes inhibit protein synthesis and cause a broad spectrum of toxic effects, including vomiting, diarrhea, nausea, immunosuppression, and hematological disorders (Cope, 2025). Their chemical stability, resistance to food processing, and widespread occurrence make them a significant concern, particularly in cereal based products (Yu et al., 2022).

Table 1: Major Mycotoxins, their Sources, and Health Effects

S/N	Mycotoxin	Fungal Source	Key Member	Health Effects
1	Aflatoxins	<i>A. flavus</i> , <i>A. parasiticus</i>	Aflatoxin B ₁	Hepatocellular carcinoma, acute aflatoxicosis, immunosuppression
2	Ochratoxins	<i>Aspergillus</i> , <i>Penicillium</i> spp.	Ochratoxin A	Nephrotoxicity, teratogenicity, immunotoxicity, carcinogenesis
3	Fumonisin	<i>F. verticillioides</i> , <i>F. proliferatum</i>	Fumonisin B ₁	Disruption of sphingolipid metabolism, neural tube defects, esophageal cancer
4	Zearalenone	<i>F. graminearum</i> , <i>F. culmorum</i>	N/A	Infertility, precocious puberty, reproductive disruption

5	Trichothecenes	<i>Fusarium</i> spp.	Deoxynivalenol, T-2 toxin	Inhibition of protein synthesis, nausea, vomiting, immunosuppression
---	----------------	----------------------	---------------------------	--

2.3 Agricultural and Environmental Factors

The production of mycotoxins is substantially influenced by the combined effects of agricultural practices and environmental conditions on fungal growth and toxin synthesis. Contamination by mycotoxins can occur at any stage in the food supply chain, from crop cultivation in the field to post harvest storage, depending on factors such as handling practices, crop stress, and prevailing climatic conditions (Gachara et al., 2024). A thorough understanding of these factors is critical for predicting contamination risk and implementing effective control strategies.

Environmental conditions play a determining role in the severity and prevalence of mycotoxin contamination. Moisture and temperature are the most influential climatic factors governing fungal growth and toxin production (Awuchi et al., 2021). Elevated relative humidity and warm temperatures promote the growth of *Aspergillus* species and the consequent production of aflatoxins, rendering tropical and subtropical regions of the world particularly vulnerable (Chasna et al., 2024). Conversely, *Fusarium* species responsible for producing fumonisins, trichothecenes, and zearalenone tend to flourish in temperate climates characterized by moderate temperatures and high rainfall during the flowering and grain filling stages of crops (Ferrigo et al., 2016). Prolonged periods of drought stress combined with high humidity can facilitate fungal invasion and toxin synthesis (Yan et al., 2026).

Agricultural practices also significantly influence the vulnerability of crops to mycotoxin contamination. Factors such as crop variety, planting density, and soil fertility affect the resilience of plants to fungal infection (Ellouze et al., 2014). Crops weakened by nutrient deficiency, drought, or pest damage are more susceptible to fungal colonization. Insect infestation is equally significant, as it creates entry points for fungi and facilitates the dissemination of spores. Poor crop rotation and inadequate field sanitation can establish fungal inoculum in the soil, leading to elevated contamination levels in subsequent growing seasons

(Palti, 2012).

Post harvest handling and storage conditions are equally important determinants of mycotoxin levels in food crops. Delayed harvest, inadequate drying, and the storage of crops with elevated moisture content create conditions conducive to fungal growth and mycotoxin production (Awuchi et al., 2021). Poorly ventilated storage facilities, infestation by rodents or insects, and high ambient humidity further promote contamination. In many low income countries, the absence of proper storage infrastructure significantly increases exposure to mycotoxins (Nji et al., 2022). More recently, climate change has emerged as a major factor influencing the production and distribution of mycotoxins. Rising temperatures, shifting rainfall patterns, and the increased frequency of extreme weather events are altering fungal ecology and expanding the geographical range of toxigenic fungi, resulting in mycotoxin contamination in regions previously regarded as low risk and thereby posing escalating challenges for food safety management and public health protection (Olariu et al., 2025).

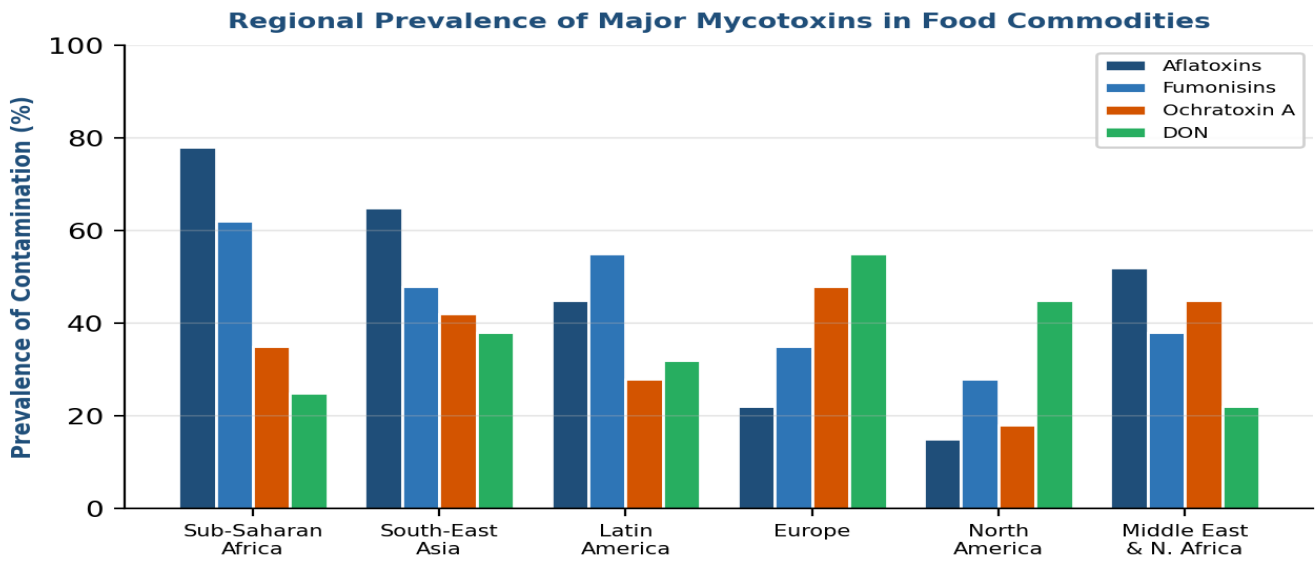


Figure 2: Regional prevalence of major mycotoxin classes in food commodities across six global regions. Data illustrate the disproportionate contamination burden in Sub-Saharan Africa and South-East Asia compared with temperate regions (Eskola *et al.*, 2020; Yilmaz *et al.*, 2025).

3. Food Commodities Commonly Contaminated

Mycotoxin contamination affects a broad range of food commodities, especially those of plant origin that are exposed to fungal infection during cultivation, harvesting, storage, and processing. Staple foods are particularly vulnerable, rendering mycotoxins a significant concern for food safety and public health in regions characterized by limited dietary diversity and heavy reliance on a few major crops (Yilmaz *et al.*, 2025).

Cereals and grains represent the most commonly contaminated food commodities and constitute the primary source of human exposure to mycotoxins worldwide. Crops such as maize, rice, and wheat are highly vulnerable to contamination by *Aspergillus* and *Fusarium* species (Nishimwe *et al.*, 2020). Maize is especially susceptible to fumonisin and aflatoxin contamination in warm and humid climates, whereas barley and wheat are primarily contaminated with trichothecenes and zearalenone. Rice can also harbor aflatoxins and ochratoxin A, particularly when improper drying and storage conditions favor fungal growth. Given that cereals comprise a substantial proportion of the daily diet, even low levels of contamination can result in chronic exposure over time.

Oilseeds and nuts represent another significant group of food commodities commonly affected by mycotoxin contamination. Groundnuts, tree nuts (including walnuts, almonds, and pistachios), and oilseeds are particularly prone to aflatoxin contamination during both the pre harvest and post harvest storage stages (Mirabile *et al.*, 2021). Insect damage, drought stress, and inadequate storage conditions significantly increase the risk of fungal invasion. Aflatoxin contamination in nuts has been reported extensively and remains a substantial challenge for food safety and international trade, given that many countries impose strict regulatory limits (Meneely *et al.*, 2023).

Spices and herbs are frequently contaminated with mycotoxins as a consequence of their cultivation in tropical regions and the traditional drying practices that expose them to environmental moisture. Products such as chili peppers, black pepper, ginger, turmeric, paprika, and dried herbs have been reported to contain aflatoxins

and ochratoxin A (Nafula *et al.*, 2021). The prolonged storage duration and absence of visible spoilage even after contamination further exemplify the "hidden" nature of mycotoxins in these products. Dairy products can be contaminated indirectly when livestock consume mycotoxin contaminated feed. When animals ingest feeds containing aflatoxin B₁, it is metabolized and excreted as aflatoxin M₁ in milk, subsequently contaminating milk, cheese, and other dairy products (Zentai *et al.*, 2023). This indirect pathway of contamination is of particular concern for young children and infants, given their vulnerability to mycotoxin toxicity and their proportionally high consumption of milk products.

Processed and stored foods are equally susceptible to mycotoxin contamination, particularly when raw materials are already contaminated or when processing and storage conditions are inadequate. Mycotoxins are largely heat stable and can withstand common food processing methods such as baking, roasting, and milling (Kaushik, 2015). Poor storage conditions, including elevated moisture, inadequate ventilation, and pest infestation, can further promote fungal growth and mycotoxin accumulation in processed foods (Magan *et al.*, 2021). Thus, mycotoxin contamination can persist throughout the food chain, constituting a long term risk to food safety and public health.

4. Routes of Human Exposure to Mycotoxins

Humans are exposed to mycotoxins through several routes, some of which occur unconsciously and over prolonged periods. Given that mycotoxins are widespread in food commodities and are chemically stable, they can gain entry into the human body through dietary intake, occupational activities, and early life exposure, posing both chronic and acute health risks.

Dietary intake constitutes the principal and most significant route of human exposure to mycotoxins. Consumption of contaminated staple foods such as cereals, grains, nuts, and their derived products leads to continuous ingestion of mycotoxins (Yu and Pedroso, 2023). Foods including maize, rice, wheat, peanuts, and dairy products are major contributors to mycotoxin exposure, particularly in regions where food safety monitoring is limited. Because mycotoxins can

withstand various food processing and cooking methods, they remain in prepared foods, allowing individuals to consume contaminated products unintentionally and without awareness of the exposure, resulting in long term health consequences (Schaarschmidt and Faulh-Hassek, 2018).

Occupational exposure represents an additional route by which workers in agriculture, grain handling, milling, and food processing may be exposed to mycotoxins through the inhalation of dust containing fungal spores and toxin particles. Poorly ventilated or enclosed working environments facilitate the accumulation of fungal spores and toxins. Occupational exposure has been associated with allergic reactions, respiratory symptoms, and systemic toxic effects, particularly upon repeated exposure (Viegas *et al.*, 2018).

Infant and maternal exposure constitutes a significant public health concern owing to the heightened vulnerability of fetuses and young children. Mycotoxins can traverse the placental barrier, thereby exposing the fetus during pregnancy, and can also be transferred to infants through breast milk, as demonstrated by the detection of aflatoxin M₁ in human milk (Fermiano *et al.*, 2025). Furthermore, infants may be exposed through contaminated complementary foods, particularly cereal based weaning products. Early life exposure to mycotoxins has been associated with stunted growth, immune impairment, and developmental deficits, underscoring the necessity for stringent mycotoxin controls in foods consumed by infants and pregnant women (Seyedtoughtouchi, 2022). Chronic low dose exposure and bioaccumulation are of particular interest because mycotoxin exposure most commonly occurs at subclinical levels over prolonged periods. Although acute toxicity may be relatively rare, long term ingestion of low doses of mycotoxins can produce cumulative toxic effects, including carcinogenesis, immunosuppression, and organ damage (Awuchi *et al.*, 2022). Additionally, certain mycotoxins such as ochratoxin A possess a long biological half life and can accumulate in body tissues, thereby amplifying the risk of chronic disease. This pattern of exposure is prevalent in populations with limited dietary variety and a heavy dependence on staple foods that may be contaminated.

5. Health Effects of Mycotoxins

5.1 Acute Toxicity

Acute mycotoxin toxicity occurs when humans or animals ingest elevated doses within a short period, resulting in severe and immediate health consequences. Although less common than chronic exposure, acute mycotoxicoses can be life threatening and have been documented in outbreaks associated with contaminated food products (Awuchi *et al.*, 2022). The severity of the effect depends on the type of mycotoxin involved, the dose, the duration of exposure, and the vulnerability of the affected individual.

Aflatoxins are among the mycotoxins most frequently associated with acute toxicity. Consumption of highly contaminated foods such as maize or groundnuts can cause aflatoxicosis, which manifests as liver damage, hemorrhage, jaundice, edema, and in severe cases, death. Outbreaks have been documented in tropical regions of Africa and Asia, with particularly high mortality rates among children (Benkerroum, 2020). Trichothecenes, including T-2 toxin and deoxynivalenol (DON), can also cause acute toxic effects. Consumption of contaminated cereals may result in vomiting, diarrhea, nausea, abdominal pain, and in serious cases, hematological disorders and immunosuppression. Exposure to T-2 toxin has been associated with toxic aleukia, a debilitating condition characterized by hemorrhage, bone marrow suppression, and high mortality (Janik *et al.*, 2021).

Ochratoxin A, while most frequently associated with chronic nephrotoxicity, can cause acute kidney damage at elevated doses, resulting in renal failure, electrolyte imbalance, and hypotension (Khoi *et al.*, 2021). Similarly, fumonisins can induce acute pulmonary edema in swine and leukoencephalomalacia in horses following high level exposure, highlighting their severe effects in both humans and animals (Smith and Gupta, 2025). Acute mycotoxin poisoning reinforces the critical importance of controlling and monitoring contamination in food supplies. Prompt detection, early intervention, and the removal of contaminated foods are essential for preventing outbreaks and minimizing the risk of severe illness and mortality in affected populations.

Mechanisms of Mycotoxin Toxicity in Human Systems

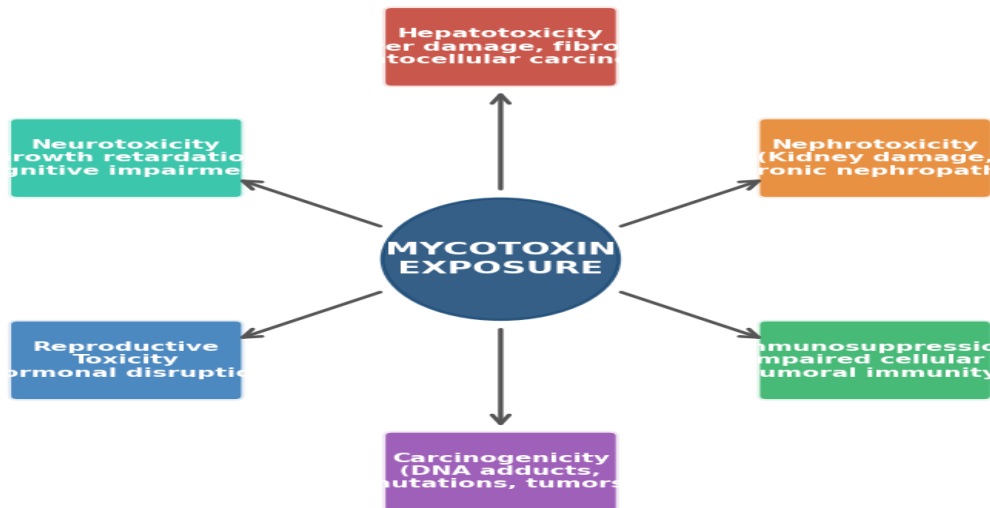


Figure 3: Schematic representation of the principal mechanisms through which mycotoxins exert toxicity in human organ systems. The central exposure event leads to multiple pathological outcomes across different organ systems (Awuchi *et al.*, 2022; Saha Turna *et al.*, 2024).

5.2 Chronic Health Effects

Chronic exposure to mycotoxins, occurring at low concentrations over prolonged periods, represents a major public health concern because of the long term cumulative effects on human health. In contrast to acute toxicity, which produces immediate symptoms, chronic mycotoxin exposure can result in serious organ damage, growth impairment, immune dysfunction, and elevated cancer risk (Huangfu *et al.*, 2025). The principal chronic health effects include hepatotoxicity, carcinogenicity, nephrotoxicity, and immune suppression.

The most extensively documented consequence of chronic mycotoxin exposure is hepatotoxicity caused by aflatoxins. Aflatoxin B₁ is metabolized in the liver to a reactive epoxide that binds to DNA, RNA, and proteins, causing hepatocyte injury, fibrosis, and potentially cirrhosis (Li *et al.*, 2022). Prolonged exposure is strongly associated with hepatocellular carcinoma, particularly in populations with high prevalence of hepatitis B virus infection, where the synergistic interaction markedly increases the risk of liver cancer (Shen *et al.*, 2023). Nephrotoxicity is predominantly associated with ochratoxin A, which accumulates in the kidney because of its long biological half life. Chronic exposure can result in diminished kidney function and, in severe situations, endemic nephropathy and chronic kidney disease. Ochratoxin induced nephropathy is characterized by fibrosis, proteinuria, and electrolyte imbalance, resulting in increased morbidity in affected populations (Khoi *et al.*, 2021).

Immunosuppression represents another serious consequence of prolonged mycotoxin exposure. Several mycotoxins, including aflatoxins, fumonisins, and trichothecenes, impair both humoral and cellular immunity (Saha Turna *et al.*, 2024). Chronic exposure diminishes the body's capacity to mount effective immune responses, thereby increasing susceptibility to infections, reducing vaccine efficacy, and exacerbating the effects of other environmental pathogens or toxins (Sun *et al.*, 2023). Carcinogenicity constitutes a grave outcome associated with certain mycotoxins. Aflatoxin B₁ is categorized as a Group 1 human carcinogen by IARC on account of its potent liver cancer inducing properties (Cao *et al.*, 2022). Chronic dietary exposure has been associated with elevated rates of hepatocellular

carcinoma in sub Saharan Africa and parts of Asia. Fumonisin and ochratoxin A are also suspected of possessing carcinogenic potential, with evidence suggesting associations with esophageal cancer and kidney cancer, respectively, although these links remain less firmly established than the association between aflatoxins and hepatocarcinogenesis (Awuchi *et al.*, 2022).

Overall, chronic mycotoxin exposure constitutes a silent yet profound risk to human health, especially in low to middle income countries where populations depend heavily on contaminated dietary staples. Food safety interventions, regular monitoring, and public health awareness campaigns are essential for minimizing these effects and protecting vulnerable communities.

5.3 Vulnerable Populations

Certain individuals within the population are inherently more susceptible to the effects of mycotoxins because of developmental, immunological, and physiological factors. Pregnant women, children, and immunocompromised persons face elevated risk of experiencing both chronic and acute effects, even at low exposure levels, rendering them priority targets for public health interventions.

Children are particularly susceptible to mycotoxin toxicity because of their lower body mass, developing organs, and proportionally higher dietary intake relative to body weight. Repeated exposure to aflatoxins and other mycotoxins has been linked to growth retardation, compromised development, and impaired cognitive function in children (Mahfuz *et al.*, 2022). Research findings from Asia and Sub-Saharan Africa have demonstrated that dietary exposure to aflatoxin contaminated maize and groundnuts is associated with reduced weight for age and height for age scores, reflecting long term impacts on child health and development (Akullo *et al.*, 2025). Pregnant women constitute another highly susceptible group, as mycotoxins can cross the placental barrier, posing risks to both maternal and fetal health (Silva *et al.*, 2025). Prenatal exposure to fumonisins and aflatoxins has been associated with intrauterine growth restriction, low birth weight, and developmental abnormalities (Kadan and Aral, 2021). Maternal exposure can also weaken the immune system of both mother and fetus, thereby

increasing their susceptibility to infections and chronic diseases later in life.

Immunocompromised individuals, including people living with HIV/AIDS, cancer patients undergoing chemotherapy, and organ transplant recipients, represent another group that is particularly susceptible to mycotoxin exposure. Mycotoxins such as aflatoxins, trichothecenes, and ochratoxin A can aggravate immune dysfunction, impairing both innate and adaptive immune responses (Kraft *et al.*, 2021). This diminished immunity increases vulnerability to opportunistic infections, delays recovery from illness, and may further deteriorate any underlying health condition.

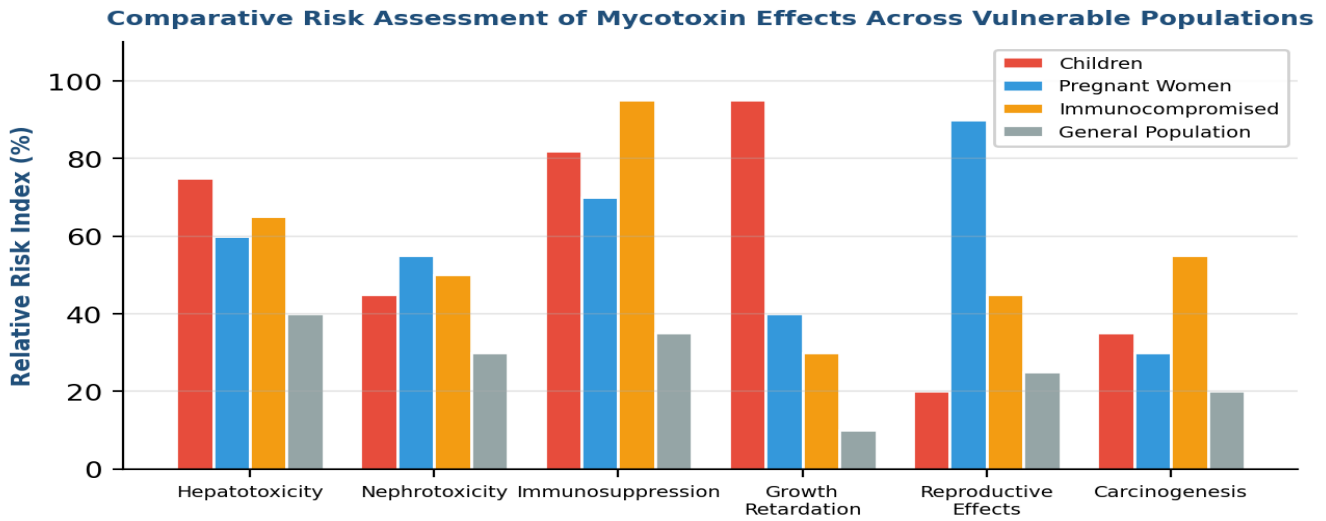


Figure 4: Comparative risk assessment of mycotoxin effects across vulnerable population groups, illustrating the heightened susceptibility of children, pregnant women, and immunocompromised individuals relative to the general population (Mahfuz *et al.*, 2022; Kraft *et al.*, 2021; Silva *et al.*, 2025).

6. Mycotoxins and Public Health Implications

Mycotoxins pose a significant public health challenge, especially in developing countries where climatic conditions, agricultural practices, and limitations in food safety infrastructure contribute to the widespread occurrence of contamination (Chilenga *et al.*, 2025). The economic, nutritional, and health burdens attributable to mycotoxin contamination are immense, affecting millions of people globally and amplifying existing public health challenges such as infectious diseases and malnutrition.

Developing countries in Sub-Saharan Africa, South-East Asia, and parts of Latin America bear the greatest burden of mycotoxin related illnesses. Populations in these regions, constrained by economic circumstances, depend predominantly on staple crops such as groundnuts and maize, which are highly susceptible to contamination by fumonisins and aflatoxins (Okello *et al.*, 2010). Chronic exposure in these settings has been linked to liver cancer, impaired growth, and immunosuppression, contributing to higher mortality and morbidity rates (Allison *et al.*, 2015). Acute outbreaks of aflatoxicosis have been reported in countries such as Tanzania and Kenya, resulting in severe illness and death and underscoring the urgent necessity for public health interventions.

Mycotoxins compromise food safety through the contamination of staple foods and agricultural products, rendering them unfit for human consumption. Contaminated foods not only pose significant health risks but also limit the availability and quality of food, thereby contributing to food insecurity (Sharif *et al.*, 2024). In parts of the world where alternative food sources are limited, dependence on contaminated staple foods can result in chronic exposure, creating a self-perpetuating cycle of poor health and diminished productivity (Lebelo *et al.*, 2021). Mycotoxin contamination also carries substantial economic implications. Losses occur at multiple points along the food supply chain, including reduced crop yields, rejection of contaminated products in both domestic and international markets, and increased expenditure on food testing and mitigation (Kumar and Kalita, 2017). In developing countries where agriculture forms the backbone of the economy, such losses can worsen

poverty and constrain investment in healthcare, perpetuating vulnerability to mycotoxin related health risks (Gbashi *et al.*, 2018).

Chronic mycotoxin exposure interacts with other determinants of health, including infectious diseases and malnutrition. Mycotoxins such as aflatoxins and fumonisins impair nutrient absorption, retard growth in children, and weaken immune function (Gbashi *et al.*, 2018). This immunosuppression increases susceptibility to infections such as malaria, diarrheal diseases, and respiratory illnesses that are prevalent in developing countries. Consequently, mycotoxin contamination serves to exacerbate both the burden of infectious diseases and nutritional deficiencies, creating compounding health risks for already vulnerable populations.

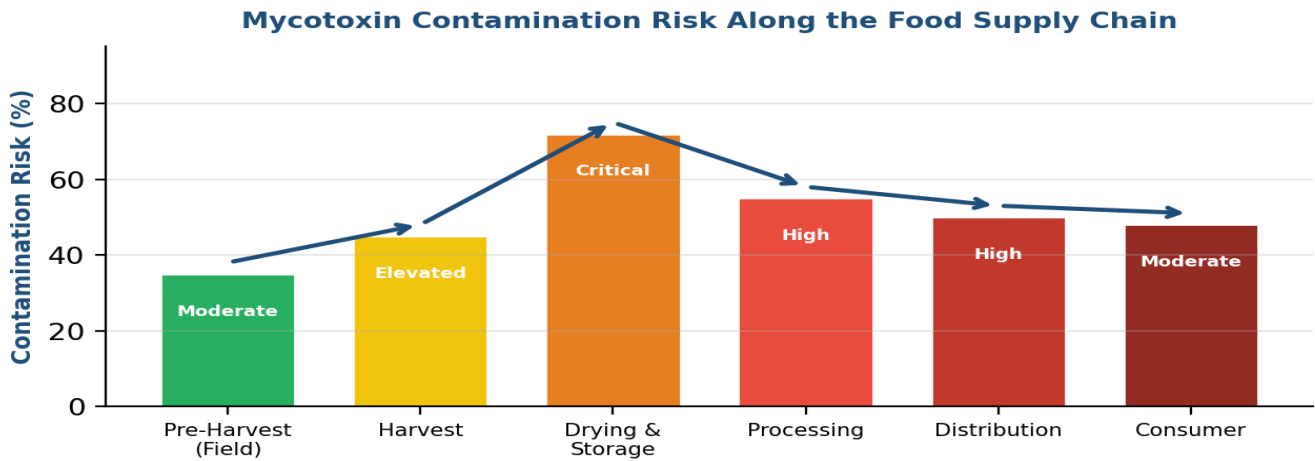


Figure 5: Mycotoxin contamination risk profile along the food supply chain, from pre harvest stages through consumer exposure. Storage represents the most critical control point for contamination management (Gachara *et al.*, 2024; Awuchi *et al.*, 2021).

7. Prevention and Control Strategies

Prevention and control of mycotoxin contamination is crucial for reducing public health risks, enhancing food safety, and minimizing economic losses. Effective control strategies must target multiple points along the food production and supply chain, encompassing cultivation practices, post harvest handling, food processing, and public education.

Pre harvest control focuses on minimizing fungal infection in crops during cultivation. The deployment of resistant crop varieties, optimized planting schedules, proper irrigation, and timely fertilizer application reduces plant stress and susceptibility to fungal infection (Begna, 2020). Crop rotation and the removal of infected plant materials diminish the fungal inoculum in the soil. Pest management practices aimed at controlling insect damage are also important, as insects create entry points for toxigenic fungi (Bava *et al.*, 2022). The application of biocontrol agents, such as atoxigenic strains of *Aspergillus flavus*, offers a promising approach to competitively exclude toxigenic strains in the field, thereby reducing aflatoxin contamination (Abbas *et al.*, 2009). Molecular breeding and genetic engineering provide additional avenues for developing crop varieties with enhanced resistance to fungal infection.

Post harvest management is equally critical. Adequate drying of grains and nuts to safe moisture levels, adherence to proper storage conditions, and the use of insect proof and hermetically sealed storage containers significantly reduce contamination after harvest and during storage. Visual sorting and removal of damaged crops also decreases mycotoxin levels in stored commodities. Food processing and detoxification methods can further reduce the mycotoxin content of contaminated products. Although complete removal of mycotoxins from food is often difficult owing to their chemical stability, techniques such as fermentation, milling, extrusion, roasting, and chemical treatment can lower toxin concentrations (Shanakhat *et al.*, 2018). Adequate cooking, washing, and sorting practices also contribute to reducing exposure. Additionally, certain bacteria and yeasts are capable of degrading mycotoxins into less toxic compounds during storage and processing, offering a biological approach to detoxification.

Regulatory frameworks and public awareness constitute the final pillars of an integrated mycotoxin control strategy. Establishing and enforcing maximum permissible limits for mycotoxins in food commodities, implementing national surveillance programs, and promoting international cooperation on food safety standards are essential for protecting public health. Community based education programs that raise awareness about proper agricultural and storage practices, the health risks of mycotoxin exposure, and the importance of consuming safe food play a vital role in reducing contamination, particularly in resource limited settings.

Integrated Framework for Mycotoxin Prevention and Control

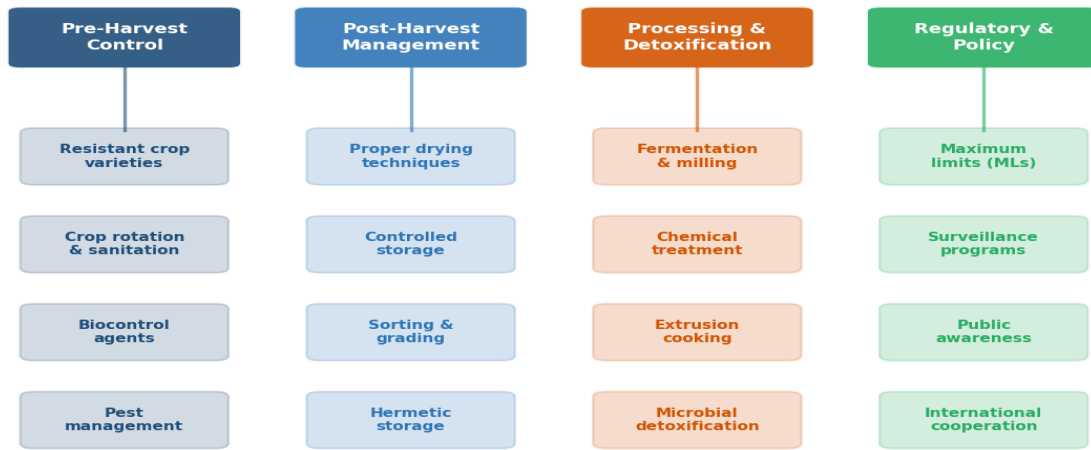


Figure 6: Integrated framework for mycotoxin prevention and control, illustrating the four major intervention categories and their constituent strategies spanning the food production and supply chain (Abbas *et al.*, 2009; Shanakhat *et al.*, 2018; Bava *et al.*, 2022).

8. Conclusion

Mycotoxins, as hidden food contaminants, represent a significant and multifaceted concern for global public health. These toxic secondary metabolites produced by fungi such as *Aspergillus*, *Fusarium*, and *Penicillium* contaminate a broad spectrum of food commodities, including cereals, nuts, spices, dairy products, and processed foods. Exposure occurs primarily through dietary intake but can also take place early in life through maternal transmission. Both acute and chronic exposures have been associated with severe health conditions, including aflatoxicosis, liver damage, immunosuppression, nephrotoxicity, stunted growth in children, and carcinogenic outcomes.

Vulnerable populations, notably pregnant women, children, and immunocompromised individuals, face elevated risk, reinforcing the need for targeted intervention. Control strategies spanning pre harvest agricultural practices, post harvest storage and processing, and biological control measures are critical for minimizing contamination along the food supply chain. Addressing the challenges posed by mycotoxin contamination necessitates integrated food safety and public health approaches that combine scientific innovation, regulatory enforcement, and community awareness. The implementation of such strategies, directed at preventing contamination, enabling early detection, and facilitating effective mitigation, will improve food security, protect vulnerable populations, and reduce the global burden of mycotoxin related illnesses.

Acknowledgments

The authors acknowledge the institutional support of their respective universities and research centers. No external funding was received for the preparation of this manuscript.

References

- [1] Abbas, H.K., Wilkinson, J.R., Zablotowicz, R.M., Accinelli, C.E.S.A.R.E., Abel, C.A., Bruns, H.A. and Weaver, M.A. (2009). Ecology of *Aspergillus flavus*, regulation of aflatoxin production, and management strategies to reduce aflatoxin contamination of corn. *Toxin Reviews*, 28(2-3), 142-153.
- [2] Abdelmotilib, N.M., Darwish, A.G., Abdel-Azeem, A.M. and Sheir, D.H. (2021). Fungal mycotoxins. In *Fungi in Sustainable Food Production* (pp. 197-226). Springer International Publishing.
- [3] Abrar, M., Anjum, F.M., Butt, M.S., Pasha, I., Randhawa, M.A., Saeed, F. and Waqas, K. (2013). Aflatoxins: biosynthesis, occurrence, toxicity, and remedies. *Critical Reviews in Food Science and Nutrition*, 53(8), 862-874.
- [4] Akullo, J.O., Okello, D.K., Mohammed, A., Muyinda, R., Amayo, R., Magumba, D. and Mweetwa, A. (2025). A comprehensive review of aflatoxin in groundnut and maize products in Africa. *Journal of Food Quality*, 2025(1), 2810946.
- [5] Alam, S., Nisa, S. and Daud, S. (2022). Mycotoxins in environment and its health implications. In *Hazardous Environmental Micro-pollutants, Health Impacts and Allied Treatment Technologies* (pp. 289-318). Springer International Publishing.
- [6] Allison, R.D., Tong, X., Moorman, A.C., Ly, K.N., Rupp, L. and Xu, F. (2015). Increased incidence of cancer and cancer-related mortality among persons with chronic hepatitis C infection. *Journal of Hepatology*, 63(4), 822-828.
- [7] Arumugam, T. and Chuturgoon, A.A. (2021). Toxicoepigentic consequences of fumonisin B1 exposure. *Epigenomics*, 13(23), 1849-1852.
- [8] Awuchi, C.G., Ondari, E.N., Eseoghene, I.J., Twinomuhwezi, H., Amagwula, I.O. and Morya, S. (2021). Fungal growth and mycotoxins production: types, toxicities, control strategies, and detoxification. In *Fungal Reproduction and Growth*. IntechOpen.
- [9] Awuchi, C.G., Ondari, E.N., Nwozo, S., Odongo, G.A., Eseoghene, I.J., Twinomuhwezi, H. and Okpala, C.O.R. (2022). Mycotoxins' toxicological mechanisms involving humans, livestock and their associated health concerns: a review. *Toxins*, 14(3), 167.
- [10] Banahene, J.C.M., Ofosu, I.W., Odai, B.T., Lutterodt, H.E., Agyemang, P.A. and Ellis, W.O. (2024). Ochratoxin A in food commodities: a review of occurrence, toxicity, and management strategies. *Heliyon*, 10(20).
- [11] Bava, R., Castagna, F., Piras, C., Musolino, V., Lupia, C., Palma, E. and Musella, V. (2022). Entomopathogenic fungi for pests and predators control in beekeeping. *Veterinary Sciences*, 9(2), 95.
- [12] Begna, T. (2020). Major challenging constraints to crop production farming system. *International Journal of Research Studies in Agricultural Sciences*, 6(7), 27-46.
- [13] Benkerroum, N. (2020). Aflatoxins: producing-molds, structure, health issues and incidence in Southeast Asian and Sub-Saharan African countries. *International Journal of Environmental Research and Public Health*, 17(4), 1215.
- [14] Cao, W., Yu, P., Yang, K. and Cao, D. (2022). Aflatoxin B1: metabolism, toxicology, and its involvement in oxidative stress and cancer development. *Toxicology Mechanisms and Methods*, 32(6), 395-419.
- [15] Chasna, M., Rajawardana, D. and Amunugoda, P.N.R.J. (2024). An overview of the impact of climatic change on the

occurrence of aflatoxins in cereals. *YSF Thematic Publication*, 2024, 19.

[16] Chen, J., Li, Z., Cheng, Y., Gao, C., Guo, L., Wang, T. and Xu, J. (2020). Sphinganine-analog mycotoxins (SAMs): chemical structures, bioactivities, and genetic controls. *Journal of Fungi*, 6(4), 312.

[17] Chilenga, C., Masamba, K., Kasapila, W., Ndhlovu, B., Munkhuwa, V., Rafoneke, L. and Machira, K. (2025). Mycotoxin management in Sub-Saharan Africa: a comprehensive systematic review. *Toxicology Reports*, 14, 101871.

[18] Cope, R.B. (2025). Trichothecenes. In *Veterinary Toxicology* (pp. 1083-1093). Academic Press.

[19] Dabuo, B., Avogo, E.W., Koomson, G.O., Akantibila, M. and Gbati, D.A. (2022). Aflatoxins: toxicity, occurrences and chronic exposure. In *Aflatoxins-Occurrence, Detection and Novel Detoxification Strategies*. IntechOpen.

[20] Egbuta, M.A., Mwanza, M. and Babalola, O.O. (2017). Health risks associated with exposure to filamentous fungi. *International Journal of Environmental Research and Public Health*, 14(7), 719.

[21] Ellouze, W., Esmaeili Taheri, A., Bainard, L.D., Yang, C. and Hamel, C. (2014). Soil fungal resources in annual cropping systems and their potential for management. *BioMed Research International*, 2014(1), 531824.

[22] Eskola, M., Kos, G., Elliott, C.T., Hajslova, J., Mayar, S. and Krska, R. (2020). Worldwide contamination of food-crops with mycotoxins. *Critical Reviews in Food Science and Nutrition*, 60(16), 2773-2789.

[23] Fermiano, J.T.A., Ali, S., Ullah, S., Rezende, V.T., Rosim, R.E. and Ramalho, F.S. (2025). Assessment of maternal exposure to mycotoxins during pregnancy through biomarkers. *Toxins*, 17(10), 518.

[24] Ferrigo, D., Raiola, A. and Causin, R. (2016). Fusarium toxins in cereals: occurrence, legislation, factors promoting the appearance and their management. *Molecules*, 21(5), 627.

[25] Fung, F. and Clark, R.F. (2004). Health effects of mycotoxins: a toxicological overview. *Journal of Toxicology: Clinical Toxicology*, 42(2), 217-234.

[26] Gachara, G., Suleiman, R., Kilima, B., Taoussi, M., El Kadili, S. and Lahlali, R. (2024). Pre- and post-harvest aflatoxin contamination and management strategies in East African Community maize. *Mycotoxin Research*, 40(4), 495-517.

[27] Gbashi, S., Madala, N.E., De Saeger, S., De Boevre, M., Adekoya, I., Adebo, O.A. and Njobeh, P.B. (2018). The socio-economic impact of mycotoxin contamination in Africa. In *Mycotoxins-Impact and Management Strategies*. IntechOpen.

[28] Guchi, E. (2015). Aflatoxin contamination in groundnut (*Arachis hypogaea* L.) caused by *Aspergillus* species in Ethiopia. *Journal of Applied and Environmental Microbiology*, 3(1), 11-19.

[29] Huangfu, B., Chen, Y., Xu, T., Huang, K., Liang, Z. and He, X. (2025). Mycotoxins and non-communicable diseases: exacerbation and susceptibility. *Critical Reviews in Food*

Science and Nutrition, 1-17.

[30] Janik, E., Niemcewicz, M., Podogrocki, M., Ceremuga, M., Stela, M. and Bijak, M. (2021). The existing methods and novel approaches in mycotoxins' detection. *Molecules*, 26(13), 3981.

[31] Kabak, B. (2009). The fate of mycotoxins during thermal food processing. *Journal of the Science of Food and Agriculture*, 89(4), 549-554.

[32] Kadan, G. and Aral, N. (2021). Effects of mycotoxins on child development. *Current Molecular Pharmacology*, 14(5), 770-781.

[33] Kaushik, G. (2015). Effect of processing on mycotoxin content in grains. *Critical Reviews in Food Science and Nutrition*, 55(12), 1672-1683.

[34] Khoi, C.S., Chen, J.H., Lin, T.Y., Chiang, C.K. and Hung, K.Y. (2021). Ochratoxin A-induced nephrotoxicity: up-to-date evidence. *International Journal of Molecular Sciences*, 22(20), 11237.

[35] Klich, M.A. (2007). *Aspergillus flavus*: the major producer of aflatoxin. *Molecular Plant Pathology*, 8(6), 713-722.

[36] Kraft, S., Buchenauer, L. and Polte, T. (2021). Mold, mycotoxins and a dysregulated immune system: a combination of concern? *International Journal of Molecular Sciences*, 22(22), 12269.

[37] Kumar, D. and Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, 6(1), 8.

[38] Lebelo, K., Malebo, N., Mochane, M.J. and Masinde, M. (2021). Chemical contamination pathways and the food safety implications along the various stages of food production. *International Journal of Environmental Research and Public Health*, 18(11), 5795.

[39] Li, C., Liu, X., Wu, J., Ji, X. and Xu, Q. (2022). Research progress in toxicological effects and mechanism of aflatoxin B1 toxin. *PeerJ*, 10, e13850.

[40] Li, X., Ma, W., Ma, Z., Zhang, Q. and Li, H. (2021). The occurrence and contamination level of ochratoxin A in plant and animal-derived food commodities. *Molecules*, 26(22), 6928.

[41] Longobardi, C., Ferrara, G., Andretta, E., Montagnaro, S., Damiano, S. and Ciarcia, R. (2022). Ochratoxin A and kidney oxidative stress: the role of nutraceuticals in veterinary medicine. *Toxins*, 14(6), 398.

[42] Lv, Q., Xu, W., Yang, F., Wei, W., Chen, X., Zhang, Z. and Liu, Y. (2025). Reproductive toxicity of zearalenone and its molecular mechanisms: a review. *Molecules*, 30(3), 505.

[43] Magan, N., Garcia-Cela, E., Verheeecke-Vaessen, C., Medina, A., Jin, Z. and Sandoval-Contreras, T. (2021). *Instant Insights: Mycotoxin Detection and Control* (Vol. 27). Burleigh Dodds Science Publishing.

[44] Magembe, K.S. (2025). Mycotoxins impact in food, human and animal health with special reference to aflatoxins, fumonisins, ochratoxins, zearalenone, and deoxynivalenol. *European Journal of Research in Medical Sciences*, 10(1).

- [45] Mahfuz, M., Hossain, M.S., Alam, M.A., Gazi, M.A., Fahim, S.M., Nahar, B. and Ahmed, T. (2022). Chronic aflatoxin exposure and cognitive and language development in young children of Bangladesh. *Toxins*, 14(12), 855.
- [46] Maurya, U. (2025). Health implications of mycotoxins in the food chain: mechanisms of toxicity and risk assessment. A review.
- [47] Meneely, J.P., Kolawole, O., Haughey, S.A., Miller, S.J., Krska, R. and Elliott, C.T. (2023). The challenge of global aflatoxins legislation with a focus on peanuts and peanut products. *Exposure and Health*, 15(2), 467-487.
- [48] Mirabile, G., Bella, P., Vella, A., Ferrantelli, V. and Torta, L. (2021). Fungal contaminants and mycotoxins in nuts. In *Nuts and Nut Products in Human Health and Nutrition*. IntechOpen.
- [49] Munkvold, G.P. (2016). *Fusarium* species and their associated mycotoxins. *Mycotoxigenic Fungi: Methods and Protocols*, 51-106.
- [50] Nafula, W.C. and Obura, N.A. (2021). Mycotoxins contaminating herbs and spices in Africa: a review. *African Journal of Biological Sciences*, 3(3), 10-28.
- [51] Nishimwe, K., Mandap, J.A.L. and Munkvold, G.P. (2020). Advances in understanding fungal contamination in cereals. *Advances in Postharvest Management of Cereals and Grains*, 31-66.
- [52] Nji, Q.N., Babalola, O.O., Ekwomadu, T.I., Nleya, N. and Mwanza, M. (2022). Six main contributing factors to high levels of mycotoxin contamination in African foods. *Toxins*, 14(5), 318.
- [53] Okello, D.K., Kaaya, A.N., Bisikwa, J., Were, M. and Oloka, H.K. (2010). Aflatoxins in groundnuts. *Management of Aflatoxins in Groundnuts*. NARO, Entebbe.
- [54] Olariu, R.M., Fit, N.I., Bouari, C.M. and Nadas, G.C. (2025). Mycotoxins in broiler production: impacts on growth, immunity, vaccine efficacy, and food safety. *Toxins*, 17(6), 261.
- [55] Omotayo, O.P., Omotayo, A.O., Mwanza, M. and Babalola, O.O. (2019). Prevalence of mycotoxins and their consequences on human health. *Toxicological Research*, 35(1), 1-7.
- [56] Palti, J. (2012). *Cultural Practices and Infectious Crop Diseases*. Springer Science and Business Media.
- [57] Perrone, G., Ferrara, M., Medina, A., Pascale, M. and Magan, N. (2020). Toxicogenic fungi and mycotoxins in a climate change scenario. *Microorganisms*, 8(10), 1496.
- [58] Saha Turna, N., Comstock, S.S., Gangur, V. and Wu, F. (2024). Effects of aflatoxin on the immune system: evidence from human and mammalian animal research. *Critical Reviews in Food Science and Nutrition*, 64(27), 9955-9973.
- [59] Sajjad, Y., Dib, J., Soliman, N., Alhmodi, M., Sajjad, S.G., Kandil, H. and Fakih, M. (2025). The role of mycotoxins in reproductive health. *Journal of IVF-Worldwide*, 3(1), 42-55.
- [60] Sanchez-Montero, L., Cordoba, J.J., Peromingo, B., Alvarez, M. and Nunez, F. (2019). Effects of environmental conditions and substrate on growth and ochratoxin A production by *Penicillium verrucosum* and *P. nordicum*. *Food Research International*, 121, 604-611.
- [61] Schaarschmidt, S. and Fauhl-Hassek, C. (2018). The fate of mycotoxins during the processing of wheat for human consumption. *Comprehensive Reviews in Food Science and Food Safety*, 17(3), 556-593.
- [62] Seyedtoughtouchi, S. (2022). The effects of mycotoxins on pregnancy and immune development: a preclinical approach.
- [63] Shanakhat, H., Sorrentino, A., Raiola, A., Romano, A., Masi, P. and Cavella, S. (2018). Current methods for mycotoxins analysis and innovative strategies for their reduction in cereals. *Journal of the Science of Food and Agriculture*, 98(11), 4003-4013.
- [64] Sharif, M.K., Sarwar, K., Abid, N. and Bashir, M.A. (2024). Food security, food safety, and sanitation. *Food Security in the Developing World*, 191-225.
- [65] Sharma, R.K. and Parisi, S. (2017). *Toxins and Contaminants in Indian Food Products* (pp. 13-24). Springer International Publishing.
- [66] Shen, C., Jiang, X., Li, M. and Luo, Y. (2023). Hepatitis virus and hepatocellular carcinoma: recent advances. *Cancers*, 15(2), 533.
- [67] Silva, P.O., Ramalho, L.N., Oliveira, C.A. and Ramalho, F.S. (2024). Reproductive, gestational, and fetal alterations induced by dietary mycotoxins. *Pesquisa Veterinaria Brasileira*, 44, e07481.
- [68] Smith, G.W. and Gupta, R.C. (2025). Fumonisin. In *Veterinary Toxicology* (pp. 1039-1056). Academic Press.
- [69] Sun, Y., Song, Y., Long, M. and Yang, S. (2023). Immunotoxicity of three environmental mycotoxins and their risks of increasing pathogen infections. *Toxins*, 15(3), 187.
- [70] Viegas, S., Viegas, C. and Oppliger, A. (2018). Occupational exposure to mycotoxins: current knowledge and prospects. *Annals of Work Exposures and Health*, 62(8), 923-941.
- [71] Yan, H., Sun, J., Fu, X., Ye, J., Wang, W. and Sun, X. (2026). Climate change: an inevitable factor in reshaping the contamination level of fungi and mycotoxins. *Comprehensive Reviews in Food Science and Food Safety*, 25(1), e70354.
- [72] Yilmaz, N., Verheeecke-Vaessen, C. and Ezekiel, C.N. (2025). Mycotoxins: an ongoing challenge to food safety and security. *PLoS Pathogens*, 21(11), e1013672.
- [73] Yu, H., Zhang, J., Chen, Y. and Zhu, J. (2022). Zearalenone and its masked forms in cereals and cereal-derived products. *Journal of Fungi*, 8(9), 976.
- [74] Yu, J. and Pedroso, I.R. (2023). Mycotoxins in cereal-based products and their impacts on the health of humans, livestock animals and pets. *Toxins*, 15(8), 480.
- [75] Zentai, A., Jozwiak, A., Suth, M. and Farkas, Z. (2023). Carry-over of aflatoxin B1 from feed to cow milk: a review. *Toxins*, 15(3), 195.