AFLATOXIN CONTAMINATION IN FOOD AND FEED: RISKS AND CONTROL STRATEGIES

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REVIEW

Abstract
The impact of aflatoxins on health is multifaceted, manifesting through both acute and chronic effects. Acute aflatoxicosis results from the ingestion of high doses and is characterized by severe hepatic damage, hemorrhage, and high mortality rates. Chronic exposure to low levels of aflatoxins, however, is far more common and has been associated with carcinogenic, immunosuppressive, and mutagenic effects. In agriculture and animal production, the effects of aflatoxins are particularly significant from an economic perspective. Animals consuming contaminated feed often exhibit reduced productive performance, reproductive disorders, immunosuppression, and increased mortality. Beyond their adverse health effects, aflatoxins also cause substantial economic losses through crop downgrading and rejection, trade restrictions, and the costs associated with monitoring and control measures.

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INTRODUCTION

Monitoring and controlling aflatoxins constitute a priority for ensuring the safety of the agri-food supply chain. International organizations such as Food and Agriculture Organization (FAO), World Health Organization (WHO), and European Food Safety Authority (EFSA) have established maximum permissible limits for aflatoxins in food and feed, as well as standardized detection methods. Compliance with these limits is essential for protecting public health and maintaining agricultural trade (EFSA, 2020).

In the context of intensified agricultural production and ongoing climate change, the study of aflatoxins has become increasingly relevant. Understanding the sources of contamination, mechanisms of toxicity, and preventive measures is essential for reducing the risks posed to both humans and animals. Therefore, the present study aims to examine aflatoxins from agricultural and veterinary public health perspectives, highlighting their impact on health, animal production, and food safety, as well as current strategies for their prevention and control.

The concept of food safety encompasses all measures and conditions necessary to prevent food contamination and to ensure that food products are safe for human consumption throughout the entire production chain, from “farm to fork” (WHO, 2020). Agricultural products may become contaminated with biological agents (bacteria, fungi, and viruses), chemical contaminants (pesticides, heavy metals, and mycotoxins), or physical hazards (foreign bodies), each of which represents a potential risk to consumer health. Among these contaminants, mycotoxins are of particular concern due to their high prevalence and their severe toxic effects, even at low concentrations (Bennett & Klich, 2003). The consumption of contaminated food can lead to the development of acute or chronic health disorders, ranging from foodborne intoxications to serious diseases such as cancer and hepatic or renal disorders. In the case of mycotoxins, chronic exposure to low concentrations is especially hazardous because their effects are cumulative and often difficult to detect at an early stage. For example, aflatoxins have been strongly associated with the development of hepatocellular carcinoma and are classified as Group 1 human carcinogens (IARC, 2012).

MATERIAL AND METHOD

Aflatoxins are among the most hazardous mycotoxins encountered in the agri-food chain due to their high toxicity, chemical stability, and ability to induce severe pathological effects in both humans and animals. They are classified into several types according to their chemical structure and the fluorescence they exhibit under ultraviolet light. Their nomenclature is derived from the color of fluorescence observed: blue (B) or green (G).

Aflatoxin B1 is the most frequently detected and the most toxic of all aflatoxins. It exhibits potent hepatotoxic, mutagenic, and carcinogenic properties. In both humans and animals, aflatoxin B1 is metabolized in the liver, where it is converted into a highly reactive epoxide capable of binding to DNA and inducing genetic mutations (IARC, 2012). From an agricultural perspective, aflatoxin B1 is the primary form monitored in cereals and animal feed, and its maximum permissible levels are strictly regulated within the European Union.

Aflatoxin B2 is structurally similar to aflatoxin B1 but exhibits lower toxicity. It is commonly detected alongside aflatoxin B1 in contaminated products and is considered an additional indicator of fungal contamination (Pitt & Hocking, 2009).

Aflatoxins G1 and G2 are produced primarily by Aspergillus parasiticus and, less frequently, by Aspergillus flavus. These toxins exhibit green fluorescence under ultraviolet light and are commonly found in peanuts, maize, and other agricultural commodities cultivated under warm climatic conditions (Klich, 2007). Although their toxicity is lower than that of aflatoxin B1, their presence contributes to the overall toxicity of aflatoxin mixtures.

Aflatoxin M1 is a hydroxylated metabolite of aflatoxin B1, formed through its biotransformation in the liver of mammals. Aflatoxin M1 is excreted in milk and can be detected in raw milk and dairy products, posing a significant risk to infants and young children (EFSA, 2020). Although aflatoxin M1 is less toxic than aflatoxin B1, it retains carcinogenic properties and is therefore strictly regulated within the European Union.From a chemical standpoint,aflatoxins are polycyclic heterocyclic compounds belonging to the difuranocoumarin class. Their complex molecular structure is responsible for both their chemical stability and their high biological activity. The principal physicochemical properties of aflatoxins include a relatively low molecular weight, a planar molecular structure that facilitates interaction with DNA, intense fluorescence under ultraviolet radiation, high solubility in organic solvents such as methanol, acetone, and chloroform, and low solubility in water.

Aflatoxins are relatively stable under moderate pH variations and are not readily degraded by simple chemical processes. This stability allows them to persist in agricultural commodities for extended periods, including during storage and industrial processing (Pitt & Hocking, 2009). An essential aspect of the hazard posed by aflatoxins is their high thermal stability. For example, conventional cooking processes may reduce aflatoxin concentrations by only 10–30%, a reduction that is generally insufficient to eliminate the risk to consumers (Williams et al., 2004). The mechanism of aflatoxin toxicity is complex and involves a series of biochemical and molecular processes that lead to cellular dysfunction and the development of severe pathological effects. Another important aspect of their toxic mechanism is the inhibition of protein synthesis. Aflatoxins interfere with ribosomal function and with the processes of transcription and translation, resulting in decreased production of proteins essential for normal cellular activity. The toxic effects of aflatoxins are influenced by the balance between metabolic activation and detoxification pathways.

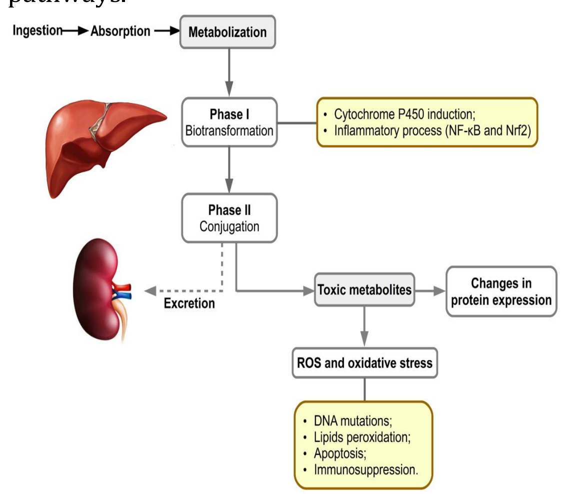

Figure 1. Toxic Mechanism of Aflatoxin (Liver and DNA Interaction) (Popescu et al., 2022)

The process of aflatoxin detection generally involves several stages, including sample collection, toxin extraction from the analyzed matrix, purification of the extract, and, finally, analytical determination. European legislation establishes standardized sampling and analytical procedures designed to ensure the representativeness and reliability of the results (Commission Regulation (EC) No. 401/2006). Among the most widely used detection methods are chromatographic techniques, particularly High-Performance Liquid Chromatography (HPLC), which provides high sensitivity and accuracy for the determination of aflatoxins in food and feed samples (IARC, 2012). A modern and highly sensitive analytical approach is Liquid Chromatography coupled with Tandem Mass Spectrometry (LC-MS/MS), which enables the simultaneous identification and quantification of multiple mycotoxins within a single analysis (EFSA, 2020). In addition to chromatographic methods, immunological assays such as Enzyme-Linked Immunosorbent Assays (ELISA) are widely employed because of their rapidity and ease of application. These tests are based on the specific interaction between the antigen (aflatoxin) and the corresponding antibody, allowing the rapid detection of toxins in the analyzed samples (Bennett & Klich, 2003).

In recent years, rapid detection methods have been developed for use in the field and at grain reception facilities. These include immunochromatographic strip tests, which provide results within minutes and do not require sophisticated laboratory equipment. Although these methods do not offer precise quantification, they are valuable for the rapid screening of contaminated lots and for supporting immediate decisions regarding their acceptance or rejection.

Furthermore, spectroscopic methods and biosensors represent emerging approaches in aflatoxin detection.Infrared spectroscopy and fluorescence-based techniques can be used for the indirect identification of contamination, while nanotechnology-based biosensors offer the potential for the development of rapid, sensitive, and portable detection systems.

RESULTS AND DISCUSSIONS

Influence of Climatic Factors and Climate Change on Aflatoxin Contamination

Climatic conditions play a crucial role in the development of aflatoxin-producing fungi and in the subsequent accumulation of aflatoxins in agricultural commodities. Temperature, relative humidity, drought stress, and rainfall patterns are among the most important environmental factors influencing fungal growth and toxin production. Species of the genus Aspergillus, particularly Aspergillus flavus and Aspergillus parasiticus, thrive under warm and humid conditions, which favor both fungal proliferation and aflatoxin biosynthesis.

Climate change has further increased concerns regarding aflatoxin contamination worldwide. Rising temperatures, prolonged drought periods, and the increasing frequency of extreme weather events create favorable conditions for the spread of aflatoxigenic fungi into regions that were previously considered low-risk areas. Consequently, crops such as maize, peanuts, wheat, and other cereals are becoming increasingly susceptible to contamination, even in temperate regions. Several studies have demonstrated that drought stress during critical stages of crop development weakens plant defense mechanisms, making plants more vulnerable to fungal infection and subsequent aflatoxin accumulation. In addition, elevated temperatures can accelerate fungal metabolism and stimulate toxin production, thereby increasing contamination levels in harvested products. The impact of climate change on aflatoxin occurrence poses significant challenges for agriculture, animal production, food safety, and international trade. Therefore, continuous monitoring, predictive risk assessment models, and the implementation of effective prevention strategies are essential to mitigate the risks associated with aflatoxin contamination under changing climatic conditions.Rising average temperatures, increased frequency of droughts, and greater variability in precipitation patterns contribute significantly to the intensification of aflatoxin contamination in agricultural crops. Recent studies have reported an increased incidence of aflatoxin contamination in maize across Southeastern Europe, including Romania, particularly during years characterized by extreme climatic conditions (Battilani et al., 2016).

The principal climate-related factors influencing the occurrence of aflatoxins include increasing annual average temperatures, frequent drought events, alternating periods of drought and heavy rainfall, elevated atmospheric CO_2 concentrations, and the extension of the growing season. These changes affect both host plants and fungal populations, altering the ecological balance within agroecosystems (Medina et al., 2014). Species such as *Aspergillus flavus* and *Aspergillus parasiticus* exhibit optimal growth temperatures between 25 and 35°C, conditions that are becoming increasingly common in temperate regions (Klich, 2007). Aflatoxins represent one of the most serious threats to global food safety, affecting approximately 25% of the world's crop production (Yohannis et al., 2025; Yonas et al., 2025). Increasing temperatures accelerate fungal metabolism and stimulate mycotoxin biosynthesis, thereby amplifying contamination levels (Battilani et al., 2016).

Drought is considered one of the most important predisposing factors for aflatoxin contamination, particularly in maize. The effects of drought include reduced plant resistance, kernel cracking, increased insect infestation, and diminished microbial competition. During periods of extreme heat, fungal proliferation rates, aflatoxin biosynthesis, and contamination persistence all increase substantially (Klich, 2007).

Water stress induces the accumulation of reactive compounds in plants, creating favorable conditions for colonization by *A. flavus* (Williams et al., 2004). Maize is the crop most susceptible to aflatoxin contamination, especially under drought and heat stress conditions. In Europe, areas considered suitable for the cultivation of maize intended for human consumption are expected to shift northward by 2050. In southeastern Romania, projected temperature increases of 4–5°C are expected to elevate the risk of *Aspergillus* infection and aflatoxin production. Prolonged drought and thermal stress create optimal conditions for the development of toxigenic fungi.

In Romania, the year 2022 was particularly problematic. The incidence of *Aspergillus flavus* infection reached 37–72% among the maize hybrids evaluated, while disease severity ranged between 15% and 40%. Contamination occurred under conditions characterized by temperatures exceeding 30°C and prolonged water deficits during July and August. Laboratory analyses revealed total aflatoxin concentrations ranging from 22 to 174 ppb, exceeding European Union regulatory limits by 5 to 43 times (EU maximum limit: 4 ppb for total aflatoxins). In certain regions of Romania, aflatoxin concentrations exceeded 400 ppb. According to a 2013 report by the United States Department of Agriculture Foreign Agricultural Service (USDA/FAS) on Romania, veterinary and food safety authorities collected 1,335 milk samples, of which 67 tested positive for aflatoxin M1 above the maximum permitted level, representing approximately 5% of all samples analyzed. More recent evidence confirms that maize continues to represent a significant source of aflatoxin-related risk in Romania. A study published in 2024 and conducted in a Romanian compound feed manufacturing facility investigated maize used as a raw material during the years 2020 and 2021. During the raw material reception stage, 1,034 analyses were performed in 2020 and 1,191 analyses in 2021. The results revealed that 77.3% of the samples analyzed in 2020 and 57.9% of those analyzed in 2021 tested positive for total aflatoxins. In stored maize stocks, the incidence of positive samples was 56.2% in 2020 and 65.1% in 2021, demonstrating that the risk of contamination is not confined to the harvesting period but may persist or even increase during storage.

Another study conducted on maize samples collected from the 2019 Romanian harvest found that 88 out of 95 samples (92.63%) were contaminated with total aflatoxins. Although most samples exhibited relatively low contamination levels, 31 samples exceeded 1.75 μg/kg, while one sample reached a particularly high concentration of 77.59 μg/kg. The regional distribution of contamination indicated a greater vulnerability in the southern and southeastern regions of Romania, where maize cultivation is extensive and drought stress occurs more frequently. In the study evaluating the 2019 maize harvest, samples originated from several macro-regions of Romania. One of the most significant findings was the identification of Argeș County, located in the South-Muntenia region, as an area in which all analyzed samples were contaminated, with aflatoxin concentrations ranging from 2.75 to 77.59 μg/kg. The same study also reported earlier findings from southeastern Romania, where contamination with aflatoxin B1 was detected in 37% of maize samples analyzed during the period 2002–2004 and in 38% of samples analyzed between 2008 and 2010.

Recent studies conducted in Ethiopia demonstrated that 22 accessions and 8 local varieties exceeded the European Union regulatory limits for aflatoxin B1 (AFB1). In Africa and Asia, which together account for approximately 95% of global peanut production, aflatoxin contamination constitutes a major barrier to international trade (Yonas et al., 2025). Furthermore, contamination with aflatoxin B1 has increased significantly in Southern Europe since the early 2000s (Battilani et al., 2016). Based on the available evidence, the principal factors influencing aflatoxin contamination can be categorized into climatic and technological factors. Climatic factors include frequent droughts, elevated temperatures, and increased variability in precipitation patterns, while technological factors include short crop rotations, the cultivation of susceptible hybrids and varieties, and inadequate storage conditions. By integrating contamination data with climate change projections, predictive models have been developed that consistently indicate an increasing risk of aflatoxin contamination across Europe, including Romania. These models suggest that rising average annual temperatures are contributing to a higher frequency of years characterized by severe contamination events, as well as a progressive expansion of risk areas toward Central and Eastern Europe.

Adaptation Strategies to Climate Change for Reducing the Risk of Aflatoxin Contamination

Climate change is one of the major factors influencing the occurrence and distribution of aflatoxins in modern agricultural systems. Rising average temperatures, prolonged drought periods, and increased variability in precipitation patterns create favorable conditions for the development of toxigenic fungi of the genus *Aspergillus*, particularly in maize crops, which are considered among the most vulnerable to aflatoxin contamination. Adaptation to climate change requires an integrated approach based on agronomic, technological, and monitoring measures aimed at limiting both fungal development and aflatoxin biosynthesis. One of the most important adaptation strategies is the cultivation of crop hybrids and varieties with enhanced resistance to drought stress and fungal infections. Such cultivars are better able to withstand adverse environmental conditions and may reduce the susceptibility of crops to colonization by toxigenic fungi.

Another key adaptation strategy involves the implementation of monitoring and early warning systems. These systems integrate climatic, agronomic, and phytosanitary data to predict periods of elevated contamination risk, thereby enabling producers and regulatory authorities to take preventive measures before significant contamination occurs. At the institutional level, adaptation strategies should be supported by agricultural policies and research programs focused on climate risk management. Within the European context, adaptation measures are closely linked to the objectives of sustainable agriculture and food safety policies. The European Union promotes integrated approaches based on prevention, monitoring, and mitigation of the impacts of climate change on agricultural production and food security.

Biological control (biocontrol) represents one of the most innovative and promising strategies for reducing aflatoxin contamination in agricultural crops, particularly in the context of increasing climate-related challenges and the limitations associated with conventional chemical control methods. The concept of biocontrol is based on the use of living organisms or their metabolites to inhibit the growth of toxigenic fungi and reduce aflatoxin production. In the case of aflatoxins, this strategy primarily targets toxigenic *Aspergillus* species, especially *Aspergillus flavus*, through the application of competitive atoxigenic strains or other antagonistic microorganisms (Cotty & Bhatnagar, 1994). This method is considered highly effective because it exploits natural mechanisms of microbial competition while exerting minimal environmental impact (Bandyopadhyay et al., 2016). Studies conducted in various agricultural regions have demonstrated that biocontrol applications can significantly reduce aflatoxin contamination levels, in some cases by more than 80%, depending on climatic conditions and the production technology employed (Atehnkeng et al., 2014). In addition, certain bacterial species have demonstrated the ability to partially degrade aflatoxins that have already been produced, thereby contributing to a reduction in the toxic burden of agricultural products (Mannaa & Kim, 2017). The use of atoxigenic strains of *A. flavus* reduces aflatoxin production through ecological competition, limiting the establishment and proliferation of toxin-producing fungal populations (Medina et al., 2014). Overall, the integration of climate-adaptation measures, advanced monitoring systems, resistant crop varieties, and biological control strategies represents a sustainable and effective approach to minimizing the risks associated with aflatoxin contamination in agricultural production systems under changing climatic conditions.

Biological control offers numerous advantages compared with conventional chemical control methods. However, its effectiveness can be influenced by several factors, including climatic conditions, soil characteristics, fungal population structure, and agricultural management practices. Extreme temperatures and prolonged drought may alter the microbial balance within agricultural ecosystems and affect the competitiveness of the applied biocontrol strains. Consequently, biocontrol strategies must be adapted to local environmental conditions and integrated into comprehensive mycotoxin management programs.

In Romania, the application of biocontrol strategies against aflatoxins is still at an early stage of development. Nevertheless, interest in these approaches is increasing due to the growing impact of climate change and the need to reduce aflatoxin contamination in maize production. Considering the expansion of areas exposed to high climatic risk, the implementation of biocontrol programs could represent an important solution for limiting crop contamination and reducing economic losses. Furthermore, integrating these methods into national food safety strategies could enhance the competitiveness of Romanian agricultural products within the European market.

At the international level, organizations such as the European Food Safety Authority (EFSA), the World Health Organization (WHO), and the Food and Agriculture Organization (FAO) continuously monitor the risks associated with aflatoxins and regularly update recommendations regarding their control and management. European rapid alert systems for food and feed facilitate the timely identification and withdrawal of contaminated products, thereby contributing to consumer protection and reducing the public health impact of aflatoxin exposure.

CONCLUSIONS

The adaptation of agriculture to climate change is essential for reducing the risk of aflatoxin contamination and maintaining food safety. The use of resistant crop hybrids, efficient water management practices, improved storage conditions, climatic monitoring systems, and rigorous feed control measures constitute fundamental strategies for limiting the impact of these toxins on agriculture and public health. Given the increasing frequency and intensity of extreme climatic events, the development and implementation of effective adaptation strategies have become a strategic priority for Romanian agriculture. An integrated approach combining preventive agricultural practices, advanced monitoring systems, biological control technologies, and supportive public policies will be crucial for mitigating aflatoxin-related risks and ensuring the long-term sustainability, safety, and competitiveness of agricultural production systems.

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