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EFFECT OF AFLATOXIN EXPOSURE IN LIVESTOCK AND PUBLIC HEALTH: REVIEW

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Abstract. Aflatoxins are toxic metabolites produced by the fungi *Aspergillus parasiticus* and *Aspergillus flavus*, which commonly infest various nutritious foods and animal feed. Given the widespread occurrence of aflatoxins and their significant impact on livestock and public health, understanding the mechanisms of toxicity, routes of exposure and economic implications is crucial. This review aims to investigate the causes and effects of aflatoxin exposure on both human and animal health while proposing strategies for preventing and controlling contamination. Aflatoxin contamination impacts the entire food chain, affecting the production, storage, processing, trade and consumption of both plant and animal products. Its consequences extend to human health, livestock welfare, agricultural productivity, environmental integrity and trade, particularly in regions with inadequate aflatoxin control measures. Aflatoxicosis can result in acute mortality, cancer, immune suppression and other chronic health issues. Effective control measures include pre-harvest interventions, careful management during harvest and post-harvest decontamination. Strategies such as selecting resistant crop varieties, employing biological decontamination using microorganisms, physically removing contaminated materials and chemically inactivating aflatoxins are crucial for prevention. Regulating aflatoxin levels in food and feed is essential for protecting public health and promoting equitable trade, necessitating the establishment and enforcement of maximum allowable limits.

Keywords: *Aflatoxins, contamination, feed, fungi, health.*

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1. Introduction

Aflatoxins are toxic metabolites produced by the harmful fungi *Aspergillus parasiticus* and *Aspergillus flavus* which commonly colonize nutritious foods and animal feeds. These primary aflatoxin-producing species predominantly contaminate cereal crops like peanuts and maize, as well as their by-products (Klich, 2007). Other *Aspergillus* species, such as *A. nomius* and *A. tamari*, can also produce aflatoxins, albeit in smaller amounts (Varga *et al*., 2007). Aflatoxins are a significant concern for food safety and public health, commonly found in grains (like corn and wheat), nuts and seeds (Khan *et al*., 2023; Zinedine *et al*., 2023).

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Contamination can occur both pre-harvest and post-harvest, often due to improper storage conditions that encourage mold growth (Ghazala *et al*., 2022). Under suitable temperature and moisture conditions, *Aspergillus* fungi thrive on various foods and feeds, posing serious risks to public and animal health (Adeyeye & Adeyeye, 2016). Animal feeds, which include groundnuts, soybean products and cereal grains, are particularly susceptible to contamination (Pitt *et al*., 2013). Aflatoxin contaminates affects a large portion of the global food supply, especially in low-income countries (Caloni & Cortinovis, 2011).

In livestock, aflatoxins can lead to severe health consequences, including liver damage, immunosuppression and reproductive issues (Dahouda *et al.*, 2023). The consumption of contaminated feed not only harms animal health but also poses risks to human health through the food chain, as livestock products such as milk, meat and eggs can carry aflatoxin residues linked to serious health problems, including liver cancer (Hussain *et al.*, 2023; Wang *et al.*, 2024). Aflatoxin B1, the most toxic form, is recognized as a potent carcinogen associated with severe health outcomes (Kemboi *et al*., 2020).

Milk from livestock consuming contaminated feed can lead to critical health risks, particularly for young animals that rely on milk for nutrition. Furthermore, products that do not meet aflatoxin safety standards may be rejected at borders, removed from distribution or diverted for non-food uses, resulting in economic losses (Dhanasekaran & Shanmugapriya, 2016).

Aspergillus fungi pose a significant threat to food and feed resources, especially during periods of low soil moisture and drought stress. Elevated temperatures and high humidity can enhance fungal proliferation and the subsequent production of mycotoxins (Pitt & Hocking, 2009).

Ensuring food safety and security has been a major focus of national and international efforts over the past century (Wu, 2010). Given the widespread occurrence of aflatoxins and their significant impact on livestock and public health, understanding the mechanisms of toxicity, routes of exposure and economic implications is crucial. This review highlights the causes and effects of aflatoxin on animal and human health and outlines strategies for preventing and controlling contamination.

Aflatoxins: An Emerging Ignored Potent Mycotoxin

Aflatoxin is a type of mycotoxin. The term “aflatoxin” is derived from three components: “a” for the Aspergillus genus, “fla” for the species flavus and “toxin”, which means poison. Aflatoxin species are known to be mutagenic, carcinogenic and teratogenic compounds (Bakirdere *et al*., 2012).

Aflatoxins were first discovered in 1960 when over 100,000 young turkeys died in England over several months due to a previously unidentified disease called “Turkey-X disease”. After thoroughly investigating the outbreaks, researchers determined that the disease was linked to peanut flour. An intensive study of groundnut meal revealed its toxicity, as it produced the characteristic symptoms of Turkey-X disease when consumed by poultry and ducklings. Further research into the nature of the toxin suggested that it originated from the fungus *A. flavus*. Consequently, the toxin was named “aflatoxin” based on its source (Guchi, 2015).

Biology and Ecology of Aflatoxin Producing Fungi

The large genus Aspergillus is subdivided into seven subgenera, further categorized into sections (Klich, 2007). The Aspergillus section Flavi, commonly referred to as the

A. flavus group, belongs to the subgenus *Circumdati* and has garnered worldwide attention due to its ability to produce toxins. Non-aflatoxigenic species include *Aspergillus oryzae*, *A. sojae* and *A. tamarii*, while the aflatoxigenic group includes *A. flavus* (Figure 1A), A. parasiticus (Figure 1B) and A. nomius (Figure 1C) (Perrone *et al*., 2014). Notably, *A. nomius* is not considered of practical importance (Pitt, 2000).

Both *A. flavus* and *A. parasiticus* are soil-borne, imperfect filamentous fungi that thrive on living and decaying plant matter, with a strong preference for oilseeds and nuts (Pitt, 2000). They are among the most economically and agronomically significant species that infect crops and produce aflatoxins either before harvest or during storage (Bennett & Klich, 2003).

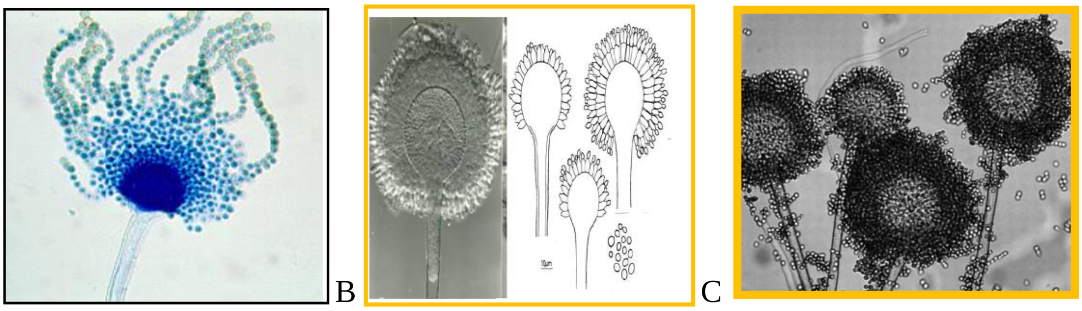

Figure 1. Aflatoxigenic group of Fungi species
A. *Aspergilllus flavus* B. *Aspergilus parasiticus* C. *Aspergilus nominus*
Source: Refai and Hassan (2003)

Factors Promoting the Growth of Aflatoxigenic Fungi and Aflatoxin Product

Fungal growth and aflatoxin contamination result from the interactions among the fungus, the host and the environment. The appropriate combination of these factors determines the infestation and colonization of the substrate, as well as the type and amount of aflatoxin produced (Kidanemariam & Fesseha, 2020).

The formation of aflatoxins is influenced by physical factors, including oxygen availability and surface area. Chemical characteristics, such as specific nutrients (especially minerals like zinc), vitamins, fatty acids, amino acids and energy sources (preferably in the form of starch), are essential for aflatoxin production (Enyiukwu *et al*., 2014). Biological factors related to the host species also play a significant role (Omotayo *et al*., 2019).

The primary factors influencing fungal growth in stored food products are moisture content and temperature (Pereira *et al*., 2019). Aflatoxin synthesis in feeds increases at temperatures above 27°C, humidity levels greater than 62% and moisture levels in the feed exceeding 14% (Dhanasekaran & Shanmugapriya, 2016). The optimal temperature range for aflatoxin production by A. flavus and A. parasiticus is reported to be between 25°C and 32°C, with limiting temperatures ranging from 12°C to 41°C (Tola & Kebede, 2016).

Water availability, high-temperature stress and insect damage to the host plant are major factors influencing mold infestation and toxin production. Additionally, specific crop growth stages, poor soil fertility, high crop densities and weed competition have been associated with increased mold growth and toxin production (Kidanemariam & Fesseha, 2020).

A high yield of aflatoxins is associated with elevated carbohydrate concentrations, particularly in crops like wheat and rice and to a lesser extent in oilseeds such as cottonseed, soybean and peanuts (Greeff-Laubscher *et al*., 2020).

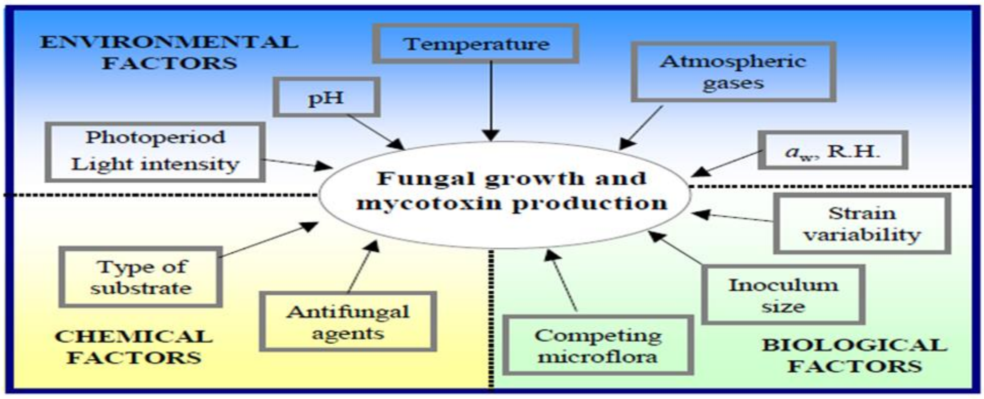

Figure 2. Factors influencing fungal growth and mycotoxin production
Source: Zaki et al. (2012)

Types of Aflatoxins

Aflatoxins are named for their fluorescence, appearing blue or green under ultraviolet (UV) light, along with other analytical characteristics (Chauhan, 2017). The "B" group fluoresces blue under long-wavelength UV light, while the "G" group fluoresces green. The primary concerns in food and feed are aflatoxins B1, B2, G1 and G2 (Haschek *et al*., 2002).

Aflatoxins can be categorized into two broad structural orders. Aflatoxins B1 and B2 (AFB1, AFB2) and M1 and M2 (AFM1, AFM2) belong to the difurocoumarocyclopentenone series, while aflatoxins G1 and G2 (AFG1, AFG2) are part of the difurocoumarolactone series. Aflatoxin metabolites found in mammalian milk are designated as "AFM", with "M" indicating milk or mammalian metabolites (Fung & Clark, 2004).

AFB1 is the most potent aflatoxin and is recognized as a carcinogen; it is generally the most abundant in food and feed. The order of toxicity is AFB1 > AFG1 > AFB2 > AFG2. Hydroxylated aflatoxin metabolites are excreted in milk, with AFM1 and AFM2 being the significant metabolites derived from AFB1 and AFB2, respectively (Haschek *et al*., 2002).

Structure of aflatoxin

Structurally, the dihydrofuran half, which contains a double bond and the components, linked to the coumarin half play important roles in the production of natural compounds. For the B series of aflatoxins, the cyclopentenone structure is reported to be responsible for the primary toxicity. In contrast, the M group of aflatoxins is chemically referred to as methoxycyclopenta (Fung & Clark, 2004).

Physical properties

Aflatoxins are white to yellow, odorless and flavorless crystalline solids that are soluble in organic solvents but insoluble in water. They fluoresce under ultraviolet light and are thermally stable (Carvajal-Moreno, 2015).

Aflatoxins have high melting and decomposition temperatures, ranging from 237°C (AFG2) to 320°C (AFB1) (Mejia-Teniente *et al.*, 2011). Therefore, aflatoxins remain stable at temperatures typically encountered during cooking, boiling, milk ultra-pasteurization and alcoholic fermentation (Carvajal-Moreno, 2015).

The molecular formulas of aflatoxins were first established by groups of researchers in England. Aflatoxin B1 has the molecular formula $C_{17}H_{12}O_6$ and aflatoxin G1 has the formula $C_{17}H_{12}O_7$. Aflatoxins B2 and G2 are derived from dihydro derivatives of the parent compounds, with formulas $C_{17}H_{14}O_6$ and $C_{17}H_{14}O_7$, respectively (Dhanasekaran & Shanmugapriya, 2016). Some physical properties of these compounds are summarized in Table 1.

Table 1. Physical properties of aflatoxin

Aflatoxin	Molecular Formula	Molecular Weight	Melting Point C	[α]D23
B1	$C_{16}H_{12}O_6$	312	268-269*	-559
B2	$C_{17}H_{14}O_6$	314	286-289*	-492
G1	$C_{17}H_{12}O_7$	328	244-246*	-533
G2	$C_{17}H_{14}O_7$	330	237-240*	-473

Source: Dhanasekaran et al. (2011)

Chemical properties

Aflatoxins (AFs) are categorized into two chemical groups. The difurocoumarocyclopentenone series is reported to be responsible for the major toxicity and includes AFB1, AFB2, AFB2A, AFM1, AFM2 and AFM2A. The difurocoumarolactone series comprises AFG1 and AFG2 (Haschek *et al.*, 2002; Fung & Clark, 2004).

Chemically, aflatoxins are derivatives of difuranocoumarin, where a bifuran group is attached to one side of the coumarin nucleus. On the other side, a pentanone ring is attached for the AFB and AFM series, while a six-member lactone ring is present in the AFG series (Bennett & Klich, 2003).

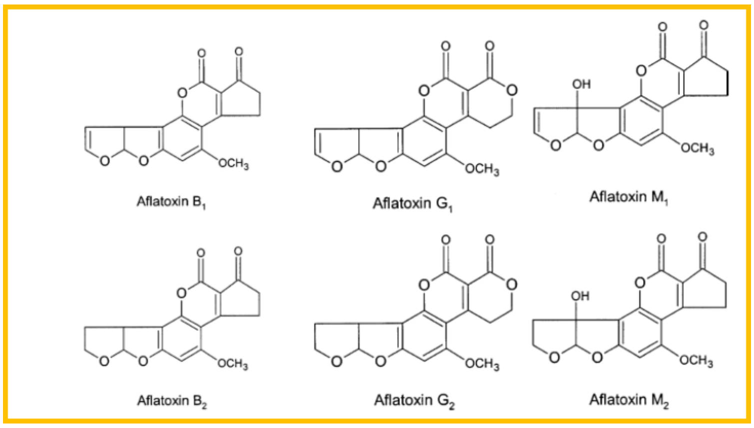

Figure 3. Chemical structure of aflatoxin B (AFB1 and AFB2), aflatoxin G (AFG1 and AFG2) and aflatoxin M (AFM1 and AFM2)
Source: Zain (2011)

Occurrences of Aflatoxin in Feed and Milk

Aflatoxin contamination in food and feed is a global issue, particularly in tropical and subtropical regions where warm temperatures and moisture promote fungal growth (Kana *et al*., 2013). These toxins are widespread natural contaminants that pose serious risks to human health, agricultural productivity, livestock, and food safety (Benkerroum, 2020).

Occurrence of Aflatoxin in Feeds

Animal feed is a significant pathway through which hazards can enter the human food chain, making it essential to assess its safety for the animals that consume it. These safety assessments are complex, considering both the well-being of the animals (the primary consumers of the feed) and the indirect impact on humans due to potential residues in animal-derived food products (FAO, 2008).

According to reports by the FAO (Eskola *et al*., 2020), a pproximately 25% of the world's agricultural products are contaminated with mycotoxins. These mycotoxins can originate from saprophytic fungi before harvest, during the harvesting process and even after storage due to endophytic fungi. Proper preservation of food is critical to prevent fungal growth and subsequent mycotoxin production. This means that mycotoxins can be present in stored food substances and poorly preserved items; when food is not adequately stored, fungal growth may occur, leading to mycotoxin production (Kabak *et al*., 2006).

Feeds most susceptible to aflatoxin include cereals (especially maize), cottonseed, peanuts, copra, palm kernel and rice bran. Caution is advised with any feed products grown in tropical and subtropical regions, especially those that are not dried or used immediately after harvesting. Aflatoxin contamination is not uniform, making it crucial to implement a sampling system. Feeds with significant aflatoxin contamination should not be fed to dairy cows or other animals that produce milk for human consumption (FAO & IFIF, 2010).

Concentrated animal feedstuffs tend to harbor the highest levels of mycotoxins. For example, the lowest level of aflatoxin B1 contamination recorded in silage (a roughage) was 7 μg/kg, while the highest level found in concentrated feeds like wheat bran, noug cake and sweet pea hull was approximately 419 μg/kg (Kidanemariam & Fesseha, 2020). Noug cake has been identified as a major source of aflatoxin contamination among concentrated animal feeds and is increasingly used in Ethiopia for its high nutrient content, which enhances animal productivity in small-scale or intensive systems (Gizachew *et al*., 2016).

Aflatoxins Occurrence in Milk and Milk Products

Aflatoxin, a mycotoxin, has garnered significant research attention in dairy cows due to its excretion as aflatoxin M1 in milk, which poses a public health risk. After consuming feed contaminated with aflatoxin, a portion of the ingested aflatoxin B1 is degraded in the rumen, resulting in the formation of aflatoxicol. The remaining fraction is passively absorbed in the digestive tract and subsequently hydroxylated in the liver to produce aflatoxin M1 (Britzi *et al*., 2013).

Milk contaminated with aflatoxin M1 (AFM1), a primary hydroxylated metabolite of AFB1, is produced by cows that consume a diet contaminated with AFB1 (Bennett & Klich, 2003). AFM1 can be detected in milk 12-24 hours after a cow ingests feed containing AFB1 and its concentration in milk correlates with the levels of AFB1 in the raw feed (Bakirci, 2001). Additionally, AFM1 can be found in certain dairy products, such as cheese, at concentrations higher than in raw milk, because AFM1 is heat-stable, binds well to casein and remains unaffected during the cheese-making process (Kebede *et al*., 2020).

Most aflatoxins consumed by dairy cows are broken down by the microbial flora in the cow's rumen. Although aflatoxins are excreted through urine and feces, a small amount of aflatoxin B1 is metabolized to aflatoxin M1 in the liver and subsequently excreted in milk. The quantity of aflatoxin M1 in milk comprises only about 1-2% of the total aflatoxins B1 ingested (Fink-Gremmels, 2008). In higher-yielding animals that consume large amounts of feed concentrates, the levels of aflatoxin M1 in their milk can reach up to 7% of the ingested aflatoxin (Masoero *et al*., 2007).

During milk processing, the separation of components results in the distribution of AFM1 across dairy products. Consequently, individual dairy products contain lower levels of the toxin compared to raw milk (Anthony *et al*., 2012). Soft cheese typically has approximately three times higher aflatoxin levels, while hard cheese can have about five times higher levels than the original milk. Interestingly, using aflatoxin-contaminated milk for cheese production can mitigate the risk. Additionally, recent studies have suggested that another toxic metabolite may also be excreted in significant amounts in milk (Carvajal-Moreno, 2015).

Carry-Over of Aflatoxins

Carry-over refers to the transfer of unwanted compounds from contaminated feed to food of animal origin. In the case of meat and eggs, the rate of aflatoxin transfer from feed to animal products is significantly lower. Given the relatively small quantities consumed, meat and eggs are unlikely to contribute significantly to the overall intake of aflatoxins in the diet (Lindahl, 2015).

Permissible Aflatoxin Levels in Feed and Milk

To protect consumers, minimizing exposure to aflatoxins is crucial. Many countries have established regulations governing acceptable aflatoxin levels in food, each with specific limits for various food items. Aflatoxins pose risks to health and business prospects, prompting importing nations to enforce increasingly stringent regulations. Additionally, worldwide restrictions on aflatoxin content in animal feed vary based on factors such as livestock species, age, production group and the specific feedstuff involved (Völkel *et al*., 2011).

Some countries have defined permissible aflatoxin levels in food to mitigate the harmful effects of these toxins. These levels vary and are influenced by the economic and developmental status of each country (Galvano *et al*., 1996). For example, in the United States, the Food and Drug Administration (FDA) permits a total of 20 ng/g in livestock feed and 0.5 g/kg (or 50 ng/L) in milk (Diaz *et al*., 2004). In European countries, aflatoxin M1 levels are limited to 0.005 mg/kg in milk, milk products and baby food. Moreover, different nations have distinct regulations for aflatoxin levels in livestock feed. The European Union (EU), for instance, sets permitted levels ranging from 0.05 to 0.5 μg/kg. Environmental factors, such as rainfall conditions, also influence permissible aflatoxin levels, with tropical countries typically allowing higher toxin levels compared to regions with milder or colder climates (Bakirdere *et al*., 2012).

Aflatoxicosis: Adverse Health and Economic Impact

Aflatoxicosis is a poisoning caused by the ingestion of aflatoxins produced by the fungus *Aspergillus* species. This occurs when animals consume moldy corn, peanuts or other foods susceptible to contamination with *A. flavus* or *A. parasiticus* (Negash, 2018). Aflatoxins produced by molds of *Aspergillus* species are of particular concern due to their acute toxicity and oncogenic effects in susceptible hosts (Dhanasekaran & Shanmugapriya, 2016).

Exposure to aflatoxin can lead to several health-related conditions, including acute and chronic aflatoxicosis, aflatoxin-related immune suppression, liver cancer, liver cirrhosis and nutrition-related issues in children, such as stunted growth. In many regions, due to widespread consumption of contaminated food and feed, aflatoxin exposure is often unavoidable because of the lack of essential food and feed resources (Khlangwiset *et al*., 2011).

Aflatoxin Exposure and Human Health

Livestock that consume aflatoxin-contaminated feed can produce contaminated meat, milk and eggs, posing risks to human health (Hussain *et al.,* 2023). Aflatoxins are classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC), indicating a high risk of liver cancer, particularly in regions where hepatitis B is endemic (Santos *et al.*, 2023). Chronic consumption of aflatoxin-contaminated foods has been linked to liver cancer, as hepatitis B and/or C viruses can act synergistically with aflatoxins in the development of hepatocellular carcinoma (Wu & Santella, 2012).

Ingesting high levels of aflatoxins can lead to acute liver failure, with symptoms such as jaundice, vomiting, and abdominal pain (Wang *et al.,* 2024). The liver is the primary organ affected by aflatoxins, which exhibit carcinogenic, teratogenic, hepatotoxic, mutagenic and immunosuppressive effects (Flores-Flores *et al.*, 2015). They are associated with both acute toxicity and chronic carcinogenicity in human and animal populations (Bennett and Klich, 2003). Aflatoxin B1 is classified as a Group 1 carcinogen by IARC, while aflatoxin M1 is classified as Group 2B (possibly carcinogenic to humans) (Ostry *et al.*, 2017).

Long-term exposure to aflatoxins can damage vital organs, suppress the immune system, and increase susceptibility to other health disorders (Arapcheska *et al.*, 2015). In particular, aflatoxins adversely affect male reproductive health, causing delayed testicular development, testicular degeneration, decreased reproductive potential, morphological changes and a decline in sperm viability and quality (CAST, 2003).

Millions of children in Africa suffer from acute or chronic aflatoxicosis, resulting in lowered immunity, low birth weight, stunted growth and even death (Gong *et al.*, 2016). These effects underscore the significant health risks associated with aflatoxin exposure, highlighting the urgent need for effective monitoring and control measures.

Human Exposure Conditions

Humans are primarily exposed to aflatoxins through the consumption of contaminated agricultural or animal products. Other modes of exposure include inhalation of toxins in occupational settings (Abbas *et al*., 2009). The effects of exposure can lead to either acute or chronic aflatoxicosis, depending on the duration and level of exposure (USAID, 2012). Children and immunocompromised individuals are particularly at risk, as their developing systems or weakened immunity can lead to more severe health outcomes from aflatoxin exposure (Schroeder *et al.*, 2023).

In utero exposure

Aflatoxins are lipophilic and can cross the placental barrier, where they can be bioactivated in utero, as evidenced by the presence of aflatoxin-albumin adducts in cord blood samples (Turner *et al*., 2007).

Exposure to breast milk

While the literature highlights the numerous benefits of breast milk for infant development and health (Horta *et al*., 2007), it has also been established that breast milk may serve as a route of exposure to environmental toxins, including mycotoxins. The contamination of breast milk is closely related to maternal dietary habits, which are influenced by the socio-demographic status of the mother and seasonal variations. The physicochemical properties of these toxic compounds, along with the biochemical characteristics of milk, such as high lipid content and low pH, facilitate the excretion of toxins, including mycotoxins, into breast milk (Ito & Lee, 2003). There is also evidence suggesting that the transfer of mycotoxins into breast milk may depend on the frequency of breastfeeding and the mother's nutritional status (Warth *et al*., 2016).

The period of breastfeeding is generally associated with lower levels of exposure because the mother's metabolism limits the transfer of dietary aflatoxins into the milk. However, children in regions with high food contamination are chronically exposed to significant levels of aflatoxins, a pattern that can persist throughout life. This lifelong exposure can manifest in various health effects at different stages of an individual's life (Turner *et al*., 2007).

Exposure via weaning food

According to the U.S. Food and Drug Administration, infant formula, which is designed to simulate human milk, can also be a source of mycotoxin exposure for infants. Although infant formula meets daily nutritional requirements, its contamination with mycotoxins has been reported in various parts of the world (Chilaka & Mally, 2020).

Effect on human health

Animal studies provide substantial evidence that high concentrations of aflatoxin in feed negatively impact animal health, growth and productivity. While these effects suggest potential harm to humans, animal studies typically involve much higher levels of aflatoxin exposure than those generally observed in human populations (Mahuku *et al*., 2013).

Acute toxicity

Acute aflatoxicosis, associated with extremely high doses of aflatoxin, is characterized by hemorrhaging, acute liver damage, edema and high mortality rates. Early symptoms of acute high-level exposure include loss of appetite, malaise and low fever; later symptoms such as vomiting, abdominal pain and hepatitis can lead to potentially fatal liver failure (Kayser, 2005). The first documented cases of acute aflatoxicosis in animals occurred in 1960, when over 100,000 turkeys died following an outbreak in the United Kingdom (Khlangwiset *et al*., 2011).

Acute toxicity cases have been reported and are often exacerbated by limited food availability. For instance, in drought-stricken areas of Kenya, more than 100 people died in 2004 after consuming corn flour contaminated with aflatoxin (Azziz-Baumgartner *et al*., 2005).

Chronic toxicity

The effects of long-term exposure to aflatoxins in humans include liver damage and immune system suppression, which can increase the incidence of other health disorders (Williams *et al*., 2004).

Aflatoxin Exposure and Animal Health

Dietary aflatoxins adversely affect animal health and production. The most common exposure route occurs through the ingestion of contaminated feed. Pasture, hay, straw and silage are prone to aflatoxin contamination, although typically at lower levels. The major source of aflatoxin ingestion by livestock comes from commercially formulated feeds. Animals may often be fed crops that are considered unfit for human consumption because of mold, insect damage or other problems and are at high risk for aflatoxin contamination (Lindahl, 2015).

In general, livestock in intensive systems are at a greater risk of dietary exposure compared to animals in extensive systems. Globally, a high and increasing proportion of dairy cattle, poultry and swine are raised in intensive systems, making aflatoxin contamination an escalating concern. All animals are affected by aflatoxins, with rabbits, ducks and pigs being highly susceptible; dogs, calves, turkeys and sheep moderately susceptible and chickens and cattle relatively resistant. Fish exhibit a range of susceptibility, while honey bees are relatively resistant (Lindahl, 2015).

In animals, exposure during gestation and via milk has significant effects on the immune competence of offspring (Atherstone *et al*., 2015). Aflatoxin exposure has been shown to decrease immunoglobulins in both humans and calves (Norlia *et al*., 2019). Consequently, there are concerns regarding the transmission of HIV to children and their ability to survive other infectious diseases (Williams *et al*., 2004).

Effects of aflatoxins on animal health

Aflatoxins have demonstrated negative health impacts on animals, including acute toxicity and death in livestock and fish. Chronic consumption of lower levels of aflatoxins can lead to liver damage, gastrointestinal dysfunction, decreased appetite, impaired reproductive function, stunted growth and reduced productivity. Additionally, immunosuppression increases susceptibility to other diseases (Lindahl, 2015).

Aflatoxins can cause liver dysfunction, reduce milk and egg production and compromise the immunity of animals. Long-term consumption of feed with low aflatoxin concentrations can lead to embryotoxicity. Young animals are generally more sensitive to aflatoxin exposure. Clinical manifestations of aflatoxicosis include digestive disorders, reduced fertility, decreased feed efficiency and anemia (Dhanasekaran & Shanmugapriya, 2016).

Acute toxicity

High doses of aflatoxins can lead to rapid onset of illness, characterized by liver damage, immunosuppression and even death. Symptoms of acute aflatoxicosis in mammals include loss of appetite, lethargy, ataxia, rough hair coat and enlarged livers. Symptoms of chronic aflatoxin exposure include reduced feed efficiency and milk production, jaundice and decreased appetite (Upadhaya *et al*., 2010).

Chronic toxicity

Chronic toxicity is the most common form of aflatoxicosis and results from the consumption of relatively small amounts of these toxic compounds over an extended period. Toxic effects depend on factors such as age, species, sex, nutritional status, dose and duration of exposure. In animals, symptoms can be relatively nonspecific, complicating diagnosis. Generally, symptoms relate to declines in productive parameters, such as reduced weight gain, lower feed conversion efficiency, decreased egg or milk production and increased vulnerability to infectious diseases. Birds are typically more sensitive than mammals, with ruminants being the most resistant among the latter (Marin *et al*., 2013).

Birds are typically more sensitive to aflatoxins than mammals, with ruminants being the most resistant among mammalian species (Marin *et al.,* 2013). Prolonged exposure leads to various health issues, including liver disease; aflatoxins are hepatotoxic and can cause liver necrosis, fibrosis and an increased incidence of liver tumors (Khan *et al.,* 2023). Additionally, immunosuppression can occur, weakening the immune response and making livestock more susceptible to infections (Ghazala *et al.,* 2022). Reproductive failure is another significant concern, with documented effects including reduced fertility, abnormal fetal development and increased rates of abortion in livestock exposed to aflatoxins (Dahouda *et al.*, 2023).

Economic Impact of Aflatoxins

Aflatoxin contamination in livestock feed can lead to significant economic losses due to decreased productivity, increased veterinary costs and mortality (Zinedine *et al.,* 2023). The natural presence of aflatoxins in raw agricultural products poses significant health and economic risks worldwide. The FAO estimates that many staple foods could be contaminated with mycotoxin-producing fungi, contributing to global food losses of approximately 1 billion metric tons each year (Bhat *et al*., 2010). The economic impacts of aflatoxin contamination should be considered in terms of direct market costs associated with lost trade or reduced revenues due to contaminated food, as well as the human health costs resulting from adverse effects (Negash, 2018).

Food safety issues present major challenges to national budgets, including costs related to outbreak investigations, food recalls and increased state surveillance due to rising treatment expenses, missed work and school days due to food borne illnesses and loss of consumer confidence in food safety. Additionally, these issues strain already underfunded healthcare systems (Boutrif, 1998).

Moreover, beyond economic losses and financial burdens for public health, agriculture and livestock, deaths due to aflatoxin contamination are linked to the treatment of food borne illnesses and associated medical expenses. According to reports by Boutrif (1998), approximately 20% of the food produced globally is contaminated with mycotoxins, with aflatoxins comprising a significant portion of this contamination. The contamination of dairy products and livestock feed can lead to various issues, including the occurrence of infectious diseases and cancer in dairy cows, decreased milk production and productivity and reduced immunity in cattle. Given the substantial economic damage and public health risks, the control and prevention of aflatoxin in animal food products and dairy cow feed are critically important (Milićević *et al*., 2010).

Current Detection Method of Aflatoxin

Accurate quantification tests are essential for diagnosing feedstuffs contaminated with mycotoxins. Chemical analyses such as thin-layer chromatography, gas chromatography, high-performance liquid chromatography and mass spectrometry can accurately detect mycotoxin concentrations in properly collected and prepared samples (Diekman & Green, 1992).

Highly reliable methods include liquid chromatography-mass spectrometry and high (or ultra-high) performance liquid chromatography. Additionally, various immunoassays, such as ELISA, have been developed; these methods are user-friendly and cost-effective (Eskola *et al*., 2020).

Control and Prevention of Aflatoxin Contamination

Preventing and controlling aflatoxin contamination involves several strategies aimed at minimizing crop contamination before harvesting and during storage. Due to the ubiquitous nature of mycotoxins, some level of contamination in food and feed is often unavoidable (Kendra & Dyer, 2007).

Pre- and Postharvest Aflatoxin Management of Feed and Feed Ingredients

Effective pre-harvest management relies on good agricultural practices designed to prevent mold proliferation during cultivation and storage, thereby reducing aflatoxin production (Andrea, 2017). Regular monitoring of feeds for contamination is essential for ensuring safety and proper storage and handling can significantly decrease mold growth (Rodriguez *et al.*, 2024).

Cereals should be dried in a manner that minimizes damage to the grains and reduces moisture accumulation, which fosters fungal growth. Controlling insect infestations is also crucial to prevent mold during storage. Incorporating antifungal agents, preservatives and essential oils, along with creating controlled storage atmospheres, can inhibit fungal growth (Devreese *et al.*, 2013). Additionally, dietary interventions like including mycotoxin binders in livestock feed can reduce aflatoxin bioavailability and enhance animal health (Fang *et al.*, 2023).

Preventing contamination of milk and milk-based products by aflatoxin

Governments and international organizations have established guidelines and limits for aflatoxin levels in animal feed and food products to protect public health (FAO, 2023). Raising awareness among farmers about the risks associated with aflatoxins and the importance of proper agricultural practices is vital for reducing exposure (Bandyopadhyay *et al.*, 2023).

To prevent aflatoxicosis, dairy animals must be fed an aflatoxin-free ration, which requires effective prevention of fungal growth in feed and good agricultural practices during processing. Ongoing monitoring and systematic analysis are critical for preventing contamination (Dashti *et al.*, 2009).

Reducing aflatoxin exposure for both animals and humans necessitates a multidisciplinary approach due to the complex nature of contamination in milk and dairy products. This includes stringent scrutiny of all dairy products and comprehensive strategies combining direct and indirect reduction methods in milk and dairy cow feed (Creppy, 2002).

Direct Methods of Aflatoxin Reduction in Milk

Natural methods, chemical absorbents and adulterant absorbents is effective in directly reducing aflatoxin levels in milk and its products (Applebaum *et al*., 1982). Using absorbents such as vermiculite, bentonite, activated carbon capture pollutants in dry environments. Hydrogen peroxide is particularly effective in reducing aflatoxin levels and is commonly used in preserving milk-based products. Combined treatments using lactoperoxidase and heat yield better results in lowering aflatoxin levels. Potassium sulfite is also established for mitigating AFM1 in milk (Bovo *et al.,* 2013).

Natural methods for reducing aflatoxin are often cost-effective and more appealing. Research is ongoing to identify active microbes, such as *Flavobacterium aurantiacum*, which can convert toxic aflatoxin components in milk into non-toxic substances (Line *et al.*, 1994).

Indirect Methods to Reduce Aflatoxin in Livestock Feed

Using aflatoxin-contaminated feed for dairy cattle typically results in contaminated milk, making hygiene in feed essential (Dashti *et al*., 2009). Strict measures to reduce contamination during crop production and in storage facilities are necessary for achieving quality and safety (Degirmenioglu *et al*., 2005). Proper crop storage practices, including maintaining dry conditions and protecting against pests, are crucial (Wu, 2010).

Sanitary conditions in manufacturing and storage facilities for livestock feed must be strictly adhered to, with monitoring of fungal growth and aflatoxin formation being essential (Milićević *et al.,* 2010). Seasonal conditions can influence aflatoxin levels in milk, with higher occurrences typically seen in winter and autumn. Therefore, improving storage conditions, including temperature and humidity control is essential.

Continuous monitoring of production and storage conditions is mandatory, along with the use of uncontaminated materials in feed preparation (Decastelli *et al.,* 2007). Various methods, including the use of microbes, chemicals and absorbent materials, can prevent mold growth (Shinha, 2018). Aflatoxin absorbents are particularly effective in preventing toxic reactions in livestock (Dakovic *et al.,* 2008).

Detoxification of Aflatoxins Contaminated Feed

When food or feed products become contaminated, detoxification is necessary. This involves minimizing the toxic effects of aflatoxins through physical, chemical or biological methods while maintaining the quality of the food product (Shi, 2016).

Physical Detoxification

Several physical techniques, such as thermal treatments, solvent extraction and UV irradiation, can reduce aflatoxin contamination (Murphy *et al.,* 2006). Removing damaged grains can also lower overall contamination (Xu *et al.,* 2017). However, common cooking procedures may not significantly reduce aflatoxin levels due to their heat resistance (Yin *et al*., 2008).

Chemical Detoxification

Various chemicals, including oxidizing agents and acids, are used to detoxify aflatoxins, often in combination with physical methods for enhanced effectiveness (Ajmal *et al*., 2022). Natural substances may be more acceptable to consumers compared to synthetic chemicals (Ajmal *et al.,* 2022).

Biological Detoxification

Biological methods involve using microbes to eliminate aflatoxins from food or feed. For example, *Flavobacterium aurantiacum* can effectively eradicates AFB1 without producing harmful byproducts (Upadhaya *et al*., 2010). These methods are generally considered less aggressive, environmentally safe and cost-effective (Tian & Chuan, 2017). By integrating these various approaches, stakeholders can effectively manage and mitigate the risks associated with aflatoxin contamination in food and feed.

2. Conclusion

Aflatoxin, a naturally chronic occurring toxin, is classified as a potential chemical hazard for both animals and humans. The contamination of food and feed is a global concern, often arising from improper storage or pre-harvest conditions. Aflatoxin significantly affects a large portion of the world's food supply and its derivatives, with the contamination of milk being particularly pressing. Since both humans and animals heavily rely on milk, this contamination poses a serious threat. Aflatoxin contamination directly contributes to animal losses, morbidity, mortality, production setbacks and trade restrictions. Inadequate hygiene measures for aflatoxin-contaminated food can lead to mold growth, adversely impacting manufacturing and cooking processes. To mitigate aflatoxin contamination, efforts should focus on minimizing crop exposure before harvesting and during storage. Addressing natural aflatoxin contaminants in the food chain requires a multifaceted approach, including sanitary measures and routine screening of primary products such as cereals and animal-derived items. Detoxification methods, whether physical, chemical or biological, also play a crucial role. Continuous research and effective management strategies are necessary to reduce the risks associated with these potent toxins. Collaborative efforts between policymakers, researchers and the agricultural sector are essential to safeguard both animal welfare and human health.

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