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Contamination of Baby Cereal Food With Aflatoxins: A Review Study

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تلوث أغذية حبوب الأطفال بالأفلاتوكسينات: دراسة مراجعة

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Abstract

Aflatoxins (AFTs) are a group of mycotoxins produced by fungi, particularly in tropical regions. AFB1 is classified as a human carcinogen by the International Agency for Research on Cancer. The growth of AFT-producing fungi depends on factors like water activity, temperature, and storage. Cereals, dried fruits, and cereal-based baby foods are commonly contaminated, posing significant health risks to infants and young children due to their physiology and diet. Special attention is needed to address this issue. **Aim of study**: To highlight the risks and concerns associated with aflatoxin contamination in food, particularly in cereal-based products and baby foods, and to emphasize the need for special attention to mitigate these risks and protect public health.

Keywords: Aflatoxins, Mycotoxin, Aspergillus flavus, Cereal grains and Infant health.

الملخص

الأفلاتوكسينات (AFTs) هي مجموعة من السموم الفطرية التي تنتجها الفطريات، وخاصة في المناطق الاستوائية. يصنف المعهد الدولي لأبحاث السرطان الأفلاتوكسين B1 (AFB1) كمادة مسرطنة للإنسان. يعتمد نمو الفطريات المنتجة للأفلاتوكسينات على عوامل مثل نشاط الماء ودرجة الحرارة والتخزين. تُعد الحبوب والفواكه المجففة وأغذية الأطفال المصنعة من الحبوب من الأطعمة الشائعة التلوث بالأفلاتوكسينات، مما يشكل مخاطر صحية كبيرة على الرضع والأطفال الصغار نظرًا لتركيبهم الفسيولوجي ونظامهم الغذائي. لذا، يلزم إيلاء اهتمام خاص لمعالجة هذه المشكلة. هدف الدراسة: تسليط الضوء على المخاطر والمخاوف المرتبطة بتلوث الأغذية بالأفلاتوكسينات، وخاصة في المنتجات المصنعة من الحبوب وأغذية الأطفال، والتأكيد على ضرورة إيلاء اهتمام خاص للتخفيف من هذه المخاطر وحماية الصحة العامة.

الكلمات المفتاحية: الأفلاتوكسينات، السموم الفطرية، الرشاشية الصفراء، الحبوب، صحة الرضع.

1. Introduction:

Aflatoxins (AFT) represent a group of highly toxic secondary metabolites produced by various species of toxigenic fungi, referred to as mycotoxins. Mycotoxins are predominantly synthesized by saprophytic molds colonizing a wide range of foodstuffs, including animal feed, as well as by numerous plant pathogenic fungi. These compounds pose significant health hazards to humans and domestic animals due to their toxicological properties. Since the early 1960s, mycotoxins have been widely recognized as etiological agents associated with a variety of diseases [1].

Contamination with mycotoxins can occur pre- or post-harvest (e.g. deoxynivalenol (DON) and T-2 toxin produced by Fusarium pre-harvest and ochratoxins (OTA) (Aspergillus and Penicillium) and AFT (Aspergillus) post-harvest, although AFT contamination can also be a field event) [1].

AFT are toxic secondary metabolites produced by Aspergillus [2-4] . In developing countries, The AFT have serious effect on the health [6,7]. In tropical and sub-tropical areas the organisms grow well in such conditions, due to environmental factors include high temperature, relative humidity, poor storage conditions, and pest damage have made mycotoxin contamination which make a major challenge [5,3,6,8].

AFT constitute a group of closely related widely researched mycotoxins that are produced by fungi *Apergillus flavus* (*A. flavus*) and *Aspergillus parasiticus* (*A. parasiticus*). AFT became a target for researchers after the death of more than 100,000 young turkeys on poultry farms in England, were in the consumption of Brazilian groundnut meal [9,10].

Cereal grains and associated by-products represente important sources of energy and protein for livestock. However, when these grains and animal feed are infested with moulds, they become susceptible to contamination by fungal secondary metabolites. a group of secondary metabolites produced by fungi that can have toxic effects toward animal and human usually related to term mycotoxins [11].

Generally, crops that are stored for long period become a source of mould mycotoxin. The foodstuff that are more affected with mycotoxins are cereals, nuts, dried fruit, coffee, cocoa, spices, oil seeds, dried peas, beans and fruit such as apples. In addition to beer and wine and other cereals and grapes in their production. The human food chain constitutes a good enviroment to fungal growth, the contamination can occur by eating of animal meat, eggs and milk products. [12].

The Infants are high risk group that make them more susceptible to contaminated by food due to immature immune system, rather limited diet and high food consumption compared to body weight. At age of 6 months, infants start to eat semi solid foods that are supporting their growth and development. Baby foods typically formulated as soft, easily digestible [13].

Cereal-based baby foods are important sources of nutrition in the diet of infants and young children and they are usually the first solid meal admitted to infants [14]. However, when these grains contaminated with microbial toxins, they constitute high risks for children's health.[15 ,16].

AFT are fungal metabolites that effect development of child, overcome the immune defenses , lead to cancer and, in serious complications to death. Regulations directed at minimizing human exposure to AFT result in severe economic loss to producers, handlers, processors and marketers of contaminated crops[17]. One of the most risk group of population are children, due to, their physiology, lack of food diversity, and a higher consumption relative to their body. Therefore, the significance and potential health risk of any contaminant in foods consumed by infants is increased and special attention must be paid to this problem.

Food contamination by AFT have significant concern by researchers and its serious effects such as liver cancer and immunosupression in various animals and humans [18-20]. AFT B1, the most potent one, is metabolized into a variety of hydroxylated derivatives (AFT P1, M 1, B2a, aflotoxicol) which are less toxic than the parent compound [21], although their presence in food is still a threat to human health [22]. AFT B1 has been detected in human foodstuffs in some African countries [23] and correlated with a high incidence of primary liver cancer.

In this study, we are reviewing on the contamination of baby cereals food with AFT and the scientific literature on how they affect human health.

2. Mycotoxin :

The name mycotoxin is a combination of the Greek word for fungus ' mykes ' and the Latin word ' toxicum ' meaning poison. The term 'mycotoxin' is usually reserved for the relatively small (MW/700), toxic chemical products formed as secondary metabolites by a few fungi that readily colonise crops in the field or after harvest. These compounds pose a potential threat to human and animal health through the ingestion of food products prepared from these commodities [1].

Mycotoxins are fungi toxins, frequently found as contaminants in cereals worldwide. In terms of exposure and severity of chronic disease, especially cancer, mycotoxins appear at present to pose a higher risk than anthropogenic contaminants, pesticides and food additives [1].

AFB1 is one of the most potentially damaging of the AFs and is classified as a human carcinogen (Group I) by the International Agency for Research on Cancer [25- 28].

2.1. Health Risks Associated with AFB1:

a. Hepatotoxicity: AFB1 can cause liver damage and impair liver function
b. Teratogenicity: AFB1 can lead to birth defects and fetal developmental issues
c. Mutagenicity: AFB1 can cause genetic mutations, potentially leading to cancer
d. Genotoxicity: AFB1 can damage DNA, increasing the risk of genetic disorders
e. Carcinogenicity: AFB1 is a known human carcinogen, particularly for liver cancer.

AFB1 contamination is a significant concern in baby food products, particularly those containing:

a. Milk powder
b. Cereals (e.g., wheat, maize, barley and rice(
c. Nuts
d. Fruits
e. Vegetables
f. Cottonseed
g. Oil products [15,29-32].

2.2. Classification of Aflatoxins:

AFT are difurano coumarins produced primarily by two species of Aspergillus fungus which are especially found in areas with high temperature. *A. flavus* is ubiquitous, favouring the aerial parts of plants (leaves, flowers) and produces B AFT. *A. parasiticus* produces both B and G AFT, is more adapted to a soil environment and has more limited distribution [33]. *A. bombysis*, *A. ochraceoroseus*, *A. nomius*, and *A. pseudotamari* are also AFT -producing species, but are encountered less frequently. From the mycological perspective, there are qualitative and quantitative differences in the toxigenic abilities displayed by different strains within each aflatoxigenic species. For example, only about half of *A. flavus* strains produce AFs-producing species more than 106 µg/ kg^{-1} [34].

Among the 18 different types of AFT identified, the major members are AFT B1(AFB1), B2 (AFB2), G1 (AFG1), G2 (AFG2), M1 (AFM1) and M2 (AFM2). AFB1 is normally predominant in amount in cultures as well as in food products. Pure AFB1 is pale-white to yellow crystalline, odorless solid. AFs are soluble in methanol, chloroform, acetone, acetonitrile. *A. flavus* typically produces AFB1 and AFB2, whereas *A. parasiticus* produce AFG1 and AFG2 as well as AFB1 and AFB2. [35].

Four others AFT M1, M2, B2A, G2A which may be produced in minor amounts were subsequently isolated from cultures of *A. flavus* and *A. parasiticus*. A number of closely related compounds namely AFT GM1, parasiticol and aflatoxicol are also produced by *A. flavus*. The order of acute and chronic toxicity is AFB1 > AFG1 > AFB2 > AFG2, reflecting the role played by epoxidation of the 8,9-double bond and also the greater potency associated with the cyclopentenone ring of the B series, when compared with the six-membered lactone ring of the G series.

AFM1 and AFM2 are hydroxylated forms of AFB1 and AFB2 [5]. AFM1 and AFM2 are major metabolites of AFB1 and AFB2 in humans and animals and may be present in milk from animals fed on AFB1 and AFB2 contaminated feed [36, 37]. AFM1 may be also present in egg [38], corn [39] and peanut [40, 41].

2.3. Chemistry of the Aflatoxins:

AFs possess a complex molecular structure featuring a coumarin ring fused to dihydrofuran or tetrahydrofuran moieties, forming a bifuran system. The lactone ring within their structure makes them vulnerable to alkaline hydrolysis, resulting in degradation. Nevertheless, AFs demonstrate remarkable thermal stability, retaining their structural integrity during high-temperature processing, such as cooking or pasteurization. Conversely, AFs are susceptible to degradation when exposed to UV light, extreme pH values, or strong oxidizing agents, highlighting the importance of controlled storage and processing conditions [42].

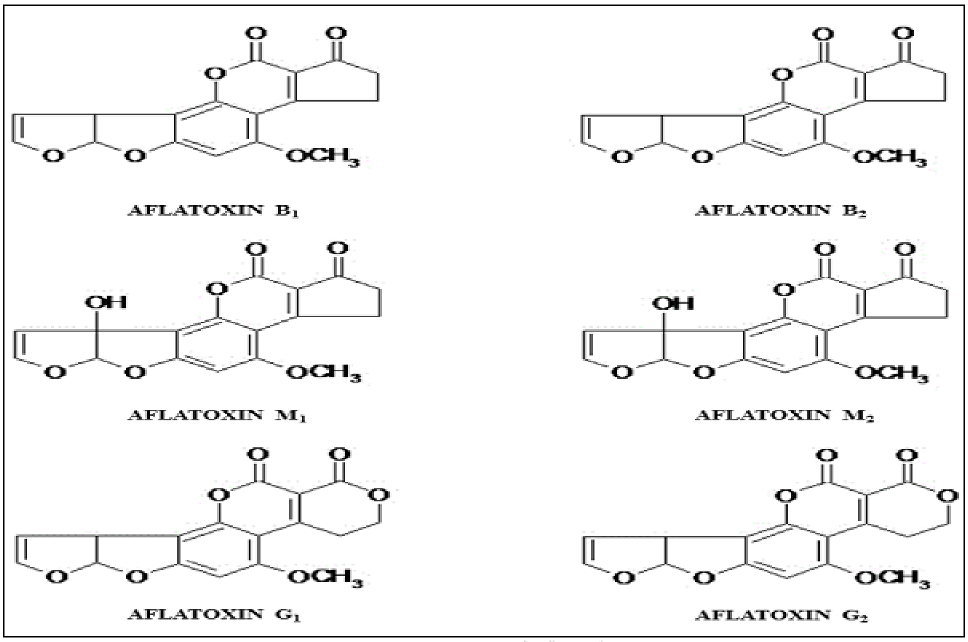

Figure 1 Chemical structure of Aflatoxins [43]

The toxicity of aflatoxins (AFs) follows a decreasing order of AfB1 > AfG1 > AfB2 > AfG2, indicating that the double bond at the 8,9-position of the terminal furan ring is a critical structural feature contributing to their toxicity. AFs are thermally stable compounds that typically resist degradation during standard food or feed processing. To mitigate their toxic effects, various detoxification strategies have been explored, including:

-Microbial degradation

-Physical methods (e.g., extraction, absorption, or high-temperature treatment(

-Chemical approaches

-Radiation-based techniques [44-47[

The structural specificity of AFs and their stability underscore the need for effective detoxification methods to ensure food safety.

2.4. Occurrence of Aflatoxin in food:

Aflatoxins can occur in food due to the growth of A. flavus and A. parasiticus under favorable conditions. These fungi thrive at temperatures between 28-30°C and 25-35°C, respectively. When conidia (spores) encounter a suitable nutrient source and optimal environmental conditions (hot and dry), they rapidly colonize and produce aflatoxins. Several factors contribute to aflatoxin contamination, including:

a. Crop stress or damage due to:
b. Drought before harvest
c. Insect activity
d. Soil type
e. Inadequate storage conditions

Given the chemical stability of aflatoxins during processing and storage, controlling their formation is challenging. The optimal temperature for aflatoxin production is often unavoidable during production, harvesting, transportation, and storage, making it difficult to prevent contamination in practice [48-50].

Aflatoxins have been detected in various food items (**Figure 2**), including:

a. Cereals: corn, barley, oats
b. Dried fruits: figs, bananas
c. Nuts and oilseeds: pistachios, peanuts, cotton seeds
d. Spices: pepper, paprika, chilies

Corn and peanuts are the most frequently contaminated food items globally, posing a significant risk to human health [51, 52].

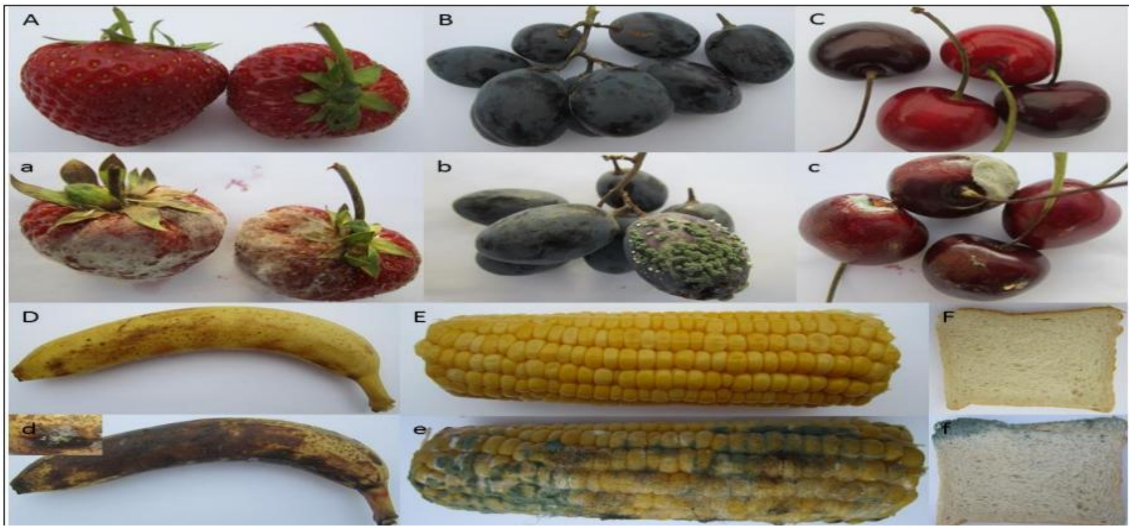

Figure 2 Before and After Fungal Contamination: Fresh – A) Strawberry B) Grape C) Cherry D) Banana E) Maize F) Bread; Contaminated – a) Strawberry b) Grape c) Cherry d) Banana e) Maize f) Bread [43].

2.4.1. Occurrence of Aflatoxin in Cereals

Cereals and their products are one of the most human foods consumption in the world. Cereal grains such as corn, rice, barley, wheat, and sorghum are susceptible to aflatoxin accumulation by aflatoxigenic fungi. The problem of aflatoxins in cereals, particularly in rice and corn, has become a significant concern due to changing agricultural practices. Aflatoxin contamination is not limited to specific geographic or climatic regions. Toxins can be produced on cereals both in the field and during storage, affecting both the grain and the entire plant [53]. Many studies have investigated the presence of aflatoxin-producing fungi in corn (Figure 3).

Corn and its by-products are used as food and feed ingredients for humans and animals, and they can be infected by various fungi, including *A. flavus*, under optimal temperature and humidity conditions [54, 55].

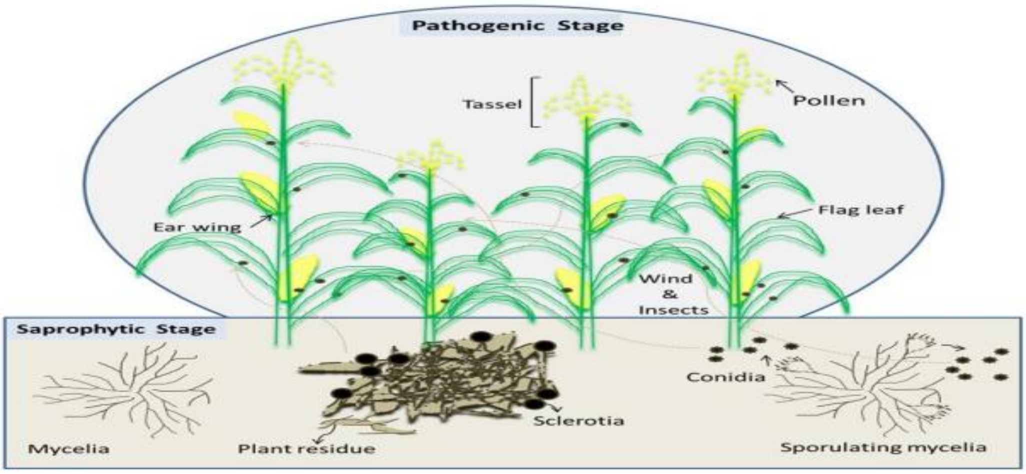

Figure 3 life cycle of Aflatoxins fungi in corn [43].

Rice and sorghum are the most conditional food worldwide. The rice need the rainy season to grow. However, the traditional sun drying employed by most farmers, may not adequately reduce the moisture content of rice grains leading to growth of fungi. Grains with moisture content exceeding 14% may enter storage facilities, resulting in discoloration, loss of viability, quality degradation, and toxin contamination. Sorghum, often cultivated in challenging environments, can benefit from improvements in production, storage, and utilization, which would significantly enhance food security and nutrition in these areas. Sorghum is typically harvested early to allow for subsequent crop planting, but this can coincide with heavy rainfall, hurricanes, and floods, promoting mycotoxin-producing fungal infections. [56].

The consumption of large amounts of aflatoxin-contaminated food can cause toxic hepatitis and death, as witnessed in the 1975 epidemic among the Bhils in India, where approximately 400 people were affected after consuming corn heavily contaminated with Aspergillus flavus [57].

2.5. Factors promoting fungal growth and Aflatoxin production

Fungal growth and aflatoxin production are influenced by various factors, including water activity, temperature, pH levels, and microbial competition. Aspergillus species, such as A. flavus and A. parasiticus, thrive in low-water environments and can grow over a wide temperature range. Optimal growth occurs between 25°C and 42°C, while aflatoxin production peaks at temperatures around 25°C. [59].

Environmental conditions, geographic location, and agricultural practices all play a role in determining the extent of aflatoxin contamination in crops. The risk of fungal infection and toxin production is constant due to non-sterile growing conditions, and the potential health impacts of aflatoxin exposure are a significant concern. [60-61].

2.5.1. Temperature:

Fungal growth and mycotoxin production are inevitable at both high and low temperatures [64]. Temperatures below 20°C favor the growth of Penicillium and Cladosporium, while temperatures above 20°C enhance the growth of Aspergillus species. Optimal fungal activity and toxin production occur at 25-37°C [65-68].

Abdel-Hadi *et al.* [69] reported high Aspergillus growth rate 6.9 mm/day at 35°C and maximum AFT production rate of 2278 - 3082 mg/g at 37°C in maize.

2.5.2. Moisture content:

Water content is a critical factor affecting the grade and storability of grains and legumes, as it significantly influences microbial growth and toxin production [69]. Storage fungi like Aspergillus require about 13% moisture or relative humidity of 65% (water activity, aw, of 0.65) for growth and toxin production [65].

The drying methods may involving inadequately crop handling that may not lead to efficient drying. This issue is sometimes compounded by continuous downpour during harvesting and drying, and makes it difficult to attain the recommended moisture level for safe storage [69].

2.5.3. Inadequate Storage Facilities and Aflatoxin Contamination:

The lack of adequate storage facilities, particularly at the farm level, exacerbates the issue of aflatoxin contamination. In Uganda, most farmers and traders store maize in woven polypropylene bags, which fail to protect grains from AFT contamination [71]. Studies have shown that grains stored on the floor or in unshelled heaps, especially under verandas, are highly susceptible to 100% AFT contamination [71].

One effective method to prevent contamination is storing grains above fire racks, but this approach is impractical for large quantities [70]. Traditional storage structures commonly used in Africa often lack proper design features, such as controlling internal atmosphere, protecting against water, insects, and rodents, and being easy to clean [69]. On-farm storage, often in heaps or rooms, can promote fungal growth and aflatoxin production in legumes and cereals [71]. These storage conditions highlight the need for improved storage solutions to mitigate aflatoxin contamination.

2.5.4. Soil properties:

The type of soil plays a significant role in the growth of fungi in peanuts, particularly *A. flavus*. Light, sandy soils tend to accelerate fungal growth under dry conditions, whereas heavier soils with higher water retention capacity tend to reduce contamination [72-74]. Research has shown that light, sandy soils promote the rapid proliferation of *A. flavus*, especially during drought stress [69].

Soil moisture stress is a critical factor influencing pre-harvest aflatoxin contamination, with studies indicating that drought-stressed groundnuts have higher levels of *A. flavus* infection compared to those grown in irrigated conditions [69].

2.6. The harmful effects of Aflatoxins on human:

Aflatoxins disrupt cellular metabolic pathways, interfering with key enzyme processes involved in carbohydrate and lipid metabolism, as well as protein synthesis [75]. Expert reviews have highlighted the severe health impacts of aflatoxins, which are among the most potent carcinogenic, teratogenic, and mutagenic compounds known [76]. The International Agency for Research on Cancer (IARC) classifies naturally occurring aflatoxins as carcinogenic to humans (Group 1), linking them to liver cancer, particularly in individuals with hepatitis B virus infections [77].

Studies in experimental animals have provided evidence for the carcinogenicity of aflatoxin mixtures and specific aflatoxins, including AFB1, AFG1, and AFM1 [77]. AFB1 has been consistently shown to be genotoxic in both in vitro and in vivo studies [77]. The primary site of tumor formation is the liver, although tumors have also been found in other organs, such as the kidney and colon.

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has estimated the carcinogenic potency of AFB1 based on epidemiological data. For individuals positive for hepatitis B virus (HBV) surface antigens, the estimated potency is 0.3 cancers per year per 100,000 population per ng AFB1/kg body weight per day, with an uncertainty range of 0.05-0.5. For HBV-negative individuals, the estimated potency is significantly lower, at 0.01 cancers per year per 100,000 population per ng AFB1/kg body weight per day, with an uncertainty range of 0.002-0.03. AFM1 has been evaluated separately due to its potential presence in milk and dairy products from livestock fed contaminated feed [78].

The JECFA concluded that AFM1 is likely to induce liver cancer through a similar mechanism to AFB1, and therefore, the potency estimates for AFB1 can be used to assess the risk associated with AFM1 intake, including in populations with high HBV prevalence. Based on a study by Cullen et al., the carcinogenic potency of AFM1 is estimated to be approximately one-tenth that of AFB1 [79].

Humans are exposed to aflatoxins through the consumption of contaminated food, which can lead to nutritional deficiencies, immunosuppression, and hepatocellular carcinoma. Aflatoxins are found in various food matrices, including spices, cereals, oils, fruits, vegetables, milk, and meat \[35\]. Approximately 4.5 billion people, primarily in developing countries, are at risk of chronic exposure to aflatoxins from contaminated food crops [80].

To mitigate the health risks, it is essential to monitor and control aflatoxin levels in foodstuffs continuously. Failure to do so may result in acute and chronic intoxications, and even deaths [81]. Children are particularly vulnerable to the adverse effects of aflatoxin exposure, which can lead to stunted growth, underweight, delayed development, immune suppression, and liver damage [82]. Exposure to aflatoxins during critical periods, such as weaning, may have long-term health consequences, including an increased risk of liver cancer [83].

The impact of aflatoxin exposure on infant growth and development is a significant public health concern, with strong links between early exposure and disease risk in later life [84]. Given the early onset of hepatocellular carcinoma in high-exposure regions and the association with growth faltering, aflatoxin B1 poses a serious health hazard.

2.7. Symptoms and Prevalence of Acute and Chronic Aflatoxicosis:

Acute aflatoxicosis can occur in humans and animals following consumption of high doses of aflatoxins over a short period. In humans, this can lead to severe liver injury, and in rare cases, death. Other symptoms include hemorrhage, edema, and changes in metabolism and nutrient absorption, potentially resulting in malnutrition [85].

A notable outbreak of acute aflatoxicosis occurred in rural Kenya in 2004-2005, where 317 people fell ill, and 125 died after consuming contaminated maize. Similar outbreaks have been documented in India (1974), Malaysia (1988), and Kenya (1982 and 2004-2005), with mortality rates reaching up to 60% [85].

Chronic exposure to low or moderate amounts of aflatoxins can also cause liver and immune system problems. More significantly, certain aflatoxins, such as AFB1, are among the most potent carcinogens known, contributing to liver cancer. Long-term epidemiological studies suggest a strong association between aflatoxin consumption and liver cancer, particularly in individuals infected with hepatitis B virus. The risk of liver cancer appears to be significantly higher in people with hepatitis B infections [85].

2.8. Prevention and Monitoring of Aflatoxins in the Food Supply:

Detoxification methods for aflatoxins, including physical, chemical, and biological approaches, are often limited due to safety concerns, potential losses in nutritional quality, and cost implications, particularly in developing countries [86]. Aflatoxins are potent agents of disease, causing carcinogenic, hepatotoxic, teratogenic, and mutagenic effects in humans and animals.

Analytical methods for determining aflatoxins play a crucial role in monitoring and estimating contaminants, protecting the agricultural environment, and ensuring the quality and safety of food products [87]. Various well-established methodologies have been reported for analyzing aflatoxins in different foodstuffs [88, 89].

Reducing or eradicating aflatoxin contamination in food is essential. Innovative methods have been developed to reduce human exposure to aflatoxins, including the use of NovaSil clay as a food supplement to absorb aflatoxins in the gastrointestinal tract and reduce toxin bioavailability [87]. Such approaches are particularly useful in populations at high risk of aflatoxicosis.

3. Conclusion

Aflatoxins (AFT) are toxic compounds produced by Aspergillus fungus, causing economic losses and health risks. Contamination affects various food commodities globally, with regulations in over 100 countries. AFT B1 is the most common and potent genotoxic and carcinogenic form. Infant foods are particularly vulnerable to contamination, posing serious health risks. Innovative methods, such as NovaSil clay, have been developed to reduce AFT exposure in high-risk populations.

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Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

