



Studies on Fungi Affecting Maize [*Zea Mays* L.] Grains in Storage: A Review

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Abstract

Zea mays L. is mentioned as the cereal of the future because of its nutritious qualities and the use of its products and byproducts. The majority of farmers in tropical and subtropical countries require accurate knowledge, tools, and drying techniques for maize grains since a significant portion of the grain is harvested and stored in hot, muggy circumstances. As a result, the maize is stored while still somewhat damp and warm; warmth and high moisture content can cause the grains to deteriorate quickly and promote the growth of bacteria, fungi, and insects inside the grains. The most widespread type of contamination in stored grains is fungus, which manifests as mold or caking on the affected grain or ear. The grain's color, vitality, and nutritional content all decrease. The greatest dreaded by-product of fungal assault is the development of deadly substances-mycotoxins. *Aspergillus*, *Penicillium*, *Fusarium*, and a few xerophytic species are the fungal genera that are frequently discovered in preserved maize grains. Some of them are accused of producing toxins. The moist material of the grains that are being stored may have an impact on the growth of these fungus. Insect and mite movement, temperature, storage duration, and the level of fungal contamination prior to storage all promote the spread of fungus. While *Aspergillus flavus* may be a food contaminant and create aflatoxin, *Fusarium* attacks over 50% of maize grain before to harvest and produces mycotoxin. Insects, microbes, and climatic conditions [such as temperature and relative humidity] should all be avoided when storing high-quality maize.

Keywords: *Zea mays*, *Aspergillus* spp., Aflatoxin, *Aspergillus flavus*

1.0 INTRODUCTION

Suleiman *et al.* [62], asserts that *Zea mays* L., sometimes known as maize in the US and Canada, is the third most significant cereal crop in the world, behind rice and wheat. Due to its beneficial effects on health and the utilization of its products and by-products, it is known as the cereal of the future. Several applications, such as food preparation, animal feed, and ethanol manufacturing, have been projected to raise the demand for maize by 50%. It might be an essential grain for much of the world, including Asia, Latin America, and Africa. One of the most significant crops in the world, *Zea mays* L. provides the staple diet of more than 1 billion people in Latin America and sub-Saharan Africa [23]. A crop with a short life cycle, maize needs a warm temperature as well as the right handling and management. According to Dilip and Aitya [18], it is a lucrative animal feed, human food, and raw material for a few companies. *Zea mays* L. is the most common cereal grain by generation, although it comes in third place as a staple food, after rice and wheat. Although there are many different explanations for this fact, some of them have to do with social or cultural preferences because maize is grown as animal feed in several countries [29]. *Zea mays* L. is a multipurpose crop that provides food and energy for people as well as fodder for farm animals, poultry, and birds. Its grains are used as raw materials to make a variety of mechanical products and have amazing nutritional value [2]. According to Niaz and Dawar [45], grains are essential for the production of glucose, carbohydrates, and oil. Although food composition data is important for dietary planning and provides information for epidemiological researchers [4].

little is known about the nutritional makeup of the various types of maize. Given that malnutrition is the cause of a significant number of metabolic disorders and diseases and that maize is the most common bread grain consumed by the majority of people worldwide, the development of high-yielding maize cultivars with improved sugar and starch content in the kernels may lead to their increased use in human and industrial applications [43]. Since a significant amount of the grain [maize] is harvested and stored in hot, humid conditions, most farmers in tropical and subtropical nations need the appropriate skills, equipment, and drying methods [69]. In this way, the maize is kept warm and slightly moist, which can accelerate grain breakdown and encourage the growth of bacteria, fungi, and insects within the grains. Fungi, which show up as mold or caking on the contaminated grain or ear, are the most common kind of contamination in grains that have been stored. The grain's color, vitality, and nutritional content all decline. The most feared consequence of fungal attack is the production of toxic substances called mycotoxins, which harm both humans and animals [51, 15]. Fungi are one of the main causes of maize grain deterioration and loss [48]. If the right conditions are present, fungi can damage farmers' maize by 50–80% while it is being stored, according to Binyam [11]. Certain kinds of fungi may cling to maize seeds while they are being stored, degrading them or just continuing to exist and contaminating young seedlings.

Among the fungal genera frequently identified in stored maize grains are *Aspergillus*, *Penicillium*, *Fusarium*, and a few xerophytic species, some of which can produce toxins [11].

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The moisture level of the product can affect the growth of these fungi [22]; temperature, storage duration, and the degree of contagious contamination before storage, as well as insect and mite movement, promote the spread of fungi [61]; there is a common increase in the use of contaminated grain that contains mycotoxins, which results in specific health problems, including death [35, 67]. *Fusarium* attacks more than 50% of maize grain before harvest and produces mycotoxin [65], while *Aspergillus flavus* becomes systemic and produces aflatoxin in seedlings of maize and damaged stored corn. According to Uzma and Shahida [65], fungi are the second most common cause of maize loss and weakening, behind insects. Maize is hygroscopic, meaning it tends to collect or release moisture, just like other food items that are kept in storage. Even if the portion is adequately dried after harvest, it will still retain moisture from the environment if it is kept in a damp, humid environment [17]. As a result, the maize will have more moisture, which will facilitate better disintegration. Insect and microbe growth, as well as climatic factors like temperature and relative humidity, should all be avoided while storing high-quality maize [52]. The current estimates of the annual cost of grain loss in poor nations owing to insects and microbes destroying grain storage range from \$500 million to \$1 billion, according to Campbell *et al.* [12], because they raise the temperature and moisture content of the grain, insects make it easier for mold to grow by creating attack points. Due to the production of mycotoxins, particularly aflatoxins, fungus growth in maize poses a major risk to both humans and animals. Storage factors like temperature, relative humidity, and length of storage affect the fungi's ability to produce aflatoxin in the grain [62]. The conditions that cause stored maize to spoil are the focus of this review. Finding a workable, affordable, and non-toxic way to stop fungal infection and mycotoxin load in stored maize grains is crucial.

2.0 MYCOTOXINS

Filamentous fungi produce mycotoxins, which are low-molecular-weight normal products or tiny particles, as auxiliary metabolites. As a result of their ability to infect and kill humans and other vertebrates, these metabolites form a chemically and toxicologically diverse array that is grouped. It should come as no surprise that many mycotoxins have overlapping toxicities to microbes, plants, and invertebrates. Around 100,000 turkey chickens perished in a strange emergency outside London, Britain, in 1962, which led to the coining of the word "mycotoxin." [9, 10]. The mycotoxins with the greatest agro-economic relevance are ochratoxins, ergot alkaloids, fumonisins, trichothecenes, zearalenone, ochratoxins, and aflatoxins. Some mycotoxins are produced by multiple fungal species, and some molds can produce many mycotoxins. A polluted substrate often contains many mycotoxin species [6]. Vertebrates and other animal groups are poisoned by low concentrations of mycotoxins, which are produced by microbes. Mycotoxins are challenging to characterize in addition to being hard to classify. Because of their many natural effects, different chemical structures and biosynthetic origins, and the fact that they are produced by a wide range of fungal species, classification schemes might occasionally reflect the preparedness of the individual executing the categorization. Clinicians frequently order them according to the organ they impact. Thus, mycotoxins can be divided into many categories, such as hepatotoxins, neurotoxins, immunotoxins, and nephrotoxins. They fall into broad groups, including teratogens, mutagens, carcinogens, and allergies, according to cell biologists [10].

2.1 AFLATOXINS

The four primary aflatoxins are identified as B1, B2, G1, and G2 based on their blue or green fluorescence when exposed to UV light and their relative chromatographic flexibility in thin-layer chromatography. Aflatoxin B1, which is often the primary aflatoxin generated by dangerous strains, is the most powerful known common carcinogen. Aflatoxin B1 could be mistaken for aflatoxin. As a result of the biotransformation of the primary metabolites in mammals, over a dozen more aflatoxins [P1, Q1, B2a, and G2a] have been identified [10]. Aflatoxin, a difuranocoumarin derivative that is transported by a polyketide route, is produced by numerous strains of *Aspergillus flavus* and *Aspergillus parasiticus*; *Aspergillus flavus* in particular may be a common contaminant in agribusiness. Although they are less frequently encountered, *Aspergillus bombycis*, *Aspergillus ochraceoroseus*, *Aspergillus nigrinus*, and *Aspergillus pseudotamari* are all aflatoxin-producing species [33, 54]. Some strains within each aflatoxigenic species show remarkable subjective and quantitative variations in their toxigenic powers, according to mycological analysis. Although some strains of *Aspergillus flavus* may produce more than 106 g/kg of aflatoxins, only about half of them do [10].

Aflatoxigenic molds can produce aflatoxin on a range of surfaces. Natural contamination of cereals, figs, oilseeds, nuts, tobacco, and various other commodities is common. Like the overall capacity to generate aflatoxin, contamination varies widely. Before harvest, crops can infrequently become contaminated with aflatoxin in the field; this is usually linked to dry-season stress. The fate of crops kept in conditions that promote the establishment of mold is far more hazardous [32]. The two most crucial factors in storage are usually the relative humidity of the surrounding air and the moisture content of the substrate [71]. Aflatoxin pollution has been connected to increased farm animal mortality, which reduces the value of grains as an export commodity and as animal feed, claim Bennett and Klich [10].

2.2 FUMONISINS

Fumonisin were originally illustrated and characterized in 1988. The most often produced member of the family is fumonisin B1. They are thought to be created when the amino acid alanine condenses into a precursor made of acetate [64]. Numerous *Fusarium* species produce fumonisins, such as *Fusarium proliferatum*, *Fusarium nygamai*, *Alternaria alternata* f. sp. *lycopersici*, and *Fusarium verticillioides* [formerly *Fusarium moniliforme*, *Gibberella fujikuroi*] [39, 59]. The primary species of economic significance is *Fusarium verticillioides*. Without harming the plant, it often develops as a corn endophyte in both vegetative and regenerative tissues [Fig. 1]. However, a combination of environmental factors, insect damage, and the right fungus and plant genotype can cause seedling blight, stalk rot, and ear rot. *Fusarium verticillioides* is present in nearly all corn samples [39].



Fig 1. *Fusarium* contaminations on *Zea mays* L. kernels [62]

2.3 OCHRATOXIN

After a thorough screening of fungal metabolites, which was done especially to find new mycotoxins, ochratoxin A was identified in 1965 as a metabolite of *Aspergillus ochraceus* [10]. After being extracted from a commercial corn sample in the United States, it was promptly determined to be a strong nephrotoxin. It has been observed that members of the ochratoxin family are metabolites of numerous *Aspergillus* species, including *Aspergillus alliaceus*, *Aspergillus auricomus*, *Aspergillus carbonarius*, *Aspergillus glaucus*, *Aspergillus melleus*, and *Aspergillus niger* [8], because *Aspergillus niger* is widely used to create citric acid and enzymes for human consumption, it is crucial to make sure that industrial strains do not produce these substances [10].

Like other mycotoxins, the amount of toxin produced depends on the substrate the molds grow on, temperature, moisture content, and the presence of competing microorganisms. It has been demonstrated that ochratoxin A is present in barley, oats, rye, wheat, coffee, beans, and other plant products, with barley being particularly susceptible to contamination. Additionally, ochratoxin may be present in some wines, particularly those produced from grapes tainted with *Aspergillus carbonarius* [55].

2.4 ZEARALENONE

The auxiliary metabolite from *Fusarium graminearum* [teleomorph *Gibberella zeae*] was given the minor title "zearalenone" [10]. The zearalenones are biosynthesised by *Fusarium graminearum*, *Fusarium culmorum*, *Fusarium equiseti*, and *Fusarium crookwellense* through a polyketide pathway. All of these species frequently contaminate grain crops around the world [24]. The use of moldy grains has been associated with swine hyperestrogenism since the 1920s. Recent studies have shown that zearalenone levels in the diet as low as 1.0 ppm can cause hyperestrogenic problems in pigs, while higher levels can lead to fetal removal, irregular conception, and other health issues [10].

3.0 FACTORS AFFECTING FUNGAL DEVELOPMENT IN STORED MAIZE

3.1 Weather conditions

Concerns about food and feed security have been linked to climate change, and its anticipated effects on the prevalence of mycotoxins in food and feed are very worrisome [7]. Interactions between the environment, the host, and the mold are what lead to aflatoxin contamination and fungal growth in food [41]. Precipitation is more significant than elevation when predicting mycotoxins [47]. Natural factors that promote *A. flavus* growth and the production of aflatoxins include high soil and/or air temperatures, high relative humidity and high rates of evapotranspiration, water availability, the dry season, plant crowding, and conditions that facilitate organism dispersal during silking [27].

The tropics and Sub-Saharan regions are more likely to be contaminated by aflatoxins, and these regions have a strong correlation with temperature and precipitation, all of which are unquestionably conducive to the growth of *A. flavus* [56]. *A. flavus* conidia production, dispersal, and kernel disease rate are all increased by high temperatures, which leads to the accumulation of significant amounts of aflatoxins under these circumstances [58]. The fact that lower elevation zones are often hotter with greater temperatures and humidity than higher

elevation zones, which are typically cooler with lower temperatures and humidity, is the reason for the aflatoxin's contamination design [47]. Aflatoxin production and fungal growth are encouraged by the current climate in sub-Saharan Africa, which is characterized by high temperatures, high humidity, and dryness [1]. Research has also shown a strong correlation between aflatoxins and maize levels [Table 1] following extended storage in agro-ecological zones with and without humidity in arid regions [27].

Table 1. Percentage occurrence of seed-borne fungal pathogens of stored maize [*Zea mays* L.] varieties obtained from NSPRI.

[%] Occurrence of Pathogens				
Varieties	<i>A. flavus</i>	<i>A. niger</i>	<i>R. stolonifer</i>	<i>F. moniliforme</i>
White	45.6a	28.5c	35.4b	25.8c
Yellow	50.6a	32.5c	43.5b	30.6c

Source: [15]

3.2 Pest infestation

Insects, pests, illnesses, weeds, rats, fungi, and pathogens are the main factors influencing maize production [63], as described by Akowuah *et al.* [3]. A key biotic stressor that affects fungal colonization and mycotoxin contamination in maize is insects. In warm climates, insects that feed on kernels are more stressed than those that feed on silk or cobs [60]. Furthermore, ear-feeding insects and mycotoxin pollution in corn kernels were positively correlated, according to Widstrom *et al.* [70]. Damaged grains are more susceptible to fungal invasion and, as a result, mycotoxin contamination [50]. Aflatoxin generation and fungal infection are encouraged by a variety of biotic and abiotic stresses, including inadequate plant nutrition, insects feeding on growing kernels, weed competition, excessive plant density, plant diseases, and other factors [31]. In developing countries, insects are responsible for 10–60% of post-harvest losses and 15–100% of pre-harvest grain losses, according to Mihale *et al.* [40]. For maize to yield a productive crop, weed control is very important. According to Amare *et al.* [5], weed control methods in maize improved grain yield.

3.3 Harvesting and drying

Aflatoxin levels increased by more than seven times and by almost four times by the third week when maize harvest was delayed for four weeks, according to Kaaya *et al.* [30]. Timely harvesting and proper drying are essential components. Prolonged field drying of maize can result in actual grain losses during storage. Wu *et al.* [72] explained how favorable conditions, such as high moisture content and warmth, affect the occurrence of aflatoxin in maize.

3.4 Storage conditions

Pre- and post-harvest handling, fungal populations, natural conditions, insect invasion, and, in most cases, complex interactions among the various variables are some of the factors that typically affect the contamination of stored products [Figs. 2 and 3]. by toxigenic organisms and the subsequent defilement with aflatoxins [21]. While certain fungi prevent the release of toxic compounds, others attract insects and promote their growth. Elevated moisture content during storage has been shown to increase grain vulnerability to aflatoxin contamination. For extended storage, crops must be kept under optimal conditions [21].



Fig 2. Poor *Zea mays* L. Drying on the ground before shelling for storage [62]



Fig. 3: Grain husks from *Zea mays* L. that have been shelled for storage [Source: 62]

4.0 The Production of Aflatoxin and Fungal Activity in Stored Maize Grains

Even though Gachara *et al.* [20], have also reported post-harvest illnesses, aflatoxin-producing *Aspergillus* [66, 14, 46, 19] may begin in crop fields. Although poorly controlled post-harvest conditions during drying and storage can result in a sharp rise in mycotoxin concentrations, aflatoxin formation cannot be entirely attributed to any particular developmental stage or processing condition [28, 16]. Although grain drying is costly, farmers can collect grains with kernel moisture contents below 13–15%, which is necessary for safe storage, by choosing a variety or crossbreed that is best suited for a particular crop field [36]. However, in most situations, artificial drying cannot be overcome. The recommended drying temperature for most feed cereals is less than 65°C, and for maize, it is less than 90°C, following quality rules. Naturally, the *Aspergillus* species that contaminate maize grains will also be impacted by these high drying temperatures. Compared to other species, *A. flavus* has an exceptionally high warm resistance, with an upper resistance constraint of 40°C [44]. Furthermore, Prencipe *et al.* [57] discovered that although *A. flavus* development was unsatisfactory above 40°C, most of the aflatoxin was synthesized at this normally high temperature.

Hawkins *et al.* [25], found that *A. flavus* growing on maize kernels was unaffected by drying at 60°C, but that reaching 70°C had an adverse effect, completely reducing fungal disease. Hell and Mutegi [26] went into further detail about the beneficial effects of high temperatures on fungal development. Aflatoxin particles are sadly extremely heat-stable, breaking down at 268–269 degrees Celsius [53]. Aflatoxin levels in stored grains cannot therefore be completely reduced by straightforward drying improvements. Conversely, extended high-temperature treatments might be beneficial [34]. Temperature, relative humidity, and kernel moisture content all have an impact on the physiological forms of fungus while they are being stored. Villers [68] and Mwakinyali *et al.* [42] claim that temperatures between 18 and 19°C and moisture contents between 12 and 13% inhibited the growth and migration of *Aspergillus*. However, when the grain moisture content is higher, lower temperatures [8–10°C] can potentially be acceptable for growth and the synthesis of mycotoxin [38]. Although these values are generally recognized as appropriate storage practices under climatic conditions, the grains bind more water during the colder months due to the greater relative humidity of grain silos. Manna and Kim [38] state that the lower temperature inhibits increases in microbial movement and that the passable water movement for the different *Aspergillus* species is 0.7. Crucially, insects or extended grain physiological action, in addition to the heat and moisture released, can encourage the growth of fungi, which is why "hot spots" can appear in grain heaps. As a result, it is crucial to maintain appropriate hygiene and control the temperature of the maize grain loads, as well as to use appropriate storage techniques [37, 53].

CONCLUSION

Aflatoxin generation is influenced by some conditions, including water stress, high temperatures (>32°C), insect damage to the host plant, vulnerable crop development phases, low soil fertility, high crop density, and weed competition. Thus, the degree of aflatoxin contamination is influenced by several factors, including geographic location, agricultural and agronomic practices, and cultivar susceptibility to fungal invasion during pre-harvest, storage, and/or handling. The length of the developing period—that is, the time frame during which water is available for crop production in well-drained soils—is used to identify agro-environmental zones. This time frame could be influenced by soil water availability, evaporation, and precipitation.

Aflatoxin poisoning in maize harvests is common, although improvements in nutrition security may be significantly hampered by food insecurity outside of the dry season. Undernutrition and increased reliance on limited food supplies exacerbate the mycotoxin problem by increasing the likelihood that contaminated foods will be consumed by humans and by making the population more susceptible to the resulting negative health effects. Indeed, a few factors contribute to a high aflatoxin hazard in stored maize, even though considerable research efforts have been made to reduce toxin contamination:

- Political support for mycotoxin research is required
- There is a shortage of skilled workers, especially for mycotoxin monitoring
- There is a lack of knowledge about risks at all levels and insufficient information on options to reduce aflatoxin contamination from the production-to-use chain.

RECOMMENDATIONS

This review suggests growing methods for preserved maize that are associated with reduced aflatoxin levels. Stakeholders should also be made aware of the dangers of commercializing and eating moldy-coated maize grains. To obtain reliable and accurate data on aflatoxin frequency in various food crops, which may then be used to describe control measures, food basket studies for aflatoxin contamination should be carried out using standard sampling procedures and contemporary expository techniques. To focus resources on identified priority areas, such as recording the impact of aflatoxin on economies and well-being, there should be a coordinated and cooperative effort to reduce reiterations in aflatoxin research in maize.

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