

Mycotoxin's Infections and Prevention Methods: State of the Art

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Abstract

Fungi that attack field crops and contaminate agricultural commodities produce mycotoxins when conditions are favorable. These are specialized metabolites made of poisonous chemical compounds created by bacteria, fungi, or plants that aren't involved in the organism's usual growth, development, or reproduction. They have an adversarial hold on humans, wildlife, and the agricultural sector, resulting in mysterious ailments and economic disruptions. Mycotoxins-tainted food and fodder can be found all over the world, posing a global concern. Consumption of contaminated food and fodder is a typical cause of epidemic outbreaks. Other mycotoxins have been associated with esophageal cancer and neural tube defects (NTDs); the immunotoxin deoxynivalenol (DON) causes diarrhea when combined with trichothecenes, and ochratoxin A (OTA) has been linked to kidney failure. The direct market costs associated with missed trade or lower revenues owing to tainted food or feed could be viewed as the economic repercussions of mycotoxins on human society. This review describes frequent groups of mycotoxins in detail, their impact on global health, their impact on the socio-economy; the methods of detection and prevention of these mycotoxins.

Keywords

Mycotoxins, Global Health Impact, Socio-Economy Impact, Mycotoxin's Detection, Prevention Methods

1. Introduction

1.1. Meaning of the Topic

Mycotoxin refers to the toxic chemical products that are produced by fungi (molds) grown on numerous foodstuffs such as cereals, direct fruits, nuts, and

spices, often under warm and humid conditions. This indicates that it is a harmful secondary metabolite produced by fungal species and they are harmful to humans, animals, and plants [1]. Dry matter, quality, and nutritional losses are the results of molds and mycotoxins contamination on cereal commodities and this represents a major hazard to the food chain; as this one can be found in food, it is capable of causing disease and death in both humans and livestock. Mycotoxins are carcinogenic, genotoxic, teratogenic, nephrotoxic, and hepatotoxic chemicals that can infect a wide variety of foods [2].

1.2. Background

Toxic fungus and mycotoxins initially infiltrated human food sources around 10,000 years ago, when humans learned to harvest crops and store them from one season to the next. Fungi pathogenic on grain crops or saprophytic on harvested grain has found a wide new biological niche in cereal storage, with many of them producing mycotoxins. Mycotoxins are climate-dependent chemicals, but other factors, such as micronutrient bioavailability and insect damage, can influence their occurrence, making it a complicated and multifactor phenomenon [3]. The majority of disorders are caused by eating mycotoxin-contaminated grain or items made from such grain, however, there are additional ways to be exposed [4]. Because the symptoms of mycotoxicoses are similar to those caused by other drugs, so diagnosing them can be difficult. As a result, proper testing for mycotoxins, which includes sampling, sample preparation, and analysis, is required for the diagnosis of a mycotoxicosis.

1.3. Current Status of the Study

Many recent studies have focused on the existence of Mycotoxins in foodstuffs, but the research question is: “Can mycotoxins attacks be avoided in cereals”? While there has been much research on mycotoxins infections in cereals, few researchers have taken into consideration how to avoid these infections to avail cereals that are free from mycotoxins.

To estimate the possibility of contamination prevention and their inactivation or reduction for the case where the incident is inevitable, it is necessary to understand the potential of the harmful effect of mycotoxins, to know the terms of mycotoxins occurrence and frequency, toxicity, and biotransformation in different animal species and humans. Currently, over 400 mycotoxins have been found and classified; however, scientists are concentrating their efforts on those that are carcinogenic or poisonous [5].

2. Main Body

2.1. Mycotoxins Natural Occurrence

Cereals are highly represented in human and animal diet, industrial food, and feed, all these may become contaminated by molds that produce mycotoxins.

Lately, about 400 different mycotoxins were described as produced mostly by molds from genera of *Aspergillus*, *Penicillium*, *Fusarium*, and *Trichotecium*, among which a smaller number is associated with the occurrence of acute or chronic intoxications. It is very difficult to uniquely classify them and create order, because of their different chemical structure, biochemical pathway, origin, and biological effects [6]. The most important are aflatoxin B1, ochratoxin A, zearalenone, deoxynivalenol, fumonisin B1, and T-2 toxin [7] (**Figure 1**).

The majority of mycotoxins are produced by three fungal genera: *Aspergillus*, *Penicillium*, and *Fusarium*. These metabolites primarily affect the seed quality, germination, viability, seedling vigor, growth of root and coleoptile, since the fungi responsible for the production of these mycotoxins are often endophytes that infect and colonize living plant tissues, accumulation of mycotoxins in the plant tissues may at times be associated with the development of plant disease symptoms [1].

While fusarium toxins are known to be created during cereal harvesting under high moisture conditions, pre-harvest aflatoxin contamination of crops is linked to high temperatures, insect-mediated damage, and extended dryness. In warm, humid, tropical, and subtropical growing environments, chronic contamination occurs. The amount of moisture in the grain depends mostly on the amount of water available at harvest, but it also depends on the frequency and extent of drying and aerating the grain before and during storage, as well as the respiration of insects and microbes hosted by the grain. The present state of knowledge about the natural occurrence, metabolism, and potential toxicity of the most major trichothecenes and zearalenone in cereals/cereal products has been reviewed [8].

Zearalenone is also a mycotoxin that can be produced by several field fungi including the *Fusarium* variety. *Fusarium* infects cereals pre-harvest in the field during blooming, but growth and toxin production may also occur post-harvest under poor storage conditions [9].

Below, are the chemical structures of the main mycotoxins.

Table 1 outlines the most prominent mycotoxins, as well as the food and animal feed restrictions set by the United States (US) and the European Union (EU).

Recommendations have been made regarding the presence of T-2 and HT-2 toxin in grains and grain products [10].

Parameters That Influence the Occurrence of Mycotoxins

Aflatoxins are produced in response to pre-harvest and post-harvest conditions. The pre-harvest factors are [12]:

- Weather conditions related to droughts.
- Infection is increased by heat stress during flowering and fruit growth.
- Excessive water.
- Nutrient deficiency.

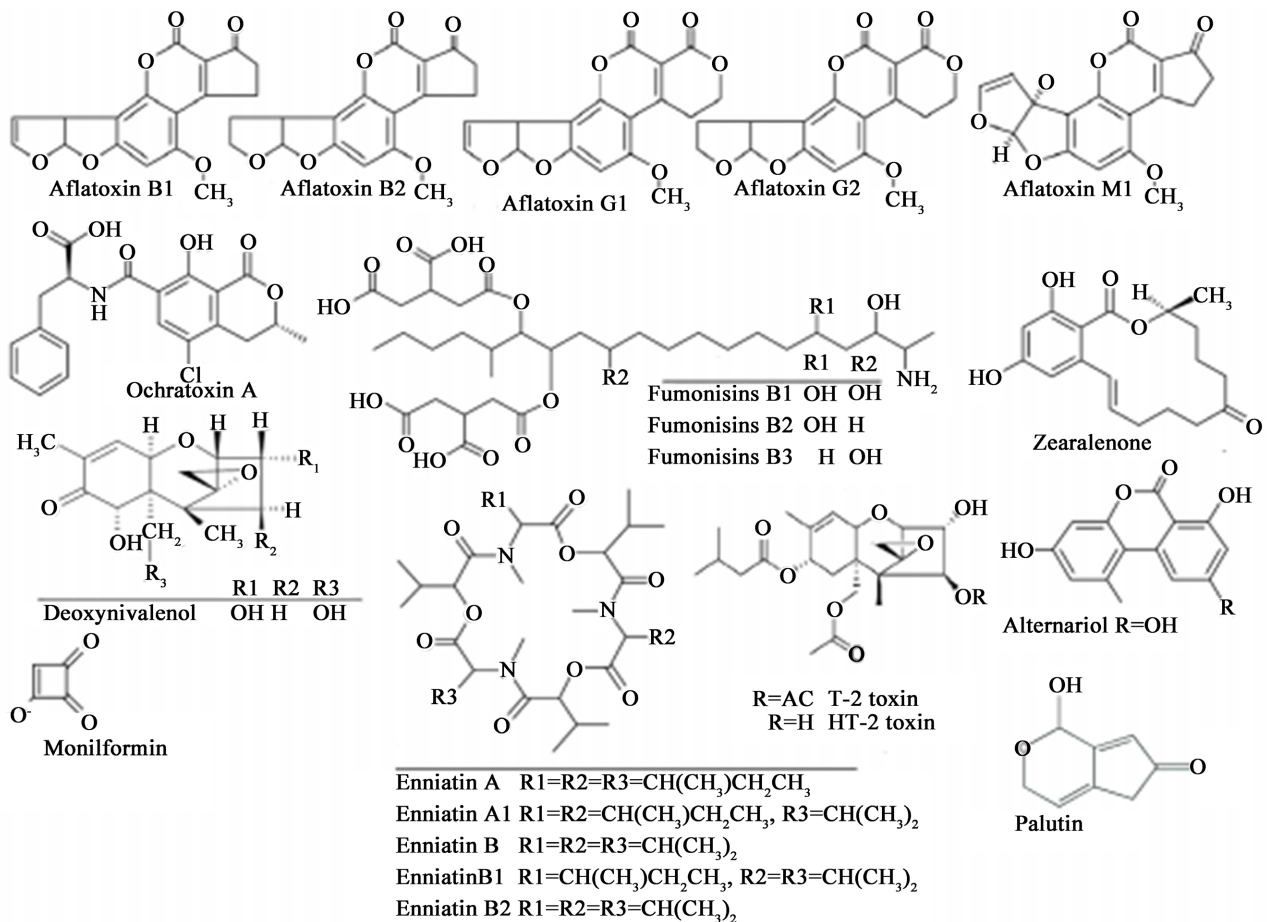


Figure 1. Chemical structures of the main mycotoxins [2].

- Insect damage.
- Harvest damage.
- Other stressors in plants that promote fungal infection and aflatoxin formation, includes:
 - Inadequate dietary intake.
 - Plant illnesses.
 - Weed competition.
 - Overgrowth of plants.
 - Insect nourishment for growing fruits.

Higher aflatoxins concentrations in post-harvest products are caused by improper product storage, which includes storage with insufficient moisture content and at an inappropriate temperature.

Additionally, some parameters have to be considered during drying and storage of cereals after harvesting, these include: [12].

- Temperature is one of the products of respiration of the crop that produces heat. As a result, lowering the temperature of the crop can help to reduce the rate of respiration, extending the crop's storage life by reducing the chance of germination.

Table 1. List of the most common mycotoxins and their maximum levels in diet and feed [11].

Mycotoxin	IARC Number*	Acronym	Fungal species	Food commodities	US FDA (µg/Kg)	EU (µg/Kg)
Aflatoxins B1, B2, G1, G2	1*	AFB1 AFB2 AFG1 AFG2	<i>Aspergillus flavus</i> <i>Aspergillus parasiticus</i>	Maize, wheat, rice, peanut, sorghum, pistachio, almond, ground nuts, tree nuts, figs, cottonseed, spices	20 for total	2 - 12 for B1 4 - 15 for total
Aflatoxin M1	2B*	AFM1	<i>Metabolite of Aflatoxin B1</i>	Milk, milk products, meat	0.5	0.05 in milk 0.025 in infant formulae and infant milk
Ochratoxin A	2B*	OTA	<i>Aspergillus Ochraceus</i> <i>Aspergillus carbonarius</i> <i>Penicillium verrucosum</i> <i>Penicillium Nordicum</i>	Cereals, dried vine, fruits, wine, grapes, coffee, cocoa, cheese	Not set	2 - 10 for EU
Fumonisin B1, B2, B3	2B*	FB1 FB2 FB3	<i>Fusarium verticillioides</i> <i>Fusarium proliferatum</i>	Maize, maize products, sorghum, asparagus	2000 - 4000	2000 - 4000
Zearalenone	3*	ZEN	<i>Fusarium Graminearum</i> (<i>F.roseum</i>) <i>Fusarium culmorum</i> <i>Fusarium Equiseti</i> <i>Fusarium cerealis</i> <i>Fusarium verticillioides</i> <i>Fusarium incarnatum</i>	Cereals, cereal products, maize, wheat, barley	Not set	20 - 100
Trichothecenes (Type B: deoxynivalenol)	3*	DON	<i>Fusarium Graminearum</i> <i>Fusarium culmorum</i> <i>Fusarium cerealis</i>	Cereals, cereal products	1000	200 - 500
Patulin	3*	PAT	<i>Penicillium Expansum</i> <i>Byssoclamus nivea</i> <i>Aspergillus clavatus</i> <i>penicillium patulum</i> <i>penicillium crustosum</i>	Apples, apple juice and concentrate pears, peaches, grapes, apricots, olives low acid fruit juice	50	10 - 50 for EU
Trichothecenes (Type A: T-2 toxins)	3*	T-2	<i>fusarium langsethiae</i> <i>Fusarium sporotrichioides</i>	Maize, wheat, barley, oat, rye	15	25 - 1000
Trichothecenes (Type A: HT-2)	3*	HT-2	<i>fusarium langsethiae</i> <i>Fusarium sporotrichioides</i>	Maize, wheat, barley, oat, rye	15	25 - 1000
Enniatins		ENNs	<i>Fusarium tricinctum</i> <i>Fusarium avenaceum</i>	Corn	Not set	Not set
Ergot Alkaloids		Eas	<i>Claviceps purpurea</i> <i>claviceps fusiformis</i> <i>claviceps africana</i> <i>Neotyphodium spp</i>	Rye, rye-containing commodities, wheat, triticum, barley, millet and oat	Not set	Not set
Alternariol		AOH	<i>Alternaria alternata</i>	Grain and grain-based products, vegetables,	Not set	Not set

- The other parameter is moisture since it fosters fungal and insect problems, respiration, and germination, high moisture content causes storage issues.
- The other parameter is Oxygen in the storing container because foods store best when oxygen is removed, eliminating oxygen minimizes food oxidation and deterioration.

Table 2 shows the sources and conditions for mycotoxins formation.

2.2. Toxic Effects of Mycotoxins on Health

Poor postharvest handling can result in a rapid loss of qualitative features, as well as a considerable decrease in seed germinability and nutritional content. Microbial activity in grains can cause discoloration, contribute to heating and dry matter losses by using carbohydrates as an energy source, degrade lipids and proteins or alter their digestibility, produce volatile metabolites that emit odors, reduce germination, baking, and malting quality, and have an impact on use as animal feed or seed [14]. Some fungal spores can cause respiratory illness in workers who come into contact with them [1].

Mycotoxins are silent killers, and their effects might go undetected for a long time, especially if they are exposed regularly. When consumed or inhaled, these fungal toxins cause a variety of metabolic dysfunctions in humans and livestock, including immunological imbalance, malignancies, allergies, abortions, and, in rare circumstances, the death of the affected hosts [15].

The role of aflatoxins in the formation of liver cell cancer, developmental

Table 2. Sources and conditions for mycotoxins formation [13].

Mycotoxins	Mold source	Grains affected	Optimal temperature	Optimal Humidity	Favorable conditions
Aflatoxins (B1, B2, G1, G2)	<i>Aspergillus flavus</i> <i>Aspergillus parasiticus</i>	Corn, sorghum, cotton seed, peanuts	75 - 95 °F	80% - 85% relative humidity 17% moisture content	Grain damage, constant high temperature and humidity
Vomitoxin (deoxynivalenol, DON)	<i>Fusarium Graminearum</i>	Corn, wheat, barley, sorghum, rye, others	70 - 82 °F	88% relative humidity 22% moisture content	alternating warm and cool temperatures during growing season, high humidity
Zearalenone	<i>Fusarium Graminearum</i>	Corn, wheat, barley, sorghum	45 - 75 °F	24% moisture content	alternating warm and cool temperatures during growing season
Fumonisin B1, B2, B3	<i>Fusarium verticillioides</i>	Corn	Likely < 77 °F	likely > 20% moisture content	Drought during growing season, followed by cool, wet conditions
Ochratoxin A	<i>Aspergillus Ochraceus</i> <i>Penicillium verrucosum</i> <i>Penicillium viricatum</i>	Corn, wheat, barley, rye	54 - 77 °F	85% relative humidity 19% - 22% moisture content	Low temperatures

impairment, acute toxicosis, fumonisins, esophageal cancer, and neural tube abnormalities has been a source of concern for humans (NTDS). Deoxynivalenol (DON) and other immunotoxin trichothecenes cause gastroenteritis, whereas ochratoxin A (OTA) has been associated with kidney disease [16]. Fumonisin intake from contaminated corn and corn-based products has been associated with neural tube anomalies [17].

In animals, mycotoxins can cause everything from instant death to chronic sickness and reproductive problems; aflatoxins can induce liver damage or cancer, as well as decreased milk and egg production and immune suppression [12] [18].

Several writers have addressed the toxicity and biological impacts of mycotoxins in foods [19] [20] [21] (Table 3).

Table 4 shows the commodities where mycotoxins have been discovered, as well as the impacts on animals and humans [12].

2.3. Mycotoxin's Detection and Control

According to a review paper on Strategies to prevent and reduce mycotoxins for compound feed manufacture, mycotoxin reduction approaches can be divided

Table 3. Mycotoxins' toxicity and biological consequences in food [21].

Mycotoxin	Major foods	Species	Health effects	LD (mg/Kg)
Aflatoxins	Maize, groundnuts, figs, tree nuts, (aflatoxins M1 secreted by cow after metabolism of aflatoxin B1), milk, milk products)	Aspergillus flavus Aspergillus parasiticus	Hepatotoxic, carcinogenic	0.5 (dog) 9.0 (mouse)
Cyclopiazonic acid	Cheese, maize, groundnuts, rodo millet	Aspergillus flavus Penicillium aurantiogriseum	Convulsions	36 (rat)
Deoxynivalenol	Cereals	Fusarium Graminearum	Vomiting, Food refusal	70 (mouse)
T-2 toxins	Cereals	Fusarium sporotrichioides	Alimentary toxic aleuki	4 (rat)
Ergotamine	Rye	Claviseps purpurea	Neurotoxin	
Fumonisin	Maize	Fusarium moniliforme	Eusophesial cancer	
Ochratoxin	Maize, cereals, coffee beans	Aspergillus Ochraceus Penicillium verrucosum	Nephotoxic	20 - 30 (rat)
Palutin	Apple juice, damaged apple	Penicillium expansum	Edema, hemorrhage, possibly cancer	35 (mouse)
Penitrem	Walnuts	Penicillium aurantiogriseum	Tremors	1 - 0.5 (mouse)
Sterigmatocystin	Cereals, coffee, beans, cheese	Aspergillus versicolor	Hepatotoxic cancer	166 (rat)
Tenuazonic acid	Tomato paste	Alternaria tenuis	Convulsions, hemorrhage	81 (female mouse) 186 (female mouse)
Zearalenone	Maize, barley, Wheat	Fusarium Graminearum	Oestrogenic	Not acutely toxic

Table 4. Commodities containing mycotoxins and their impact on animals and humans [12].

Mycotoxins	Commodities found contaminated	Affected species	Pathological effects
Aflatoxins (B1, B2, G1, G2, M1, M2)	Peanuts, corn, wheat, maize, cottonseed, nuts, various food, milk, eggs, cheese, figs	Birds(Duckling, turkey, chicken, Mammals (cattle, sheep, lab animals) fish)	hepatotoxicity, bile duct hyperplasia, hemorrhage, intestinal track, kidneys, carcinogenesis (liver tumors)
Ochratoxin	Cereal grains (wheat, barley, corn) dry beans, cheese, coffee, dried fruits, grapes, wine	Chicken, duckling, rat, human	Nephrotoxicity (tubular nephrosis of kidney), porcine nephrogally, mild liver damage, teratogenesis, carcinogenesis (Kidney tumors), urinary tract tumors
Fumonisin	Corn, polenta	Horse, rat, mouse, humans	Pulmonary edema, Leukoencephalomalacia, nephrotoxicity, hepatotoxicity
Zearalenone	corn, moldy hay, elleted commercial feed	Dairy cattle, chicken, turkey, lamb, rat, mouse	Estrogenic effects (Edema of vulva prolapse of vagina), enlargement of uterus, atrophy of testicles, trophy of ovaries, enlargement of mammary glands, abortion

into four categories: Physical methods, thermal methods, chemical methods, and mycotoxin-controlling feed additives are all examples of mycotoxin-controlling feed additives. The first three methodologies primarily focus on reducing mycotoxins in feed ingredients during processing, whereas the last one focuses on compensating for the negative effects of mycotoxin-contaminated diets in animal bodies, and that mycotoxin prevention management and the processing stage of cleaning and sorting are still the most effective strategies to control mycotoxin hazards in a current era [22].

To control mycotoxins in foods and feeds, a variety of techniques are used. These tactics could be divided into preventive and curative strategies on a broad scale.

2.3.1. Preventive Strategies of Mycotoxins

Pre-harvest and post-harvest methods are two types of prophylactic techniques for preventing mycotoxigenic fungal development and/or the production of their toxin. There are three degrees of fungal and associated mycotoxins protection in agricultural commodities: primary, secondary, and tertiary prevention [12].

1) Primary prevention entails a variety of activities aimed at keeping the environment unfavorable for fungal growth, these includes:

- Establishing a pre-harvest schedule that is appropriate.
- Fungal types of growing plants are being developed.
- Managing fungi-infected planting crops in the field.
- Reducing the moisture content of plant seeds upon harvest and during storage.
- Whenever feasible, keep commodities at a low temperature.
- Fungicides and preservatives are used to prevent fungal development.
- Use approved insecticides to control insect infestations in stored bulk grains.

Grain dryer control systems can be used to increase drier throughput while maintaining optimal energy efficiency and minimizing grain quality degradation. The three most common methods for drying cereal grains are in-storage layer drying, batch drying, and continuous flow drying [23].

2) Secondary prevention deals with early prevention if some fungi infect commodities at an early stage. This includes:

- Re-drying items to stop the growth of infected fungus.
- Seeds that have been infected must be removed.
- Detoxification or inactivation of mycotoxins that have been contaminated.
- Keeping kept goods safe from conditions that foster fungus growth.

3) Tertiary prevention is applied, when products are heavily infested with dangerous fungus. This includes:

- Complete eradication of tainted goods.
- Mycotoxins are detoxified or destroyed to a minimum amount.

The first step for being able to reduce mycotoxins in cereals is to be able to detect them early, The development of electronic nose technology has generated interest in using characteristic volatiles and fragrances as a rapid, early indicator of grain quality decline to detect quality changes in cereal grains [24].

Mycotoxins can be kept out of the food chain if only high-quality items are stored in silos and suitable farming practices are followed. Decontamination of mycotoxin in the later phases of food production is challenging; it raises production costs and the outcomes aren't always good. A review of mycotoxin contamination prevention in food and feed provided agronomical approaches, food and feed storage guidelines, practical feed decontamination procedures, and the use of feed additives where mycotoxin contamination prevention has failed [25].

2.3.2. Curative Strategies on Mycotoxins Detection and Control

Deactivation of existing mycotoxins in feed or food is one of the therapeutic approaches [15]. To decontaminate/detoxify mycotoxins from various agricultural products, natural methods (physical treatment) such as thermal insulation, radiation treatment, and low-temperature plasma, chemical methods such as oxidation, reduction, hydrolysis, alcoholysis, and absorption, and biological methods with the use of biological agents can all be used [2].

1) Physical treatment

Mycotoxins are naturally removed through a variety of methods. Sorting, processing, storage, radiation, cold plasma, and mycotoxins binders are a few of them.

Sorting is the initial step in natural disinfection, which is accomplished by cleaning and sorting processes. Because aflatoxin infection is typically diverse, separating damaged nuclei can significantly limit infection. A reduction of 27 percent to 93 percent is projected after sorting the diseased grain. This process is considered preferable because there is no risk of manufacturing degraded items [26].

Processing: Although mycotoxins are thermally stable molecules, they have been demonstrated to be diminished by several traditional food preparation processes (baking, frying) at temperatures surpassing 1000°C. The processing temperature and moisture content of the granules have an impact on the decrease of mycotoxins by 50% to 80% during the extrusion process. Furthermore, temperatures between 150 and 2000 degrees Celsius significantly reduce aflatoxin (AFB1), with an average drop of 79 percent, and are much more effective at high humidity levels [27].

Storage: Controlling mycotoxins is complicated by environmental factors. Temperature and humidity are two essential variables that boost both fungal growth and the manufacture of mycotoxins because they affect the total growth of fungus. Storage under controlled environments, such as packing, temperature control, ventilation, and proper air humidity, helps to prevent fungal growth and the accumulation of mycotoxins. Crop losses have ranged from 20% to 50% in underdeveloped countries due to insufficient storage techniques [28].

Radiation is usually classified as ionizing and non-ionizing. It contributes to the reduction or elimination, Mycotoxins are a natural detoxifying agent for pathogenic microbes in grains, although they are only partially eliminated in diets. This technology can be used in an industrial setting because it distributes energy and modifies the molecular structure of food items through a series of reactions [29].

Cold plasma (CP) Plasma is a word for the fourth state of matter, which is mostly made up of photons, ions, and free radicals such as reactive oxygen and nitrogen species, all of which have specific physical and chemical properties. Using low-pressure cold plasma, researchers were able to detoxify up to 50% of aflatoxins on the surface of nuts. However, due to the lack of information on the possible creation of hazardous chemicals, this approach should be used with caution [30].

Mycotoxin binders attach to mycotoxins and prevent them from entering the bloodstream through the gut, preventing mycotoxins from being absorbed. Absorbent compounds include activated carbon, aluminosilicates, complicated non-digestible polysaccharides, and cholesterol. Binding mycotoxin is a physical method of stopping bacteria from degrading aflatoxins [31]. Activated carbon was used to eliminate patulin from naturally contaminated cider and aflatoxin from naturally infected milk, according to studies [32]. Mycotoxins levels were lowered using this method, but more research is needed to ensure food safety.

To eliminate, destroy, or suppress the toxicity of mycotoxins, many physical procedures have been revised. Physical removal of contaminated areas of foodstuffs, heat treatment, and irradiation to transform toxins into comparatively benign chemicals, or the inclusion of adjuvants to reduce or otherwise hide the adverse effects of toxins are examples of these procedures. These treatments include food drying and roasting, irradiation, bio-absorption of aflatoxins in animal feed, and other ozone-based methods [15].

In 2004-2005, the Lithuanian University of Agriculture, Laboratory of Heat and Biotechnological Engineering investigated the efficacy of physical means (ozone) for reducing mycological pollution of grain surfaces, as well as the use of ozone for reducing mycological infection in cereal grain to clean grain from microbiological contamination. Based on moisture content w (for grain $w = 15.2$ percent) to 3 times (for grain $w = 22.0$ percent), an ozone-air mixture used for active ventilation grain drying (with an ozone concentration of 700 ppb) can reduce drying time by roughly 20%, and mycological pollution by about 2.2 percent) [33].

2) Chemical treatment

This can be achieved using bases (ammonia, hydrated oxide), chitosan, ozone treatment.

Bases (ammonia, hydrated oxide) are used to treat seeds with ammonia to reduce the number of mycotoxins (AFs, FBs, OTs) to undetectable levels while blocking mycotoxigenic fungal growth. Treatment with bases, on the other hand, is prohibited in the European Union for food meant for human consumption. Mycotoxin detoxification was aided greatly by the use of a glycerol and calcium hydroxide combination. Although sodium hydroxide and potassium hydroxide are commonly used to break down AFB1 in tainted oil, these chemicals have the potential to cause secondary contamination and have poor nutritional effects on the commodities [29].

Chitosan is a linear polymer that inhibits fungi, bacteria, and viruses. It is the second most abundant carbohydrate in nature after cellulose. Chitosan's biocompatibility and antibacterial characteristics make it a promising candidate for food preservation [34]. The combined effects of chitosan on maize and wheat grains for controlling fungal growth and mycotoxin production of FBs and DON by *Fusarium* species (*F. proliferatum*, *F. graminearum*, and *F. verticillioides*) were reported, showing a decrease in DON and FB production in irradiated maize and wheat grains after the application of low-molecular-weight chitosan with deacetylation above 70%. Furthermore, wheat grains containing 1 percent chitosan and 1 percent lemon essential oils from the marine brown algae *Ascophyllum nodosum* had decreased DON levels [35].

Ozone treatment deals with Ozone therapy by applying ozone (O_3) to aid in the breakdown of certain mycotoxins. Ozonation is a straightforward procedure that leaves no hazardous leftovers after use [36]. Ozone is used to sterilize cereals, vegetables, and fruits, as well as to detoxify mycotoxins [37]. Because aflatoxins, particularly AFB1 and AFG1, have a C8 - C9 double bond in their structures, Agriopoulo *et al.* discovered that ozone gas was particularly effective in destroying them [38]. Aflatoxin AFG1 was discovered to be the most sensitive. Ozone therapy resulted in a significant reduction in DON under optimum conditions (55g O_3 -1 for 6 hours) (29 percent - 32 percent) [39].

3) Biological control

This is done by using the bacteria treatment method, Yeast application me-

thod, food fermentation, applying non-toxic fungi, and enzymatic detoxification.

The bacteria treatment method is useful since certain bacteria can bind mycotoxins in food or liquids, they are used in the bacteria treatment strategy. *Flavobacterium aurantiacum* B-184 was the only bacteria out of over 1000 evaluated for probable aflatoxins degradation that was capable of irreversibly eliminating aflatoxins from solutions [40]. The bacterium *Enterococcus faecium* detoxifies AFB1 by adhering to the bacterium's cell wall components. With the help of microorganisms, peptidoglycans and polysaccharides found in bacterial cell walls were found to be responsible for the binding of mycotoxins [41]. Furthermore, bacterial detoxification of the mycotoxin DON has evolved as a result of research and improvements. Aerobic oxidation and partitioning of DON into C3 carbon, which is carried by various *Devosia* species, can reduce DON pollution. Lactic acid bacteria (*Lactobacillus* (L.) *casei* and *Lactobacillus reuter*) may successfully bind to aflatoxins in aqueous solutions [22]. In additional in vitro experiments, *Lactobacillus amylovorus* and *Lactobacillus rhamnosus* demonstrated a binding efficacy of up to 60% AFB1, showing their potential to bind specific dietary contaminants. A reduction of 98 percent FB1 and 84 percent T-2 was also reported during fermentation of whole-grain sorghum with *Lactobacillus fermentum* [42].

The yeast application approach is a potential technique for mycotoxin infection therapy that involves the use of biological control agents (BCA) [43]. The use of yeast is particularly interesting since yeast produces antimicrobial compounds that are beneficial to people and animals; yet, yeasts may quickly grow on any substrate in bioreactors [44]. Moreover, yeasts do not produce allergens or other secondary compounds, unlike many filamentous fungi or bacterial antagonists [45]. *Saccharomyces cerevisiae* is a probiotic yeast that digests DON and reduces the synthesis of lactate dehydrogenase (LDH) in DON-stimulated cells [46].

Food fermentation is utilized to improve food while also making it more appealing to consumers. Fermentation is a low-cost mycotoxin disinfection technology that can be used to improve food ingredients while also lowering or eliminating mycotoxins. Fermentation is a more cost-effective and practical way to reduce mycotoxins than the more costly and inconvenient options. The nature of metabolites and the toxicity of products formed after fermentation should be thoroughly documented for safe food production.

Applying Fungi done by the application of fungus to maize, cotton, pistachio, and peanuts using non-toxic strains of *A. flavus* and *A. parasiticus* resulted in considerable reductions in aflatoxins contamination. In terms of fungus and detoxification, it has been discovered that fungi that create Mycotoxins can also degrade them [47]. When fungi are starving for energy, they can degrade, convert, and use degradation products as a source of energy. Fungi including *Aspergillus*, *Rhizopus*, *Trichoderma*, *Clonostachys*, and *Penicillium* spp. successfully detoxify mycotoxins. In both west and east Africa, competition is used to

suppress Aflatoxins in maize with non-toxigenic microbial strains. Non-toxic *A. parasiticus* inoculants, in large quantities, enter the soil around the crops, competing with toxigenic strains [48].

Enzymatic Detoxification: here the chemical and biological processing aspects of Enzymatic Detoxification of Mycotoxins are combined. It has excellent performance and specialization, and it may be utilized in low-toxicity situations without harming organisms. In non-stoichiometric mycotoxin ratios, enzymes also behave as catalysts [49]. Some species of *Aspergillus* can produce an enzyme that can detoxify fumonisins, including those produced by *Fusarium*. The anti-infection activity of enzymes like 1,3-glucanases and chitinase varies depending on the microorganism's characteristics. Fruit rotting fungus growth is slowed and reduced when 1,3-glucanases and chitinases are used [50]. *A. Niger* complex *Penicillium simplicissimum* is suppressed. The growth of *Penicillium nalgiovense* and *A. flavus* was enhanced by spraying 50 percent 1,3-glucanase and 50 percent and 40 percent chitinase on salami surface samples. As a result, 1,3-glucanase and chitinase could be employed as a safe alternative in the fermented sausage industry to control fungal deterioration. Using microbial manganese peroxide, oxidase enzymes, catalase, and laccase enzymes, enzymatic detoxification of AFB1 was also achieved [48]. Enzymes, on the other hand, have an untapped profile when it comes to detoxifying food toxins due to their favorable toxicity and specificity [51]. In the European Union, no enzyme for eliminating mycotoxin contamination from foods has been approved.

2.4. Effects of Mycotoxins on the Economy

The direct market costs of lost commerce or poorer revenues as a result of polluted food or feed can be considered the economic consequences of mycotoxins on human society [16]. This occurs in systems that monitor the presence of mycotoxins in food and feed supplies [52]. Food with mycotoxin levels beyond a specified maximum allowed level is either rejected outright or sold at a lower price for a different purpose in local markets or even on a global scale. As a result, food producers face enormous financial losses [53].

Due to its location near the equator, which makes it particularly favorable to the multiplication of mycotoxigenic fungus species, Africa is the most impacted of all continents. Poverty and climate change are two other variables that are complicating the continent's mycotoxins problem. In Africa, the economic impact of mycotoxins can be felt in overall human and animal health, sustainable development, food security and safety, damage to Africa's agricultural export brand, decreased self-sustainability, and increased reliance on foreign aid, not to mention the high cost of research, mitigation, and regulation of mycotoxins' prevalence [54].

3. Conclusion

According to this research study, mycotoxins are common in grains and feed. To

prevent animal exposure to various mycotoxins, which might have detrimental repercussions for animal health and production output, special attention should be made to certain raw materials. As a result, human health and the occurrence of residues in animal-derived products may be compromised indirectly. In humans and animals, several mycotoxins have been reported to have teratogenic and genotoxic effects, as well as synergistic effects. Furthermore, relevant approaches for the further development and application of sophisticated specific methodologies for the detection and reduction of mycotoxin contamination may be found in the literature. It is recommended that nationwide monitoring be carried out on a large number of grains and feed samples in a systematic manner.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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