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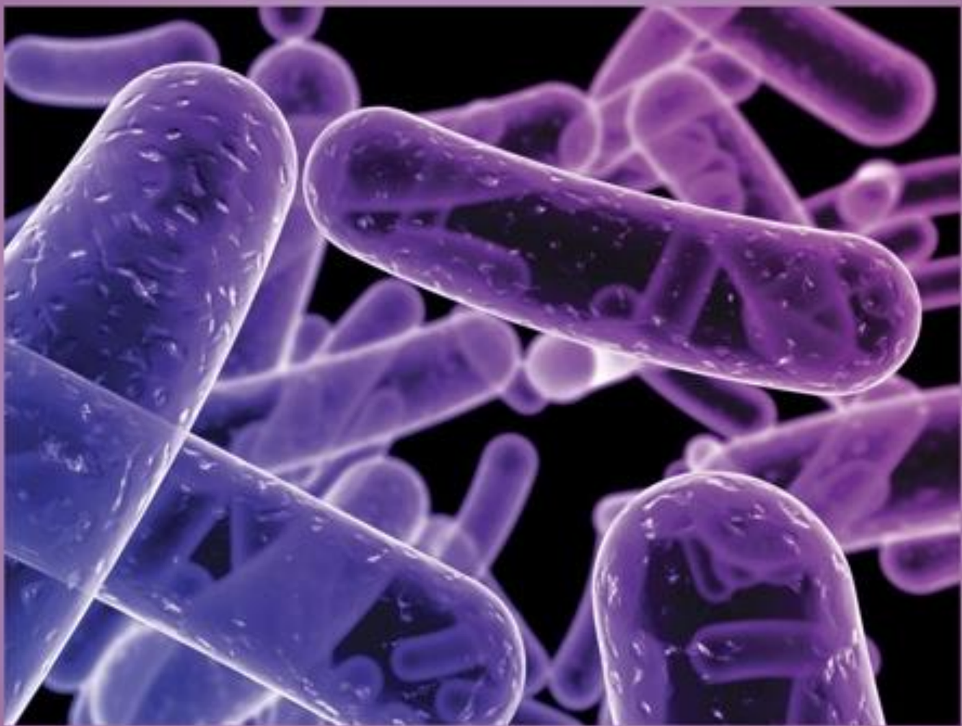

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Mycotoxins in Food

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ABSTRACT

Mycotoxins are naturally occurring toxins produced by certain moulds (fungi) and can be found in food. The moulds grow on a variety of different crops and foodstuffs including cereals, nuts, spices, dried fruits, apples and coffee beans, often under warm and humid conditions. Mycotoxins can cause a variety of adverse health effects and pose a serious health threat to both humans and livestock; The adverse health effects of mycotoxins range from acute poisoning to long-term effects such as immune deficiency and cancer. Mycotoxin contamination of food is an ongoing global concern. Mycotoxin contamination is considered an unavoidable and unpredictable problem, even where good agricultural, storage and processing practices are implemented, posing a difficult challenge to food safety. Additionally, many mycotoxins are not easily eliminated during food processing because of their stability against heat, physical, and chemical treatments. Furthermore, feed contamination can also pose an extra hazard for food safety due to the possible carry-over of mycotoxins to animal-derived products such as milk, meat, and egg, leading to mycotoxin intake by humans.

INTRODUCTION

The Ascomycota phylum of filamentous fungus produces mycotoxins, which are toxic (poisonous) secondary metabolites. (Channaiah., 2019). Bennett proposed the following definition of mycotoxins: "Natural compounds generated by fungus that elicit a harmful response when delivered in low concentration to higher vertebrates and other animals through a natural pathway." Phytotoxicity or antimicrobial activity are two additional impacts that certain mycotoxins may have. Typically, Bennett's description of "mushroom and yeast poisons" is not included in the definition of mycotoxins.” (Bennett., 1987). Aspergillus, Fusarium, and Penicillium are the three main fungus genera that often and problematically contaminate foods and feeds with mycotoxins. (Alshannaq & Yu., 2017) While Aspergillus and Penicillium species typically develop on foods and feed when they are stored (Saleemi *et al.*, 2010) In the field, Fusarium species frequently infect and spread to plants growing crops like wheat, barley, and maize. There are now approximately 300 mycotoxins known and documented, however only a small number consistently contaminate food and animal feeds, (Alshannaq & Yu., 2017).

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These include the trichothecenes deoxynivalenol (DON), zearalenone (ZEA), patulin, fumonisins, ochratoxins (OT), and ochratoxins (AF), as well as the T-2 toxin. (Grajewski *et al.,* 2012).

Mycotoxins pose a hazard to both human and animal health, obstruct international trade, waste food and feed, and divert funds from necessary research, enforcement, regulation, and mitigation efforts. (Alshannaq & Yu., 2017). Unfortunately, every year mycotoxins contaminate around 25% of the world's harvested crops, causing enormous losses in agriculture and industry that are measured in the billions of dollars. (Moretti *et al.,* 2017). Aflatoxins (AFs) are among the mycotoxins that are thought to be the most dangerous and have a substantial financial impact on agriculture. While AFs are largely a financial problem in the United States (US) and the European Union (EU), they are a major cause of hepatocellular carcinoma in poor nations in Asia and Africa, where they are linked to hundreds of cases annually. It is significant to note that estimates of the yearly losses to the US maize sector from aflatoxin contamination range from 52.1 million to 1.68 billion dollars. (Magnoli *et al.,* 2019) According to the Rapid Alert System for Food and Feed (RASFF), mycotoxins are also the biggest risk mentioned in alerts on EU border rejections, with AFs being the particular mycotoxins most frequently mentioned in the reports. (Alshannaq& Yu ., 2021).

Mycotoxins Commonly Found in Food:

Certain varieties of mould that develop on cereal, dried fruit, nuts, and spices naturally create mycotoxins, which are dangerous substances (Hosseini & Bagheri., 2011). Before and/or after harvest, during storage, on or within the food itself, and frequently in warm, wet, and humid circumstances are all times when mold can thrive (Fowler& Coutel., 2017). However, mycotoxins are not apparent to the naked eye like mold development. (Marín *et al.,* 2021).

In food preparation, such as roasting, baking, and even frying, mycotoxins are comparatively resistant to high temperatures. Due to this, they may continue to be present in the finished food items that customers finally ingest. (Choudhary& Kumari., 2010).

When consuming food products infected with some food-borne mycotoxins, signs of serious sickness might arise swiftly. mycotoxins (Moslehi et al., 2010). Other mycotoxins that can be found in food have also been linked to long-term negative effects on health, such as the development of cancer and immunological deficiencies. (Wu *et al.,* 2014). Of the several hundred mycotoxins identified so far, Due to their detrimental effects on human health and frequent occurrences in food, about a dozen have attracted the most attention. (Freire *et al.,* 2017). Therefore, consuming infected plant items or meat and dairy products made from animals given contaminated feed might expose people to mycotoxins. (Yang *et al.,* 2020).

Occurrence and Toxicity of Major Mycotoxins:

Mycotoxin contamination can happen before harvest when the crop plant is developing or after harvest while the food items are being processed, packaged, distributed, and stored. In general, mold development and mycotoxin contamination can occur on any crops or grains that are inadequately kept for an extended period of time in a hot, humid environment. Rice is thought to be the crop least likely to be contaminated by mycotoxins, while maize is (Awuchi *et al.,* 2021). During food preparation, such as cooking, boiling, baking, frying, roasting, and pasteurization, the majority of mycotoxins are chemically and thermally stable. (Kabak, 2009). Animal goods including meat, eggs, and milk that have consumed tainted feed can also include mycotoxins. These items can end up on a person's plate. The US Food and Drug Administration is only one example of the numerous national and worldwide public health and governmental organizations (FDA) (Alshannaq& Yu., 2017) Mycotoxin contamination in food and feed is a serious concern for the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the European Food Safety Authority (EFSA), who have taken action to address this global issue by adopting stringent regulatory guidelines for the main mycotoxin classes in food and feed. There are already restrictions on the amount of main mycotoxins present in food and feed in around 100 nations. (Benkerroum., 2020). Table 1 covers the significant contaminants, major food manufacturers, some frequently contaminated food items, and the US FDA and EU regulation limitations for mycotoxin levels in food and animal feed. (Agriopoulou *et al.,* 2020).

Table 1: Major mycotoxins and US and EU limits on food and animal feed levels (Lee *et al.,* 2017)**.**

Mycotoxin	Fungal Species	Food Commodity	US FDA (µg/kg)	EU (EC 2006) (µg/kg)
Aflatoxins B1, B2, G1, G2	*Aspergillus flavus* *Aspergillus parasiticus*	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	Metabolite of aflatoxin B1	Milk, milk Products	0.5	0.05 in milk 0.025 in infant formulae and infant milk
Ochratoxin A	*Aspergillus ochraceus* *Penicillium verrucosum* *Aspergillus carbonarius*	Cereals, dried vine fruit, wine, grapes, coffee, cocoa, cheese	Not set	2–10
Fumonisins B1, B2, B3	*Fusarium verticillioides* *Fusarium proliferatum*	Maize, maize, products, sorghum, asparagus	2000–4000	200–1000
Zearalenone	*Fusarium graminearum* *Fusarium culmorum*	Cereals, cereal products, maize, wheat, barley	Not set	20–100
Deoxynivalenol	*Fusarium graminearum* *Fusarium culmorum*	Cereals, cereal products	1000	200–50
Patulin	*Penicillium expansum*	Apples, apple juice, and concentrate	50	10–50

Types of Mycotoxins in Food:

Aflatoxins:

Aflatoxins (Fig. 1) are a set of structurally similar, poisonous, secondary metabolites that are naturally found in soil and other organic materials. They are mostly generated by the bacteria A. flavus and A. parasiticus. A. flavus strains only generate aflatoxins B1 (AFB1) and B2 (AFB2), but A. parasiticus strains are capable of producing AFB1, AFB2, G1 (AFG1), and G2 (AFG2). Since the identification of AFs as the causal agents of Turkey X sickness killing 100,000 young turkeys in Great Britain in 1960, AFs have been the focus of much research and are thought to be the most researched. mycotoxins (Perrone& Gallo, 2017) (Ren *et al.,* 2020).

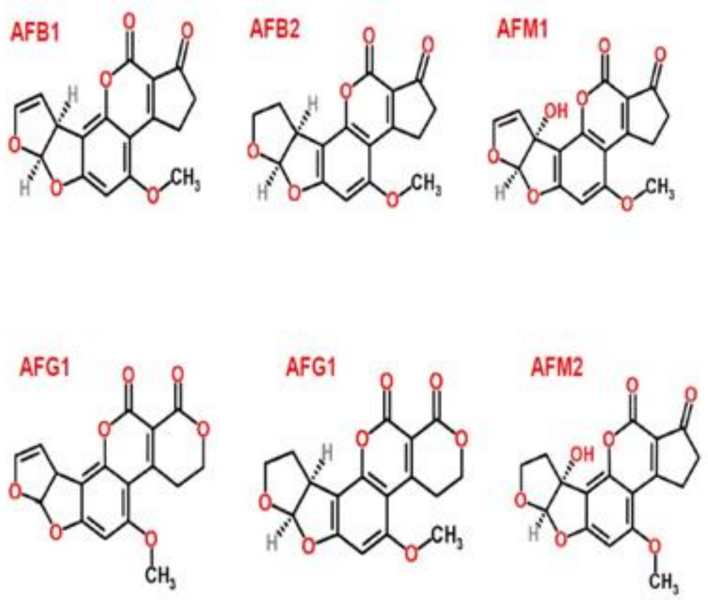

Fig.1: Chemical structures of aflatoxins (Ren *et al.*, 2020).

Aflatoxisis originally affected humans in India, where there was an outbreak that claimed 100 lives. Foods including cereals (maize, rice, barley, oats, and sorghum), peanuts, ground nuts, pistachio nuts, almonds, walnuts, and cottonseeds are among the many items that are home to aflatoxins-producing fungus. (Cinar & Onbaşı., 2019). AFM1 is a primary hydroxylated-AFB1 metabolite that is biotransformed by hepatic microsomal cytochrome P450 in cows given an AFB1-contaminated feed, and it can also contaminate milk. 12 to 24 hours after a cow consumes feed contaminated with AFB1, AFM1 may be found in their milk, and the concentration of AFM1 in their milk is proportional to the concentration of AFB1 in their raw feed. Due to the fact that AFM1 is heat stable, binds to casein well, and is unaffected by the cheese-making process, it may also be found in various dairy products, such as cheese, in concentrations that are higher than those of raw milk. (Khaneghah *et al.*, 2021).

Ochratoxins:

Ochratoxins, a class of similar substances produced by Aspergillus ochraceus, Penicillium verrucosum, and other Penicillium species, were first identified in South Africa in 1965. Ochratoxin A, the most significant toxin in the category (OTA, Fig. 2). In general, P. verrucosum may produce OTA in cool-temperate climates, but A. ochraceus likes to thrive in hot-tropical environments (Hadi et al., 2021). Ochratoxins have been discovered in a wide range of agricultural products, including maize, wheat, barley, flour, coffee, rice, oats, rye, beans, peas, and mixed feeds. They are particularly prevalent in wine, grape juice, and dried vine fruits. Ochratoxin contamination can also occur in meat and dairy products, including human milk. Wines and coffees are recognized as the two main food sources of OTA among all conceivable sources. Importantly, OTA is highly stable in acidic environments and can withstand severe heat processing; as a result, it may be found in cereal goods, beer, and roasted coffee and is challenging to remove from food under standard cooking circumstances. (Li *et al.*, 2021).

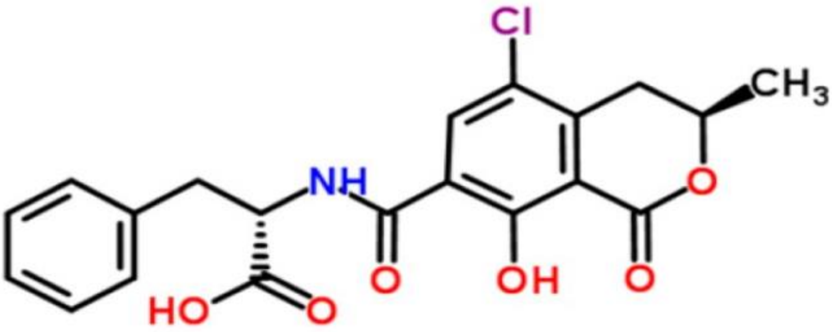

Fig. 2: Chemical structures of Ochratoxins (Hadi *et al.,* 2021)

Zearalenone:

Zearalenone (ZEA, Fig. 3), A macrocyclic -resorcyclic acid lactone is generated by Fusarium species, primarily F. graminearum and F. semitectum (Navale et al., 2022). Given that ZEA shares structural similarities with naturally occurring estrogens, it is best referred to as an estrogenic mycotoxin because it causes both people and animals to exhibit clear estrogenic effects (Kowalska et al., 2019). Wheat, barley, corn, rye, and sorghum are among the common sources of ZEA. While oats, rye, and wheat are the main sources of ZEA contamination in European nations, corn and wheat are more commonly infected with the disease in the United States and Canada. High humidity and low temperatures are favorable for the formation of ZEA. While aflatoxins are less common, ZEA contamination can happen simultaneously with DON. Under normal cooking conditions, ZEA is stable; under extreme conditions, it is largely removed. (Kovač *et al.*,2022).

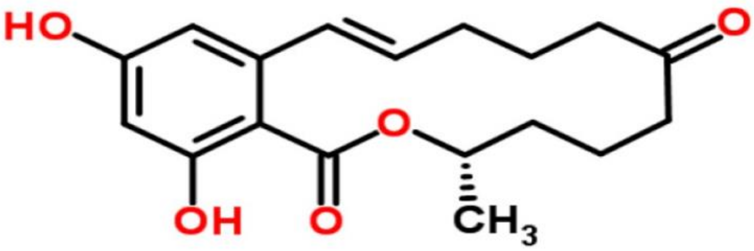

Fig. 3: Chemical structures of Zearalenone (Navale *et al.,* 2022).

Fumonisins:

In 1988, researchers identified a class of mycotoxins known as fumonisins. In contrast to the majority of other mycotoxins, fumonisins are hydrophilic mycotoxins that may dissolve entirely in organic solvents, as seen in Figure 4. (Ingle *et al.,* 2020). When leuko-encephalomalacia (LEM) in horses first appeared in South Africa in 1970, fumonisins, which are mostly generated by F. verticillioides, were found to be present in the maize that was responsible for the epidemic. Pigs given infected maize with fumonisins also developed pulmonary edema. The fungus F. proliferatum also makes fumonisins. There are now four categories of fumonisins, which number over 28. (A, B, C and P). The majority of the fumonisins family, or fumonisin B1 (FB1) (Figure 4), are present in this compound. (Wang *et al.,* 2020) FB1 commonly contaminates maize kernels. Fumonisins can also occur in sorghum, wheat, barley, soybean, asparagus spears, figs, black tea, and medicinal plants. In the US, F. verticillioides contaminate about 80% of all harvested corn. In China, FB1, FB2, and FB3 were detected in 98.1% of corn product samples collected from Shandong Province in 2014 (Ji *et al.,* 2022).

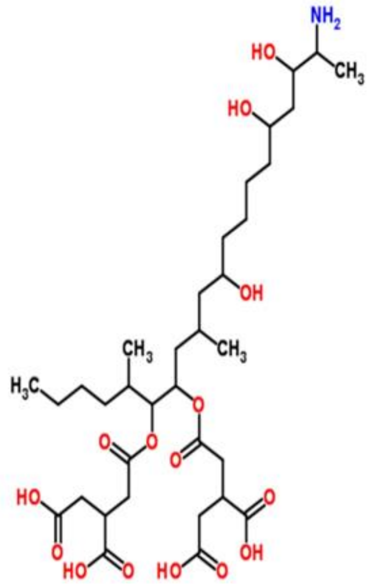

Fig.4: Chemical structures of Fumonisins (Ingle *et al.*, 2020).

Trichothecenes:

Trichothecenes (TCTC) were identified as the cause of alimentary toxic aleukia (ATA) toxicosis in the USSR in 1932. Only a small number of the more than 150 TCTC variations that have been discovered so far are significant for agriculture (Alshannaq., 2018). Of all mycotoxins, TCTC has the widest chemical diversity. Deoxynivalenol and TCTC (DON, Fig. 5) is among the least poisonous and most often used substances. It is also highly investigated. Most Fusarium species fungus are responsible for producing TCTC. The ability to manufacture TCTC is shared by the species of Acremonium (Cephalosporium), Cylindrocarpon, Dendrodochium, Myrothecium, Trichoderma, Trichothecium, and Stachybotrys. In the field, agricultural plants are often infected by Fusarium species and generate TCTC. The two species that cause Fusarium Head Blight (FHB), a devastating disease of cereal grain crops with an impact on the global economy, F. graminearum and F. culmorum, are the most significant TCTC producers, according to the economy. (Aydinoglu *et al.*, 2022). Pre-harvest is the time when toxins are produced, and the fungal species that produce them are also diseases that are seeded (for example head blight in wheat and other small grains, associated with F. graminearum invasion of plants). It is possible to assess the levels of toxins throughout the entire plant, but the kernels and especially the outer hulls have the highest levels. The coexistence of fungus and bacteria, which have the ability to detoxify and change the chemical makeup of TCT, may have an impact on how it behaves in the environment. Several families of structurally similar toxins are included in trichothecenes (closely related chemical compounds called sesquiterpenoids). Type A and Type B trichothecenes are of particular relevance since they are exceedingly poisonous and are present in large quantities. (Polak-Śliwińska & Paszczyk, 2021).

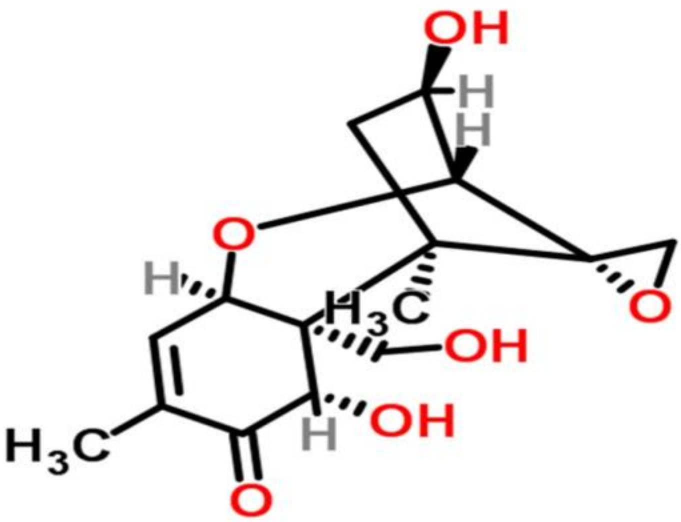

Fig. 5: Chemical structures of Trichothecenes (Aydinoglu *et al.,* 2022).

Patulin:

Patulin (Fig. 6) is a polyketide mycotoxin that was discovered in 1943. It is created by certain Penicillium, Aspergillus, and Byssochlamys species that grow on fruits and vegetables, with P. expansum being the most important fungus for its production (Saleh& Goktepe, 2019). Patulin contamination may also occur in other fruits, such as pears, peaches, and grapes, despite the fact that it mostly affects apples, apple juice, and apple-related goods. The possible antibiotic patulin was first investigated, but further studies revealed that it was hazardous to humans and might cause nausea, vomiting, ulcers, and hemorrhages. Patulin has a 29–55 mg/kg body weight oral LD50 in animals. Patulin is classified as belonging to Carcinogenicity Group 3, despite the fact that the IARC has voiced considerable worry about its potential carcinogenicity. In foods intended for human consumption, the US FDA sets a patulin action level of 50 ppb. A committee of the EU has established a maximum limit of 50 ppb for fruit juices and concentrated fruit juices, 25 ppb for solid apple products, and 10 ppb for consumable liquids and meals. (Pal *et al.*, 2017).

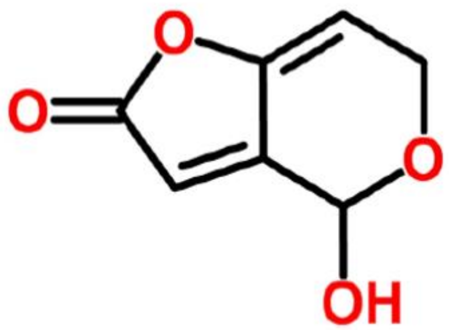

Fig. 6: Chemical structures of Patulin (Saleh& Goktepe, 2019).

Protection From the Effects of Mycotoxins:

It is important to note that molds that produce mycotoxins can grow on a range of different crops and foods and get deep into foods, not just on the surface. Mold usually does not grow on foods that have been dried and kept well, so effective drying of the goods and keeping them dry, or storing them appropriately, is an effective measure to combat mold growth and the production of mycotoxins. (Bradford *et al* ., 2020).Checking whole grains (particularly corn, sorghum, wheat, and rice), dried figs and tree nuts such as peanuts, pistachios, almonds, walnuts, coconut, brazil and hazelnuts, all of which are often contaminated with aflatoxins, for traces of mold, and dispose of them if they look moldy, faded or shriveled (Kihara ., 2015)Avoid damaging the grains before or during drying, and when storing them, as rotten grains are more vulnerable to mold attack and thus contamination with mycotoxins. buy grains and nuts as fresh as possible (Misra *et al.*, 2019). Making sure food is stored appropriately – protecting it from insects, drying out and overheating, not holding food for extended periods before it is used; ensuring a varied diet – not only helps reduce exposure to mycotoxins but improves nutrition as well. (Udomkun *et al.*, 2017)

Conclusion:

Some foodborne mycotoxins have acute effects and are accompanied by symptoms of severe illness that appear rapidly after the consumption of food products contaminated with mycotoxins. Some other mycotoxins found in food are linked to long-term health effects, including cancer and immunodeficiency.

Not giving molds a chance to grow and produce their toxins, good storage of foods on which molds are likely to grow, such as all kinds of grains, nuts and some fruits, and the presence of high humidity during storage is one of the most important factors for the growth of molds and the production of their heat-resistant toxins.

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