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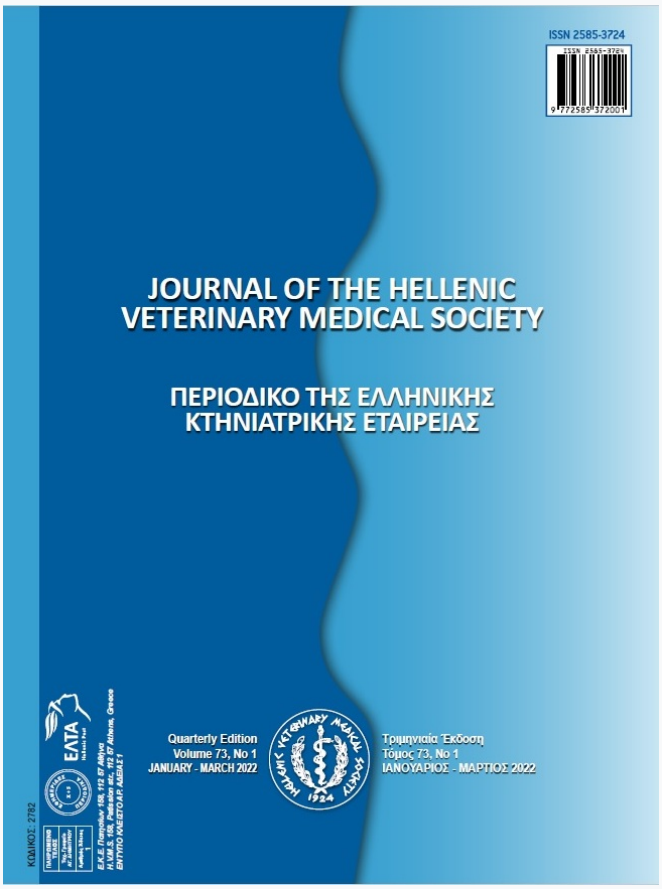


# Mycotoxins occurrence in food commodities, their associated hazards and control strategies

*Ali Akbar, FATIMA ABDUL MAJEED, MUHAMMAD Bilal Sadiq, Shabir Ahmad Khan, Ali A Rabaan*

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# Mycotoxins occurrence in food commodities, their associated hazards and control strategies

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**ABSTRACT:** Globally, the food is contaminated by various means, but microorganisms are predominant factor in contaminating the food and agriculture commodities. Among microorganisms, fungi are mainly involved in the spoilage of food due to their diversified nature and minimal requirement for growth. The toxigenic fungi associated with mycotoxins, can grow during any stage of food chain including harvesting, handling, distribution and storage. Mycotoxins are fungal secondary metabolites and their production is influenced by various factors such as environmental conditions, crop type and storageconditions. Mycotoxins in agriculture commodities expose serious health hazards. This review entails different types of mycotoxins involved in the spoilage of food and agriculture commodities, their potential health hazard, maximum allowable limits of mycotoxins in different food commodities and possible control strategies. In developing countries, regulatory authorities need to establish quality control strategies and limits of mycotoxins in food, in order to ensure the consumer safety.

***Keywords*:** mycotoxins, secondary metabolites, food spoilage, aflatoxins, maximum allowable limits

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## INTRODUCTION

Food contamination is a problem since ages and fungal contamination has been identified as main cause of food spoilage (Ashiq, 2015). Since ancient times, spoilage of crops and other food commodities have shown the presence of fungi and molds (Umesha et al., 2017). There is a high chance of fungal contamination if agricultural commodities are not stored properly and are exposed to high moisture content. Once agricultural commodities are infected by fungi, the infection spreads through the different stages i.e. harvesting, processing, and storage due to favorable conditions for the fungal growth (da Rochaet al., 2014).

The population of the world is expected to reach 8.2 billion by 2030 and 842 million people were estimated undernourished during 2011-2013. In coming decades, the food supply chains will be associated with growing challenges related to urbanization, family size, population aging and consumer concerns for healthy and sustainable food production. These trends will have a significance influence on food supply which will need to be more efficient in order to meet the demands. As a result, the food supply will need to grow within the domain of available natural resources and technologies (FAO, Food and Agriculture Organization of the United Nations, 2014).

The word "mycotoxin" means a poisonous substance that is produced by fungi. Food contamination by mycotoxins is a major food safety threat and possess several health risks to the users depending on the specific type of mycotoxin consumption, exposure level and a person's health status (Reddyet al., 2010). Mycotoxins are natural contaminants and present a serious challenge due to their diversified nature in terms of chemical structure and symptoms in humans and animals (Zychowski et al., 2013). The predominant effects of mycotoxins include carcinogenicity and neurotoxicity (Kolpinet al., 2014). The presence of mycotoxins not only poses a threat to human and animal health but it also accounts for significant economic losses, these losses can arise at any step during the food supply chain from farm to fork level (Rodrigues et al., 2011). The prevention can be best solution to overcome the mycotoxin contamination due to diversified nature of mycotoxins to contaminate wide variety of food products along the supply chain and difficulties associated with its detection (Anater et al., 2016).

Generally, most of the mycotoxins are low molecular weight secondary metabolites that apparently have no function in the metabolism of fungi (da Rocha et al., 2014). Mycotoxin chemical structure ranges mostly from simple C4 compounds to complex compounds (Paterson and Lima, 2010).Many species of fungi produce mycotoxins and few mycotoxins have been reported to exhibit carcinogenic potential in humans and animals (Huffman et al., 2010). Among mycotoxin producing fungi, *Fusarium, Aspergillus, and Penicillium* species are main mycotoxin producers and are called field fungi due to their ability to contaminate various food commodities (Jajić et al., 2019; Ashiq, 2015). Mycotoxins including aflatoxins (AFs), fumonisins (FMN), ochratoxin A (OTA), trichothecenes (include deoxynivalenol (DON) and T-2 toxin), and zearalenone (ZEN) gained more awareness because of their high frequency of occurrence and adverse health effects to humans and animals (Bhat et al., 2010).The consumption of mycotoxin contaminated food can result in carcinogenic, immunosuppressive, and teratogenic effects (Binder et al., 2007). The mycotoxins mainly target kidneys, liver, immune and nervous systems and in humans' general manifestations of mycotoxicosis are diarrhea, gastrointestinal distress and vomiting (Bhat et al., 2010).

The ingestion, inhalation and absorption of mycotoxins can cause mortality in humans and animals (Bankole and Adebanjo, 2003). The term mycotoxicosisis associated with the ingestion of mycotoxin contaminated food by animals or humans (Binder et al., 2007). The mycotoxicosis can be experienced through indirect exposure to products of animals (meat or milk) which are contaminated with mycotoxin (Bankole and Adebanjo, 2003).

The foods contamination by mycotoxins can be avoided by maintaining the higher quality of food during the entire food supply chain. The high-income developed countries have less exposure to high mycotoxins level due their food safety standards and regulations (Ashiq, 2015). In hot and humid areas of the world, food spoilage thorough fungi are more common (Sabahat et al., 2010; Thompson and Henke, 2000). The developing countries with high temperature and relative humidity need to adopt the modern food safety standards and regulations in the entire food supply chain to minimize the fungal and mycotoxin food contamination. The present review summarizes different types of food contaminating mycotoxins, their influence on human and animal health and possible control strategies.

## MYCOTOXINS

The word mycotoxin is derived from Greek words, i.e. mykes indicates fungi or molds and toxicum means "poison". In 1960s the word "mycotoxin" was first used to explain the toxin in animal feed related to contaminated peanuts and the death of turkeys in England called Turkey-X-disease (Bennett, 1987). Normally the word 'mycotoxin' is used for relatively low molecular weight toxic chemicals (Mw<500 Da) (da Rocha et al. 2014). Generally, the effects of mycotoxins on humans and animals vary with change in their molecular structures (Miller, 1995).

## FACTORS AFFECTING MYCOTOXINS PRODUCTION

Fungi are dependent on oxygen due to their aerobic nature; therefore, fungi have to face the consequences of oxygenic conditions such as presence of reactive oxygen species. The reactive oxygen species are produced during metabolic processes and their production can be influenced by environmental stress (Halliwell and Gutteridge, 2007). The accumulation of reactive species can potentiate morphological and metabolic transitions in fungi which in turn can result in toxin synthesis (Reverberi et al., 2010).

Miller (2001) reported that secondary metabolites are produced from one of the primary metabolites due to limitation of one or more nutrient. Proline, asparagine and tryptophan can increase the biosynthesis of AFs in *A. parasiticus* (Reverberi et al., 2010) however, their presence can reduce the production of AFs in *A. flavus* (Wilkinson et al., 2007). Temperature, pH, water activity and various other environmental factors significantly affect the production of mycotoxins such as OTA and AFs (Chein et al., 2019a). The environment-based factors influence the mycotoxin synthesis at transcription level and even the exposure of suboptimal quantities of fungicides can potentiate the biosynthesis of mycotoxins (Schmidt-Heydt et al., 2007).

The nature and production quantity of mycotoxins are mainly influenced by synergies of various factors: available nutrition, temperature, types of substrate, moisture content conditions, humidity, colony maturity, co-occurrence of mycotoxins with other fungi, and competing with other microbes and stress factors (Rao, 2001). The major contributing factors in the production of mycotoxins and consequences of their consumption are summarized in Figure 1.

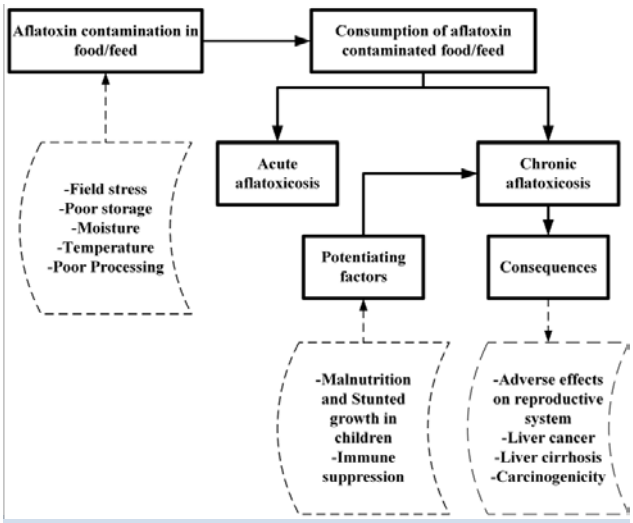


**Figure 1.** Contributing factors for mycotoxins contamination and consequences of their consumption (adopted from Bbosaet al. 2013)

## MYCOTOXIGENIC FUNGI

Several fungal genera produce mycotoxins including *Aspergillus, Fusarium, Penicillium*, *Alternaria* and *Claviceps* spp. (Majeed et al., 2021; Reddy et al., 2010). These different mycotoxigenic fungi genera are most abundant and have a strong environmental relation with human food materials (Samsudin and Abdullah, 2013). *Fusarium* spp is reported as mycotoxigenic fungi in cereal crops as well as other food commodities. *Aspergillus* spp and *Penicillium* spp are most common pathogens for plants and food commodities during drying and storage periods (Mohale et al., 2013).

## TYPES OF MYCOTOXINS

### AFLATOXINS

Aflatoxins (AFs) are well-known mycotoxins and in 1960s, for the first time reported in the UK when turkey poults 100, 000 suffered and died (known Turkey X disease) after consuming AFs contaminated peanut meal (CAST, 1989).AFs are derivatives of difuranocoumarin produced by species of *A. flavus* and *A. parasiticus* via polyketide mechanism (Ellakany et al., 2018; Turner et al., 2009). Among the 18 AFs categories, (AFB1 and AFB2) B series, (AFG1 and AFG2) G series and (AFM1 and AFM2) M series have been identified as the most important AFs affecting humans and animals (Figure 2). B and G series of AFs are characterized on the basis of their fluorescence under ultraviolet light (B = blue, G = green) (da Rocha et al. 2014). M series is associated with B series hydroxylated derivatives, reported in dairy

cattle, milk, meat and various mammals which consumed contaminated food and feed with AFs (Acaroz et al., 2019a; Chen et al., 2005). AFB1 and AFG1 dihydroxy derivatives are AFB2 and AFG2, respectively (Chunet al., 2007). The main reason that AFB1 and AFG1 are generally more toxic and carcinogenic than AFB2 and AFG2 is the presence of a double bond in the form of vinyl ether in their terminal furan ring, which is the active site and intensifies their fluorescence. Thus, their active site can experience a reaction of reduction leading to a change in activity (Turner et al., 2009). AFs are stable at constant high temperatures with minimum loss through cooking or pasteurization. AFs are unstable with UV, intense pH (< 3 or >10) values and oxidizing agents in the presence of oxygen (Herzallah, 2009).

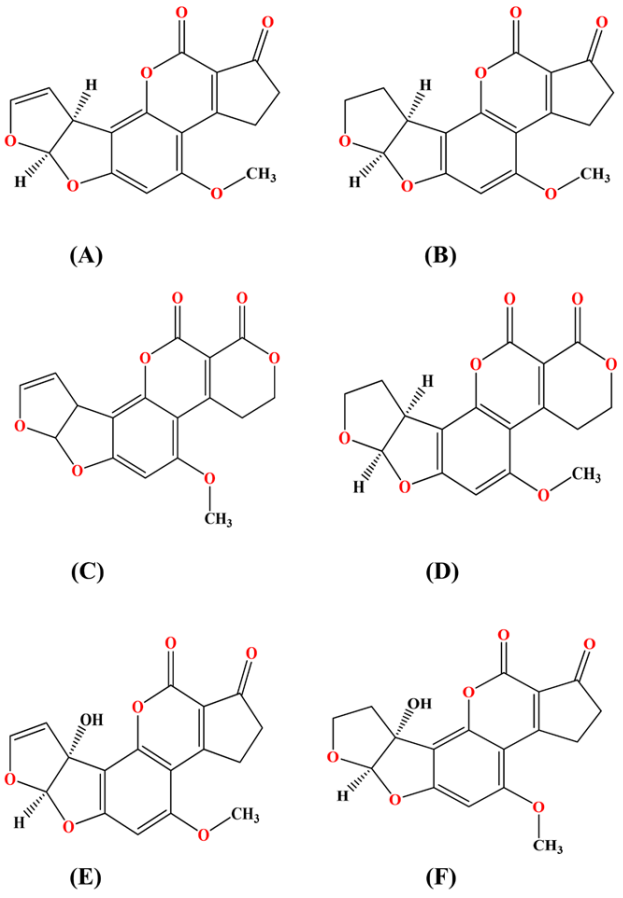


**Figure 2.** Chemical structure of (A) Aflatoxin B1 (B) Aflatoxin B2 (C) Aflatoxin G1 (D) Aflatoxin G2 (E) Aflatoxin M1 (F) Aflatoxin M2

*A. flavus* only produces B AFs (B1 and B2) and around 40% of *A. flavus* species produce AFs. *A. parasiticus* produces G AFs (G1 and G2) (Umesha et al., 2017). Morphologically *A. nomius* is like *A. flavus* but it produces both B and G AFs. *A. flavus* commonly occurs in crops in the world's warm temperature regions (Pepeljnjak et al., 2004).

AFs are mainly produced by *A. Parasiticus* and *A. flavus*, the optimum growth temperature rangesare25 to 35 °C and 28 to 30 °C, respectively (Bhat et al., 2010).AFs are of main concern in hot and humid areas, as the optimum temperature in warm areas of the world are favorable for fungal growth (Fernandez-Cruz et al., 2010).AFs are typically found in agriculture products like cereals (barley, sorghum, wheat, maize and rice), spices (ginger, turmeric, coriander, black pepper, and chili), tree nuts (nuts, walnuts, peanuts, pistachios and almonds) and oilseeds (cotton soybean, sunflower and sesame) (Acaroz et al., 2019b; Firdous et al., 2012). Whereas AFM1 and AFM2 are mainly present in milk, milk products and meat (da Rocha et al., 2014).

### Health Hazards of Aflatoxin

In tropical and subtropical regions, including Africa and Asia, various studies have been reported that indicated the adverse effects of AFs food contamination (Acaroz et al., 2019a, 2019b).The ingestion of food heavily contaminated with AFs can cause death in various cases (Ashiq, 2015). A wide variety of animals are affected by AFs including rodents, cattle, poultry fish and swine. Though the AFs response depends on the level of exposure, exposure duration, nutrition status, health, age, and environmental factors (Wagacha and Muthomi, 2008).

AFs are carcinogenic, teratogenic, hepatotoxic, mutagens, immunosuppressants and can induce various other serious hazards in animals and humans (da Rocha et al., 2014; Eaton and Gallagher, 1994). AFs are categorized as group 1 carcinogens by International Agency for Research on Cancer (IARC, 1993). AFs interfere with the protein synthesis due to their DNA binding capacity, hence, effect various essential cellular metabolisms and immune system (da Rocha et al., 2014). Generally, aflatoxicoses is recognized as disease associated with the AFs consumption. The death can be encountered in acute aflatoxicoses, whereas the chronic conditions can induce cancer, immunosuppression and hepatotoxicity (Zain, 2011).

## FUMONISINS (FMNS)

FMNs were first discovered and reported in 1988 (Bennett andKlich, 2003). FMNs are mainly produced by *Fusarium* genera (*Fusarium proliferatum, F. verticillioides, and F. nygamai*) and 28 different

types of FMNs have been isolated and classified in four groups (A, B, C and P).The different species of *Fusarium*genera produce FMNs, particularly *F. verticillioides* formerly *Fusarium moniliforme, F. proliferatum*, *F. anthophilum*, as well as *Alternaria alternata* (Omurtag 2008). *Aspergillus niger* has been reported to produce FMNs like B2 and B4, and a new B series of FMNs (FB6) was recognized from *A.niger* (Huffman et al., 2010).

The major types of FMNs (FB1, FB2, and FB3) are contaminants of natural cereals (Omurtag, 2008). Among FMNs, the most important and abundant mycotoxin family member is FB1 (Figure 3) (Reddy et al., 2010).FMNs are polyketide metabolites derived from repetitive condensation of acetate units or other short carboxylic acids by a similar mechanism of enzyme bound for fatty acid synthesis (Huffman et al., 2010).

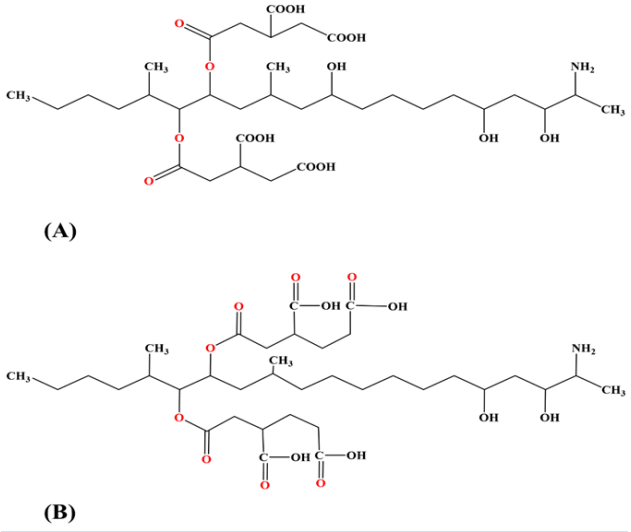


**Figure 3.** Chemical structure of (A) Fumonisin B1 (B) Fumonisin B2

Temperature and humidity are important factors for *Fusarium* contamination and synthesis of mycotoxins (Omurtag, 2008).The optimum temperature and water activity for the production of FMNs were reported in the range of 15-30 °C and 0.9-0.995, respectively (Sanchis and Magan, 2004).The presence of FMNs was found in agriculture and food commodities including bovine milk, dried figs, corn, products of corn, medicinal plants, and herbal tea (Omurtag et al., 2010).FMNs were observed as common contaminant of feeds and food in Philippines, South America, China, USA, Africa, France, Italy, Indonesia, and Thailand (Kumar et al., 2008).

**Health Hazards of Fumonisins**

Human intake of FMNs contaminated foods has been associated with esophageal cancer in Asia, South Africa, and Central America, (Alizadeh et al., 2012; Marasas et al., 2004).FMNs are categorized as a group 2B substance (human carcinogenic) by International Agency for Research on Cancer (IARC, 1993) and immunosuppressive by World Health Organization (WHO, 2002).The chronic FMNs effect on animals include impairment of basic immune function, nephrotoxicity, hepatotoxicity, respiratory disorders, and reduced milk production (Diaz et al., 2000). FMNs do not interact with DNA like AFs, however, due to similarity with sphingosine it might intervene with the biosynthesis of sphingolipids (Shier, 1992), which in turn influence the essential cellular activities as sphingolipids are essential for membranes, inter and intra cellular communication (Merrillet al., 1993).

## OCHRATOXINS (OTS)

In South Africa, Ochratoxin A (OTA) was first reported in 1965 (Van der Merwe et al., 1965) and isolated from cornmeal contaminated by *Aspergillus ochraceus*. Later in 1969, ochratoxin (OT) was isolated and reported in the United States from corn (Shotwell et al., 1969).OTA was later identified as secondary metabolite associated with *Aspergillus* and *Penicillium* spp (Duarteet al., 2010). Historical reports revealed that OTA was found in Egyptian tombs and considered for the suspicious deaths of many architects (Pittet, 1998).

OTA contains 7-carboxy-5-chloro-8-hydroxy-3, 4 dihydro- (3R) -methylisocoumarin in a carboxyl group linked to L-ß-phenylalanine (Figure 4) (Fernandez-Cruz et al., 2010). OTA is a crystalline white powder that is stable in food processes but unstable in the presence of light.Acid hydrolysis of OTA changes it to phenylalanine and an optically active lactone acid named OT*α* (IARC, 1993).

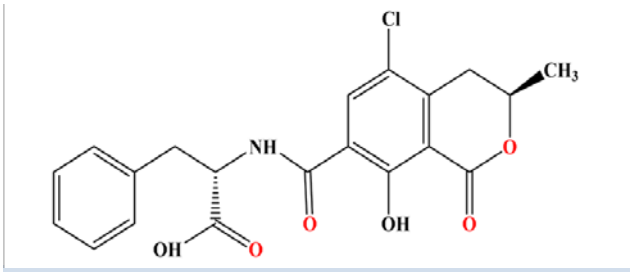

**Figure 4.** Chemical structure of Ochratoxin A

OTA is produced by various species of *Aspergillus* and *Penicillium* genera. Main producers are *A.*

*carbonarius,* and *A. ochraceus*, (Bachaet al., 2009). Some species of *Aspergillus (A. niger, A. carbonarius, A. ochraceus, P. verrucosum)* are responsible for OTA production (Bhat et al*.,* 2010). OTA is a natural contaminant in various foods, like cocoa, corn flour, cereals, dried fruits, maize, soya beans, peanuts, nuts, fish, milk, eggs, poultry, kidney beans, tea, and some herbs (Batista et al*.,* 2009). Hence, in tropical areas, it is however linked to moldy green coffee beans. It is also found in a coffee brew and roasted coffee beans (Sibanda et al., 2002). OTA contaminates spices, and dried fruit, whereas, grapes are commonly contaminated with OTA during storage (Bhat et al., 2010). Exposure of OTA to human generally occurs by the intake of poorly stored food products. The presence of OTA has been observed in the tissues and organs of animals and humans, including blood, breast milk, and meat (Kumar et al., 2008). The optimum temperature and water activity to produce OTA are 25-30 °C and 0.98, respectively (Milani, 2013).

**Health Hazards of OTA**

OTA has been associated with carcinogenic, nephrotoxic, teratogenic, and immunosuppressive effects in humans and animals (da Rocha et al., 2014).OTA was categorized as carcinogen to humans (group 2B) by the International Agency for Research on Cancer (IARC, 1993).OTA was linked with Balkan endemic nephropathy (BEN), a disease of kidney which was observed incertain areas of Balkan countries (Pfohl-Leszkowicz et al., 2002).The previous reports reported OTA as a potent teratogen, immunosuppressive, liver toxin, and carcinogen in animals (Pfohl-Leszkowicz and Manderville, 2007).

**TRICHOTHECENES (TCT)**

In 1949, Trichothecin from *Trichothecium roseum* was isolated and defined for the first time by Freeman and Morrison. Trichothecin discovery was associated with other TCT for example, T-2 toxin (T- 2), and deoxynivalenol (DON) (Omurtag, 2008).TCTs are chemically defined by a tetracyclic sesquiterpenoid 12, 13-epoxytrichothec-9-ene ring system (Zöllner and Mayer-Helm, 2006). TCTs were further categorized as macrocyclic, or non-macrocyclic, depending on macrocyclic presence of esteror an ester-ether bridge between C-4 and C-15 (Merhej et al., 2011).

TCT is a family of mycotoxins that includes more than200 compounds divided into four subclasses (Group A-D), based on their functional characteristic. The most toxic TCTs are Group A (Bhat et al., 2010). Generally, TCT are found as contaminants in cereals and their derivative (Foroud and Eudes, 2009). TCT found in food/feedstuffs are produced by *Fusarium graminearum* and *F.culmorum*. *F.pseudograminearum, F. graminearum*, and *F. culmorum* are accountable of producing deoxynivalenol (DON) toxins (Figure 5) which is a member of TCT (Ashiq, 2015; Glenn, 2007). TCTs are leading source of contamination in grains like oats, maize, barley and wheat (Zöllner and Mayer-Helm, 2006).TCT have also been observed in cereal products and milk (Spanjer et al., 2008). *F. culmorum, F. sporotrichioides* and *F. graminearum*, were reported to produce DON toxins, (Merhej et al., 2011).

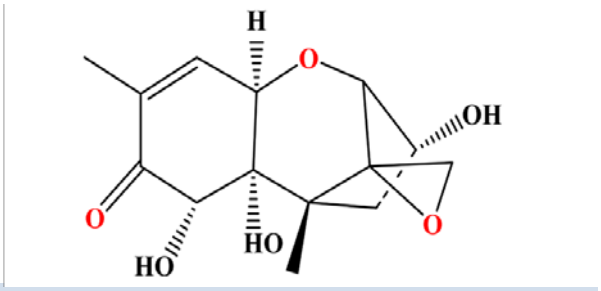


**Figure 5.** Chemical structure of Deoxynivalenol (DON)

**Health Hazards of TCT**

In humans and animals TCTs are associated with serious and chronic toxicosis. In eukaryotes contact of TCT results in slowed growth. Therefore, TCTs can affect wide range of invertebrates, mammals, fish, and plants (Wannemacher et al., 1997). TCTs can inhibit cell division, RNA and DNA synthesis, which might influence the structure and integrity of membranes, as well as function of mitochondria (Cundliffe and Davis, 1977), DON andT-2 toxins affect immunity through inhibition of cell and protein synthesis (Bhat et al.2010). DON lowers the body's level of antibodies and immunoglobulins (Richard, 2007).

**ZEARALENONE (ZEN)**

ZENs are estrogenic lactone resorcylic acid compounds mainly produced by *Fusarium* species (Diekman and Green, 1992). The production of ZEN is mainly associated with *Fusarium graminearum* and *F. culmorum* (Logriecoet al., 2002).ZEN is a non-steroidal mycotoxin and referred asF-2 toxin (Zinedine et al., 2006).ZEN is biosynthesized by various species of *Fusarium* via a polyketide pathway (Huffman et al., 2010). Chemically ZEN is 3, 4, 5, 6, 9, 10-hexahydro-14, 16-dihydroxy-3-methyl- 1*H*-2 benzoxacyclotetradecin 1, 7 (8*H*) - dione, is a macrocyclic ß-resor-

cylic acid lactone (Figure 6) (Cozzini and Dellafiora, 2012).

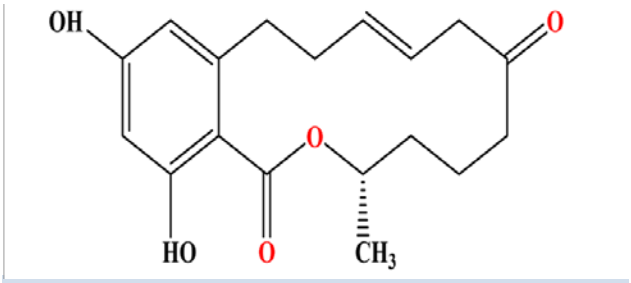


**Figure 6.** Chemical structure of Zearalenone

The crops that are mainly contaminated by ZENs are wheat, corn, oats, maize, barley, rice, millet, and sorghum (Zinedine et al., 2006). The presence of ZEN was reported in cereal by-products of corn and soya meal (Schollenberger et al., 2007), eggs (Sypecka et al., 2004) and milk (Seeling et al., 2005). ZENs are stable to heat, but under alkaline conditions the toxins can be degraded at a high temperature (>150 °C) (European Commission, 2000). Children are more affected by ZEN contaminated foods because of their high consuming rate of cereal based foods (Bhat et al., 2010).

### Health Hazards of ZEN

ZENs may cause abortion, infertility, and problems with reproduction system (especially swine) and are linked with cervical cancer (El-Nezamiet al., 2002).ZEN contaminated feed ingestion leads to interference with exocrine and endocrine systems. Like other environmental estrogens, ZEN is able to interfere with the function of sex steroids (Bhat et al., 2010). Metabolites of ZEN bind to receptors of estrogen and activate transcription of genes (Fink-Gremmels and Malekinejad, 2007). Because of ZEN estrogenic activity, contaminated feed with ZEN showed changes in the reproductive tract, fertility reduction, and rise in number of fetal resorptions (Morgavi and Riley, 2007).Among animals, pigs have been the most sensitive to ZEN and poultry is least affected (Bhat et al., 2010).

## MYCOTOXIN REGULATIONS

Food and Agriculture Organization declared mycotoxins as the major contaminants, accountable for 25% of food crops across the world. The mycotoxin contamination presents a serious threat to food security and economy (Aiko and Mehta, 2015; Alshannaq and Yu, 2017). Maximum allowable limits of different types of mycotoxins in food and feed have been specified by various national and international monitory organizations. The US Food and Drug Administration (FDA), World health Organization (WHO), European Union (EU), and several other countries have set the maximum limit of the mycotoxins in food, which are summarized in Table 1.

**Table 1.** Maximum allowable limits of mycotoxins in food commodities

| Country/ Region | Mycotoxins | Products | Maximum limit (ppb) | References |
|---|---|---|---|---|
| **European Union** | Aflatoxins: B1 G1, B2, G2 | Maize, wheat, rice, spices, almonds, oil seeds, dried fruits, cheese | 0.1-8<br>4-15 | EC (European Commission 2010). |
| | Aflatoxin M1 | Milk, eggs, meat | 0.5 | CAC (Codex Alimentarius Commission 2015). |
| | Fumonisins (FB1 and FB2) | Maize-based breakfast cereals and maize-based snacks | 800 | (EC 2007). |
| | | Raw maize grain | 4000 | (CAC 2015) |
| | | Maize flour and maize meal | 2000 | (CAC 2015) |
| | | Maize intended for direct human consumption | 1000 | (EC 2007). |
| | Ochratoxin A | Cereals, dry fruits, wine, spices, oat, raisins, coffee, cocoa, soybeans, meat | 0.5-15 | (EC 2006). |
| | | Wheat, barley and rye | 5 | (CAC 2015). |

| | | | | |
|---|---|---|---|---|
| | Deoxynivalenol (DON) | wheat, oats and maize | 1250 | (EC 2007). |
| | | Flour, meal, semolina and flakes derived from wheat, maize or barley | 1000 | (CAC 2015). |
| | | Cereal grains (wheat, maize and barley) destined for further processing. | 2000 | (CAC 2015). |
| | Zearalenone | Unprocessed cereals other than maize | 100 | (EC 2007). |
| | | Maize intended for direct human consumption, maize-based snacks and maize-based breakfast cereals | 100 | (EC 2007). |
| | | cereal flour, bran and germ for direct human consumption | 75 | (EC 2007). |
| **USA** | Aflatoxins B1, B2, G1, G2 | Total aflatoxins in food for human consumption corn, peanut products, cottonseed meal, maize, wheat, rice, peanut, sorghum, pistachio, almond, ground nuts, tree nuts, figs, cottonseed, spices | 20 | USDA (United States Department of Agriculture 2015). |
| | Aflatoxin M1 | Milk, milk products | 0.5 | FDA (Food and Drug Administration 2011) |
| | Total Fumonisins (FB1, FB2 and FB3) | Cereals | 2000-4000 | (Alshannaqand Yu 2017). |
| | | Corn products and cleaned maize used for popcorn | 2000-3000 | |
| | Ochratoxin A | Cereals, wheat, barley, and rye and derived products. | 5 | (CAC 2015). |
| **China** | Aflatoxin B1 | Corn, corn flour (grits, flake) and corn products, peanut and its products, peanut oil, corn oil | 20 | (Clever 2018) |
| | | Paddy rice, brown rice, rice. Vegetable oil and fat | 10 | |
| | | Wheat, barley, other grains, | 5.0 | |
| | | Wheat flour, cereal, other husked grains and bean products, other cooked nuts and seeds. Soy sauce, vinegar, fermented paste | | |
| | Aflatoxin M1 | Foods intended for special dietary uses. | 0.5 | |
| | | Milk and milk products | 0.5 | |
| | Ochratoxin A | Grains and grain products, beans and bean products, Baked coffee beans, ground coffee (roast coffee) | 5.0 | (Clever 2018). |
| | | Instant coffee | 10.0 | |
| | Deoxynivalenol | Corn, corn flour (grits, flake). Barley, wheat, cereal, wheat flour | 1000 | (Clever 2018). |
| | Zearalenone | Wheat, wheat flour, corn, corn flour (grits, flake) | 60 | (Clever 2018). |

| | | | | |
|---|---|---|---|---|
| **South Korea** | Aflatoxin B1 | Grains, cereal products, dried fruits, Meju, and streamed rice | 10 | (Yoshizawa 2011; Chun 2011). |
| | Aflatoxin B1 | Baby foods | 0.1 | (Chun 2011). |
| | Aflatoxin B2, G1, and G2 | Grains, cereal products, dried fruits, Meju, streamed rice, and baby foods | 15 | |
| | Aflatoxin M1 | Raw milks and milks prior to manufacturing processing | 0.5 | (Yoshizawa 2011; Chun 2011). |
| | Fumonisin B1, B2 | Grain products, Cereals processed corn products for popcorn, confectionaries (contain>50% corns). | 1000 | (Chun 2011). |
| | | Corn processed food, corn powder | 2000 | |
| | | Corn | 4000 | |
| | Deoxynivalenol | Grain and their processed foods | 1000 | (Chun 2011). |
| | | Corn and their processed foods | 20000 | |
| | | Cereals | 500 | |
| | Ochratoxin A | Meju | 20 | (Chun 2011). |
| | | Instant coffee and raisins | 10 | |
| | | Red pepper powder | 7 | |
| | | Grains and their processed food (grinding, cutting, etc). Coffee beans, and roasted coffee. | 5 | |
| | | Baby foods for infants and young children | 0.5 | |
| | Zearalenone | Grains and processed grain foods | 200 | (Chun 2011). |
| | | Confectionaries | 50 | |
| | | Baby foods | 20 | |
| **Indonesia** | Total aflatoxins | Corn feed | 50 | (Suparmoet al. 2011) |
| | Total aflatoxins | All foods | 35 | |
| | Aflatoxin B1 | All foods | 20 | |
| | Aflatoxin B1 | Peanut, corn and their products | 15-20 | |
| | Aflatoxin M1 | Dried milk and related products | 5 | |
| | Aflatoxin M1 | Milk, drink milk products, fermented milk and rennin hydrolyzed milk products, concentrated milk, cream, cheese, pudding, yogurt, whey and their products | 0.5 | |
| | Fumonisin B1, B2 | Corn (raw material) | 2000 | (Suparmoet al. 2011) |
| | | Corn foods products, e.g., popcorn, corn chips | 1000 | |
| | Ochratoxin A | Spices | 20 | (Suparmoet al. 2011) |
| | | Instant Coffee | 10 | |
| | | Cereals (rice, corn, sorghum, wheat) and their products and coffee | 5 | |
| | Zearalenone | Maize | Not detectable | FAO (2003) |
| **Japan** | Total | All foods | 10 | (Kawamura 2011; Srianujata 2011) |
| | Aflatoxin B1 | Rice | 10 | (Srianujata 2011; Yoshizawa 2011). |
| | Aflatoxin B1 | Other grains | 5 | (Srianujata 2011). |
| | Deoxynivalenol | Wheat | 1, 100 | (FAO 2003). |
| | Zearalenone | Compound feeds | 1000 | (FAO 2003). |

| | | | | |
|---|---|---|---|---|
| **Brazil** | Aflatoxins B1, G1, B2, G2 | Oil seeds, nuts, dried fruits, cereals, spices | 20 | (Anfossiet al. 2016). |
| | Aflatoxin M1 | Milk and infant formula | 0.5-5 | |
| | Fumonisins | Maize | 2000-5000 | (Anfossiet al. 2016). |
| | Ochratoxin A | Cereals, dried fruits, coffee, cocoa, wine, beer, grape juice, spices, liquorice, blood products | 2-30 | (Anfossiet al. 2016). |
| | Deoxynivalenol | Cereals, bakery products | 750-3000 | (Anfossiet al. 2016). |
| | Zearalenone | Cereals, bakery products, maize oil | 200-1000 | (Anfossiet al. 2016). |
| **India** | Aflatoxins | Oil seeds, nuts, dried fruits, cereals, spices | 30 | (Anfossiet al. 2016) |
| | Aflatoxin M1 | Milk and infant formula | 0.5 | |
| | Ochratoxin A | Cereals, dried fruits, coffee, cocoa, wine, beer, grape juice, spices, liquorice, blood products | 20 | (Anfossiet al. 2016). |
| | Deoxynivalenol | Cereals, bakery products | 1000 | (Anfossiet al. 2016). |
| **Russia** | Aflatoxin B1 | Maize | 5 | (Abdallah et al. |
| | Aflatoxin M1 | Milk | 0.5 | 2015). |
| | Ochratoxin A | Cereals, dried fruits, coffee, cocoa, wine, beer, grape juice, spices, liquorice, blood products | 5 | Anfossiet al. 2016). |
| | Deoxynivalenol | Cereals, bakery products | 700-1000 | Anfossiet al. 2016). |
| | Zearalenone | Cereals, bakery products, maize oil | 1000 | Zinedineet al. 2007). |

## CONTROL STRATEGIES FOR MYCOTOXIN CONTAMINATION

It is difficult to control contamination of mycotoxin in the field, during harvesting, storage and transportation of food and feed commodities (Umesha et al., 2017).The factors like soil moisture, invasion mostly with insects and mineral deficiencies contribute to mycotoxin contamination (Murphy et al., 2006). The way to protect and ensure consumers safety is to prevent fungal contamination of food/feed commodities which eventually leads to mycotoxin production (Figure 7). Plantation and pre-harvesting approaches can be improved by exercising preventing measures to reduce mycotoxin contamination. The control of mycotoxins in food produce is essential for public health and can be achieved by number of strategies such as, prevention of fungal contamination in food and feed, decontamination of mycotoxins and continuous surveillance. The fungal growth in food and feedstuff can be prevented by implementation of hygiene practices, drying and storage under appropriate conditions (Tola and Kebede, 2016). The high moisture content of food produce favors the growth of fungi and mycotoxin production. The drying of food produce can reduce the moisture content and hence prevents the growth of fungi and mycotoxins (Cheinet al., 2019a). The mold growth and accumulation of mycotoxins in food can be prevented by using natural preservatives such as acetic acid, lactic acid, benzoic acid and various essential oils (Chein et al., 2019b; Sriwattanachai et al., 2018).

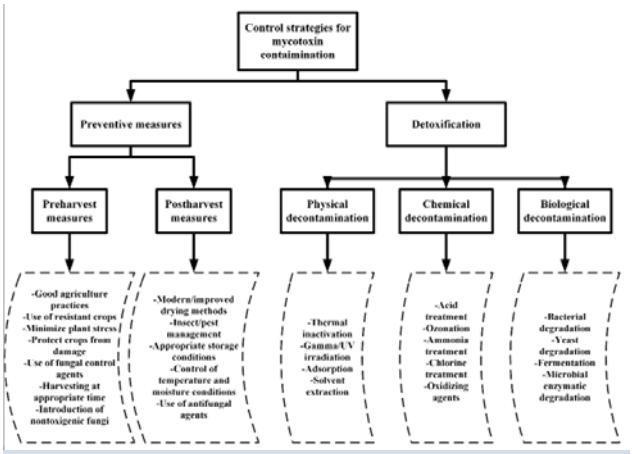


**Figure 7.** Aflatoxin prevention and control strategies in food and feed commodities. (Adopted from Ashiq, 2015)

Prevention of mycotoxin contamination may not always be possible, so decontamination process is important (Aiko and Mehta, 2015; Rustom, 1997). The mycotoxins can be decontaminated by physical and chemical treatments. Irradiation, cooking, boiling and extrusion are categorized as physical treatments

for decontamination of mycotoxins. During food processing, food undergoes heat treatment that might result in thermal inactivation of mycotoxins. However, most of the mycotoxins are heat stable and may not be easily inactivated by heat processing (Bullerman and Bianchini, 2007). The thermal deactivation of mycotoxins is influenced by certain essential factors such as temperature, water content and duration of exposure to heat. Mycotoxins can be decontaminated by chemical treatment however, the resultant degradation products might influence the food quality and safety (Aiko and Mehta, 2015).

## BIODEGRADATION OF MYCOTOXINS

In comparison to other degradation approaches, biodegradation provides a better chance of deactivation of mycotoxin. Certain microbes and enzymes may reduce secondary metabolites toxicity such as AFs, FMNs, OTAs, TCTs, and ZENs can be converted into less toxic metabolites through changes in the structure of these mycotoxins (Pintonet al., 2010). Biodegradation has been widely used in many countries to detoxify mycotoxins. Cleavage of ring, acetylation, hydrolysis, glycosylation, deamination, and decarboxylation are the key procedures for biotransformation reactions (Guan et al., 2008). Biodegradation typically begins with the mycotoxin's identification through high performance liquid chromatography or enzyme linked immunosorbent test following by incubation media with specific microbes (Ding et al., 2015). In addition, many bacterial species can detoxify mycotoxins by biotransformation mechanism (Dalié et al., 2010; Tokai et al., 2005).The degradation of mycotoxins by different microorganisms are summarized in table 2. Lactic acid bacteria (LAB) were reported to inhibit the accumulation of mycotoxins and it was found that the inhibition of mycotoxin accumulation was not dependent on low pH rather it was associated with production of low molecular weight LAB metabolites (Dalié et al., 2010).

Earlier studies focused on mycotoxin toxicity and biodegradation mechanisms. The mechanism of microbial degradation of mycotoxins involves the use of microbial catabolic pathways, which results in fewer toxic effects or harmless end products. (Yang et al., 2014).

**Table 2.** Biodegradation of mycotoxins by microbes

| Mycotoxin | Microbes | Biodegradable products | Mechanism | References |
|---|---|---|---|---|
| Aflatoxin | *Nocardia corynebacteroides, Corynebacterium rubrum, Pseudomonas putida, Rhodococcus spp, and Saccharomyces Cerevisiae* | Aflatoxicol; Aflatoxin M1; Aflatoxin B2a | Act on lactone ring | (Adeboet al. 2015; Du et al. 2017). |
| Fumonisin B1 | *Exophialaspinifera, Sphingopyxisspp, Sphingomonas spp.* | Fumonisin hydrolyzed B1 (HFB1) | Removes tricarballylate groups with carboxylesterases in C-14 and C-15 | (Du *et al.* 2017; Vanhoutte*et al.* 2016) |
| Ochratoxin A | *Bacillus licheniformis, Bacillus spp, Brevibacteriumiodinum, Acinetobacter calcoaceticus, Brevibacterium epidermidis, Lactobacillus acidophilus, Aspergillus versicolor, Aspergillus niger, Aspergillus ochraceus, Rhodoturulaspp, Saccharomyces spp.* | Phenylalanine; Ochratoxin A | Hydrolyze the amide bond | (Du *et al.* 2017; Vanhoutte*et al.* 2016) |
| Trichothecenes | *Blastobotrys capitulate, Trichomonascus, Aspergillus, Curtobacteriumspp, Anaerovibriolipolytica, Selenomonas and Saccharomyces* | 3-acetyl T-2 toxin; T-2 toxin 3-glucoside; Neosolaniol | Acetylation deacetylation, deep oxidation, oxygenation, Epimerization, and glucosylation | (Du *et al.* 2017; Vanhoutte*et al.* 2016) |
| Zearalenone | *Mucor bainieri, Rhizopus spp, Cunninghamellabainieri, Alternaria alternate, Thamidium elegans, Aspergillus ochraceous, Rhodococcus spp, Streptomyces rimosus, Trichosporonmycotoxinivorans, Pseudomonas spp, Aspergillus niger and Acinetobacter spp* | (α-ZEL) and β-zearalenol (β-ZEL) ; ZOM-1; 2, 4- dimethoxyl zearalenone; zearalenone- 4-β-D-glucoside | Cleavage of the lactone ring and change of the hydroxyl groupC-4 | (Du *et al.* 2017; Vanhoutte*et al.* 2016) |

## CONCLUSION

The fungal contamination and mycotoxin accumulation account for major food spoilage in the world and can greatly influence the world economy. The presence of mycotoxins in food or feedstuff not only accounts for food spoilage but poses a serious health hazard to both humans and animals. Therefore, the control of mycotoxins in food and feed is essential to ensure the food safety and food security. Mycotoxins accumulation in food can be controlled by implementation of good agriculture practices. The consumption of mycotoxin contaminated food can lead to serious health hazards. Mycotoxins can be eliminated from food or feedstuff by physical and chemical decontamination. The complete elimination of mycotoxins from food and feed commodities is a difficult task and requires a combined effort from policy makers, government agencies, farmers, processors and distributors. However, the developing countries should opt for the modern strategies for minimizing the mycotoxin contamination to control their level in food commodities within the maximum allowable limits. The maximum allowable limits for mycotoxins, their control strategies should be communicated with farmers and processors.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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## REFERENCES

Acaroz U (2019a) Assessment of aflatoxin M1 levels in Tulum and white cheeses in Afyonkarahisar, Turkey. Fresenius Environ Bulletin 28 (11 A) :8663-8668.

Acaroz U (2019b) Determination of the total aflatoxin level in red pepper marketed in Afyonkarahisar, Turkey. Fresenius Environ Bulletin 28 (4 A) ; 3276-3280.

Adebo OA, Njobeh PB, Gbashi S, Nwinyi OC, Mavumengwana V (2017) Review on microbial degradation of aflatoxins. Critical Reviews Food Sci Nutri 57 (15) :3208-3217.

Abdallah MF, Girgin G, Baydar T (2015) Occurrence, prevention and limitation of mycotoxins in feeds. Anim. Nutr. Feed Technol 15:471-490.

Sabahat A, Bhatti IA, Asi MR, Bhatti HN, Sheikh MA (2010) Occurrence of aflatoxins in maize grains from central areas of Punjab, Pakistan. Inter J Agri Biol 12 (4) :571-575.

Aiko V, Mehta A (2015) Occurrence, detection and detoxification of mycotoxins. JBiosci 40 (5) :943-954.

Alizadeh AM, Roshandel G, Roudbarmohammadi S, Roudbary M, Sohanaki H, Ghiasian SA, Taherkhani A, Semnani S, Aghasi M (2012) Fumonisin B1 contamination of cereals and risk of esophageal cancer in a highrisk area in northeastern Iran. Asian Pacific J Cancer Preven13 (6) : 2625-2628.

Alshannaq A, Yu JH (2017) Occurrence, toxicity, and analysis of major mycotoxins in food. Inter J Environ Res Pub Health 14 (6) :632.

Anater A, Manyes L, Meca G, Ferrer E, Luciano FB, Pimpão CT, Font G (2016) Mycotoxins and their consequences in aquaculture: A review. Aquaculture 451:1-10.

Anfossi L, Giovannoli C, Baggiani C (2016) Mycotoxin detection. CurrOpinion Biotech 37:120- 126.

Ashiq S (2015) Natural occurrence of mycotoxins in food and feed: Pakistan perspective. Compreh Reviews Food SciFood Safety 14 (2) :159-175.

Bacha N, Atoui A, Mathieu F, Liboz T, Lebrihi A (2009) *Aspergillus westerdijkiae* polyketide synthase gene "aoks1" is involved in the biosynthesis of ochratoxin A. Fungal Genetics Biol 46 (1) : 77-84.

BankoleSA, Adebanjo A (2003) Mycotoxins in food in West Africa: current situation and possibilities of controlling it. African J Biotech 2 (9) :254-263.

Batista LR, Chalfoun SM, Silva CF, Cirillo M, Varga EA, Schwan RF (2009) Ochratoxin A in coffee beans (*Coffea arabica* L.) processed by dry and wet methods. Food Cont 20 (9) : 784- 790.

Bhat R, Rai RV, KarimAA (2010) Mycotoxins in food and feed: present status and future concerns. ComprehReviews Food Sci Food Safety 9 (1) :57-81.

Bennett JW (1987) Mycotoxins, mycotoxicoses, mycotoxicology and mycopathologia. Mycopathologia, *100*: 3-5.

Bennett JW, Klich M (2003) Mycotoxins. Clin Microbiol Reviews16 (3) :497-516.

Binder EM, Tan LM, Chin LJ, Handl J, Richard J (2007) Worldwide occurrence of mycotoxins in commodities, feeds and feed ingredients. Ani Feed Sci Tech 137 (3-4) :265-282.

BullermanLB, Bianchini A (2007) Stability of mycotoxins during food processing. InterJFood Microbiol 119 (1-2) :140-146.

CAC (Codex Alimentarius Commission). General standard for contaminants and toxins in food and feed (CODEX STAN 193-1995), Adopted in 1995, Revised in 1997, 2006, 2008, 2009, Amended in 2010, 2012, 2013, 2014, 2015. 59 pages.

CAST Council for Agricultural Science and Technology (1989) Mycotoxins: economic and health risks. Task force report nr 116. Ames, Iowa: *Council for Agricultural Science and Technology.*

Chein SH, Sadiq MB, Datta A, Anal AK (2019a) Prevalence and identification of Aspergillus and Penicillium species isolated from peanut kernels in central Myanmar. JFood Safety 39 (6) : e12686.

Chein SH, Sadiq MB, Anal AK (2019b) Antifungal effects of chitosan films incorporated with essential oils and control of fungal contamination in peanut kernels. JFood ProcesPreserv 43 (12) :e14235.

Chen CY, Li WJ, Peng KY (2005) Determination of Aflatoxin M1 in Milk and Milk Powder Using High-Flow Solid-Phase Extraction and Liquid Chromatography− Tandem Mass Spectrometry. J AgricultFood Chemist 53 (22) :8474-8480.

Chun HS, Kim HJ, OkHE, Hwang JB, Chung DH (2007) Determination of aflatoxin levels in nuts and their products consumed in South Korea. Food Chemist 102 (1) :385-391.

Chun HS (2011) Risk assessment of mycotoxin contamination in Korean foods. Proceedings of FFTCeKU 2011 conference, International seminar on risk assessment and risk management of mycotoxins for food safety in Asia. Thailand: Kasetsart University; 2011.

Cozzini P, Dellafiora L (2012) In silico approach to evaluate molecular interaction between mycotoxins and the estrogen receptors ligand binding domain: a case study on zearalenone and its metabolites. ToxicolLetters 214 (1) : 81-85.

Cundliffe E, Davies JE (1977) Inhibition of initiation, elongation, and termination of eukaryotic protein synthesis by trichothecene fungal toxins. AntimicrobAgents Chemother11 (3) : 491-499.

Dalié DKD, Deschamps AM, Richard-Forget F (2010) Lactic acid bacteria-Potential for control of mould growth and mycotoxins: A review. Food Cont 21 (4) :370-380.

da Rocha MEB, Freire FDCO, Maia FEF, Guedes MIF, Rondina D (2014) Mycotoxins and their effects on human and animal health. Food Cont

36 (1) :159-165.
Diaz DE, Hopkins BA, Leonard LM, Hagler Jr WM, Whitlow LW (2000) Effect of fumonisin on lactating dairy cattle. J Dairy Sci 83 (1.171).
DiekmanMA, Green ML (1992) Mycotoxins and reproduction in domestic livestock. J Animal Sci 70 (5) : 1615-1627.
Dong X, Jiang W, Li C, Ma N, Xu Y, Meng X (2015) Patulin biodegradation by marine yeast Kodameaeohmeri. Food Addit Contaminants: Part A 32 (3) :352-360.
Du K, Wang C, Liu P, Li Y, Ma X (2017) Effects of dietary mycotoxins on gut microbiome. Protein and Peptide Letters 24 (5) :397-405.
Duarte SC, Pena A, Lino CM (2010) A review on ochratoxin A occurrence and effects of processing of cereal and cereal derived food products. Food Microbiol 27 (2) : 187-198.
Eaton DL, Gallagher EP (1994) Mechanisms of aflatoxin carcinogenesis. Annual Review of PharmacolToxicol34:135-172.
El-Nezami H, Polychronaki N, Salminen S, Mykkänen H (2002) Binding rather than metabolism may explain the interaction of two food-grade Lactobacillus strains with Zearalenone and Its Derivative ά-Zearalenol. Appl Environ Microbiol 68 (7) : 3545-3549.
Ellakany HF, Abd-Elhamid HS, Tantawy LA, Elsamadony HA, Elbestawy AR, Gado AR, El-Sayed YS, Ismael HS (2020) Immunological and pathological adverse effects of avian influenza virus subtype H9N2 infection in aflatoxicated-broiler chickens. J Hellenic Vet Med Soc 70 (4) :1889-1900. doi:https://doi.org/10.12681/jhvms.22241.
European Commission (2000) Opinion of the Scientific Committee on Food on Fusarium toxins: Part 2: Zearalenone (ZEA). Brussels, Belgium. Foroud NA, Eudes FO. (2009). Trichothecenes in cereal grains. Int J Mol Sci 10: 147-73.
EC (European Commission). Commission Recommendation 2006/576/EC of 17 August 2006 on the presence of deoxynivalenol, zearalenone, ochratoxin A, T-2 and HT-2 and fumonisins in products intended for animal feeding. Off J Eur Union L. 2006: 229:7-9.
EC (European Commission). Commission Regulation (EC) No. 1126/2007 on maximum levels for certain contaminants in foodstuffs as regards *Fusarium* toxins in maize and maize products. Off J Eur Union. 2007; 255:14-17.
EC (European Commission). Commission Regulation (EU) No 178/2010 of 2 March 2010 amending Regulation (EC) No 401/2006 as regards groundnuts (peanuts), other oilseeds, tree nuts, apricot kernels, liquorice and vegetable oil. Off J Eur Union. 2010; 52:32.
FAO, Food and Agriculture Organization of the United Nations, 2014. Economic Analysis of Supply and Demand for Food up to 2030 — Special Focus on Fish and Fishery Products, Rome, 2014 (Audun-Lem, Trond Bjorndal, Alena Lappo).
FAO. Worldwide regulations for mycotoxins in food and feed in 2003. FAO food and nutrition paper no. 81. Rome, Italy: Food and Agriculture Organization of the United Nations; 2004. http://www.fao.org/docrep/007/y5499e/y5499e00.HTM.
FDA (Food and Drug Administration). U.S. Food and Drug Administration (FDA) mycotoxin regulatory guidance. In: U.S.Food and Drug Administration (FDA), editor. Washington, D.C.: National Grain and Feed Association. 2011; 1-9.USFDA (US Food and Drug Administration). Guidance for Industry and FDA: Advisory Levels for Deoxynivalenol (DON) in Finished Wheat Products for Human Consumption and Grains and Grain By- Products Used for Animal Feed. US FDA: Silver Spring, MD, USA; 2010.
Fernández-Cruz ML, Mansilla ML, Tadeo JL (2010) Mycotoxins in fruits and their processed products: Analysis, occurrence and health implications. J Adv Res 1 (2) :113-122.
Fink-Gremmels J, Malekinejad H (2007) Clinical effects and biochemical mechanisms associated with exposure to the mycoestrogen zearalenone. Ani Feed Sci Tech 137 (3-4) :326-341.
Firdous S, Ejaz N, Aman T, Khan N (2012) Occurrence of aflatoxins in export-quality Pakistani rice. Food Additives Contaminants: Part B 5 (2) : 121-125.
Foroud N, Eudes F (2009) Trichothecenes in cereal grains. Int JMol Sci 10 (1) : 147-173.
Glenn AE (2007) Mycotoxigenic Fusarium species in animal feed. Ani Feed Sci Technol 137 (3-4) : 213-240.
Guan S, Ji C, Zhou T, Li J, Ma Q, Niu T (2008) Aflatoxin B1 degradation by Stenotrophomonas maltophilia and other microbes selected using coumarin medium. Int JMol Sci 9 (8) : 1489- 1503.
Halliwell B, Gutteridge JMC (2007) Oxygen is a toxic gas—an introduction to oxygen toxicity and reactive species. In: Halliwell B, Gutteridge JMC (eds) Free radicals in biology and medicine. Oxford University Press, New York, pp 1-29.
Herzallah SM (2009) Determination of aflatoxins in eggs, milk, meat and meat products using HPLC fluorescent and UV detectors. Food Chemist 114 (3) : 1141-1146.
Huffman J, Gerber R, Du L (2010) Recent advancements in the biosynthetic mechanisms for polyketide-derived mycotoxins. Biopolymers 93 (9) : 764-776.
IARC (Intl. Agency for Research on Cancer), 1993. Monographs on the evaluation of the carcinogenic risk of chemicals to humans: some naturally occurring substances—food items and constituents, heterocyclic aromatic amines and mycotoxins. Vol. 56. Lyon, France: IARC, p 245-521.
Jajić I, Glamočić D, Krstović S, PolovinskiHorvatović M (2019) Aflatoxin M1 occurrence in Serbian milk and its impact on legislative. JHellenic Vet MedSociety 69 (4) :1283-1290.
Jennifer Clever (2018). China Releases Standard for Maximum Levels of Mycotoxins in Foods. USDA foreign Agricultural service
Kolpin DW, Schenzel J, Meyer MT, Phillips PJ, Hubbard LE, Scott TM, Bucheli TD (2014) Mycotoxins: diffuse and point source contributions of natural contaminants of emerging concern to streams. Sci Total Environ 470: 669-676.
Kumar V, Basu MS, Rajendran TP (2008) Mycotoxin research and mycoflora in some commercially important agricultural commodities. Crop Protect 27 (6) : 891-905.
Logrieco A, Rizzo A, Ferracane R, Ritieni A (2002) Occurrence of beauvericin and enniatins in wheat affected by Fusarium avenaceum head blight. Appl Environ Microbiol 68 (1) : 82-85.
Majeed FA, Akbar A, Shafee M, Sadia H, Iqbal S, Phadungchob B, Khan IG, KhanSA (2021) Detection of Mycotoxigenic Fungi and Mycotoxins in Poultry Feed ofBalochistan Pakistan.J Hellenic Vet Med Soc 72 (1) :2741-2746.
Marasas WF, Riley RT, Hendricks KA, Stevens VL, Sadler TW, Gelineau-van Waes J, ... Allegood J (2004) Fumonisins disrupt sphingolipid metabolism, folate transport, and neural tube development in embryo culture and in vivo: a potential risk factor for human neural tube defects among populations consuming fumonisin-contaminated maize. JNutrit 134 (4) : 711-716.
Merhej J, Richard-Forget F, Barreau C (2011) Regulation of trichothecene biosynthesis in Fusarium: recent advances and new insights. Appl Microbiol Biotechnol 91 (3) : 519-528.
Merrill AH, Van Echten G, Wang E, Sandhoff K (1993) Fumonisin B1 inhibits sphingosine (sphinganine) N-acyltransferase and de novo sphingolipid biosynthesis in cultured neurons in situ. JBiol Chemist 268 (36) : 27299-27306.
Milani JM (2013) Ecological conditions affecting mycotoxin production in cereals: a review. VeterinarniMedicina58: 405-411.
Miller JD (1995) Fungi and mycotoxins in grains, implications for stored products research. J Stored Prod Res31:1-16.
Miller JD (2001) Factors that affect the occurrence of fumonisin. Environ Health Perspect 109 (Suppl 2) :321.
Mohale S, Medina A, Rodríguez A, Sulyok M, Magan N (2013) Mycotoxigenic fungi and mycotoxins associated with stored maize from different regions of Lesotho. Mycotoxin Res 29 (4) : 209-219.
Moretti A, Ferracane L, Somma S, Ricci V, Mule G, Susca A, Ritieni A, Logrieco AF (2010) Identification, mycotoxin risk and pathogenicity of Fusarium species associated with fig endosepsis in Apulia, Italy. Food Additives and Contaminants 27 (5) :718-728.
Morgavi DP, Riley RT (2007) An historical overview of field disease outbreaks known or suspected to be caused by consumption of feeds contaminated with Fusarium toxins. Ani Feed Sci Tech 137 (3-4) :201-212.
Murphy PA, Hendrich S, Landgren C, Bryant CM (2006) Food mycotoxins: an update. Journal of Food Sci71 (5) :51-65.
Paterson RRM, Lima N (2010) How will climate change affect mycotoxins in food?. Food Res Int 43 (7) :1902-1914.
Pfohl-Leszkowicz A, Petkova-Bocharova T, Chernozemsky IN, Castegnaro M (2002) Balkan endemic nephropathy and associated urinary tract tumours: a review on aetiological causes and the potential role of mycotoxins. Food additives Contaminants 19 (3) : 282-302.
Pfohl-Leszkowicz A, Manderville RA (2007) Ochratoxin A: An overview on toxicity and carcinogenicity in animals and humans. Mol Nutrit-

Food Res 51 (1) : 61-99.
Pinton P, Braicu C, Nougayrede JP, Laffitte J, Taranu I, Oswald IP (2010) Deoxynivalenol impairs porcine intestinal barrier function and decreases the protein expression of claudin-4 through a mitogen-activated protein kinase-dependent mechanism. J Nutrit 140 (11) : 1956-1962.
Pepeljnjak S, Slobodnjak Z, Šegvić M, Peraica M, Pavlović M (2004) The ability of fungal isolates from human lung aspergilloma to produce mycotoxins. Human Experiment Toxicol 23 (1) :15-19.
Rao CY (2001) Toxigenic fungi in the indoor environment. In: Spengler JD, Samset JM, McCarthy JS, editors. Indoor air quality handbook. Washington, D.C.: McGraw-Hill. p 1-17.
Reddy KRN, Nurdijati SB, Salleh B (2010) An overview of plant-derived products on control of mycotoxigenic fungi and mycotoxins. Asian JPlant Sci 9 (3) : 126.
Reverberi M, Ricelli A, Zjalic S, Fabbri AA, Fanelli C (2010) Natural functions of mycotoxins and control of their biosynthesis in fungi. Appl Microbiol Biotech 87 (3) : 899-911.
Richard JL (2007) Some major mycotoxins and their mycotoxicoses—An overview. Int JFood Microbiol 119 (1-2) :3-10.
Rodrigues I, Handl J, Binder EM (2011) Mycotoxin occurrence in commodities, feeds and feed ingredients sourced in the Middle East and Africa. Food Additives and Contaminants: Part B 4 (3) : 168-179.
Rustom IYS (1997) Aflatoxin in food and feed: occurrence, legislation and inactivation by physical methods. Food Chem59 (1) :57-67.
Samsudin NIP, Abdullah N (2013) A preliminary survey on the occurrence of mycotoxigenic fungi and mycotoxins contaminating red rice at consumer level in Selangor, Malaysia. Mycotoxin Res 29 (2) :89-96.
Sanchis V, Magan N (2004) Environmental conditions affecting mycotoxins. In: Magan N, Olsen M, editors. Mycotoxins in food. Cambridge: Woodhead Publishing. p 174-89.
Schmidt-Heydt M, Baxter E, Geisen R, Magan N (2007) Physiological relationship between food preservatives, environmental factors, ochratoxin and otapksPV gene expression by Penicillium verrucosum. Int JFood Microbiol 119 (3) : 277-283.
Schollenberger M, Müller HM, Rüfle M, Terry-Jara H, Suchy S, Plank S, Drochner W (2007) Natural occurrence of Fusarium toxins in soy food marketed in Germany. International J Food Microbiol113 (2) : 142-146.
Seeling K, Danicke S, Ueberschar K, Lebzien P, Flachowsky G (2005) On the effects of Fusarium toxin-contaminated wheat and the feed intake level on the metabolism and carry over of zearalenone in dairy cows. Food AdditContam22, 847-55.
Shier WT (1992) Sphingosine analogs: an emerging new class of toxins that includes the fumonisins. JToxicol: Toxin Reviews 11 (3) : 241-257.
Shotwell OL, Hesseltine CW, Goulden ML (1969) Ochratoxin A: occurrence as natural contaminant of a corn sample. Appl Microbiol 17 (5) : 765.
Sibanda L, De Saeger S, Barna-Vetro I, Van PeteghemC (2002) Development of a solid-phase cleanup and portable rapid flow-through enzyme immunoassay for the detection of ochrato xin A in roasted coffee. J Agri Food Chem 50 (24) :6964-6967.
Spanjer MC, Rensen PM, Scholten JM (2008) LC-MS/MS multi-method for mycotoxins after single extraction, with validation data for peanut, pistachio, wheat, maize, cornflakes, raisins and figs. Food Additives Contaminants25 (4) : 472-489.
Srianujata S (2011) Regulatory update and control measures for prevention and reduction of mycotoxins contamination in foods and feeds. Proceedings of FFTCeKU 2011 conference, International seminar on risk assessment and risk of mycotoxins for food safety in Asia. Thailand: Kasetsart University.
Sriwattanachai S, SadiqMB, Anal AK (2018) Synergistic antifungal effects of thyme essential oil and *Lactobacillus plantarum* cell-free supernatant against *Penicillium* spp. and in situ effects. J Food ProcessPreservation 42 (1) : e13400.
Suparmo FMC, Setyabudi S, Hidayat C (2011) Integrated control management of aflatoxins in Indonesia.In Proceedings of FFTC-KU 2011 conference: International Seminar on Risk Assessment and Risk Management of Mycotoxins for Food Safety in Asia. Kasetsart University, Bangkok, Thailand.
Sypecka Z, Kelly M, Brereton P (2004) Deoxynivalenol and zearalenone residues in eggs of laying hens fed with a naturally contaminated diet: Effects on egg production and estimation of transmission rates from feed to eggs. J Agri Food Chem 52 (17) :5463-5471.
Thompson C, Henke SE (2000) Effect of climate and type of storage container on aflatoxin production in corn and its associated risks to wildlife species. J Wildlife Dis 36 (1) :172- 179.
Tokai T, Fujimura M, Inoue H, Aoki T, Ohta K, Shibata T. Kimura M (2005) Concordant evolution of trichothecene 3-O-acetyltransferase and an rDNA species phylogeny of trichothecene-producing and non-producing fusaria and other ascomycetous fungi. Microbiol151 (2) :509-519.
Tola M, Kebede B (2016) Occurrence, importance and control of mycotoxins: A review. Cogent Food Agri 2 (1) : 1191103.
Turner NW, Subrahmanyam S, Piletsky SA (2009) Analytical methods for determination of mycotoxins: a review. Analytica ChimicaActa 632 (2) :168-180.
Umesha S, Manukumar HMG, Chandrasekhar B, Shivakumara P, Shiva Kumar J, Raghava S, Nandhini M (2017) Aflatoxins and food pathogens: impact of biologically active aflatoxins and their control strategies. J Sci Food Agri 97 (6) : 1698-1707.
USDA (United States Department of Agriculture). Mycotoxin Handbook. Grain Inspection, Packers and Stockyards Administration Federal Grain Inspection Service. September 17, 2015:60.
Van der Merwe KJ, Steyn PS, Fourie L, Scott DB, Theron JJ (1965) Ochratoxin A, a toxic metabolite produced by Aspergillus ochraceusWilh. Nature 205 (4976) : 1112.
Vanhoutte I, AudenaertK, De Gelder L (2016) Biodegradation of Mycotoxins: Tales from Known and Unexplored Worlds. Frontiers Microbiol 7:561.doi:10.3389/fmicb.2016.00561.
Wannemacher RW, Wiener SL, Sidell FR, Takafuji ET, Franz DR (1997) Trichothecene mycotoxins. Med Aspects ChemBiol Warfare 6: 655-76.
Wagacha JM, Muthomi JW (2008) Mycotoxin problem in Africa: current status, implications to food safety and health and possible management strategies. IntJFood Microbiol 124 (1) :1- 12.
WHO (World Health Organization) (2002) Evaluation of certain mycotoxins in food. World Health Organization Technical Report Series 906:62.
Wilkinson JR, Yu J, BlandJM, Nierman WC, Bhatnagar D, Cleveland TE (2007) Amino acid supplementation reveals differential regulation of aflatoxin biosynthesis in Aspergillus flavus NRRL 3357 and Aspergillus parasiticus SRRC 143. ApplMicrobiol Biotech 74 (6) : 1308-1319.
Yang J, Li J, JiangY, Duan X, Qu H, Yang B, Sivakumar D (2014) Natural occurrence, analysis, and prevention of mycotoxins in fruits and their processed products. Crit Reviews Food SciNutrit 54 (1) : 64-83.
Omurtag G (2008) Fumonisins, trichothecenes and zearalenone in cereals. Int J Mol Sci 9 (11) : 2062- 2090.
Yoshizawa T (2011) A current situation of mycotoxin management in Asia in relation to recent actions in Japan. proceedings of FFTCeKU 2011 conference, International seminar on risk assessment and risk management of mycotoxins for food safety in Asia. Thailand: Kasetsart University.
Zain ME (2011) Impact of mycotoxins on humans and animals. Journal of Saudi Chemical Society, 15 (2) :129-144.
Zinedine A, Soriano JM, Molto JC, Manes J (2007) Review on the toxicity, occurrence, metabolism, detoxification, regulations and intake of zearalenone: an oestrogenic mycotoxin. Food Chem Toxicol 45 (1) : 1-18.
Zinedine A, Brera C, Elakhdari S, Catano C, Debegnach F, Angelini S, De Santis B, Faid M, Benlemlih M, Minardi V, Miraglia M (2006) Natural occurrence of mycotoxins in cereals and spices commercialized in Morocco. Food Cont 17 (11) : 868-874.
Zöllner P, Mayer-Helm B (2006) Trace mycotoxin analysis in complex biological and food matrices by liquid chromatography-atmospheric pressure ionisation mass spectrometry. J Chromatograp A 1136 (2) : 123-169.
Zychowski KE, Hoffmann AR, Ly HJ, Pohlenz C, Buentello A, Romoser A, Phillips TD (2013) The effect of aflatoxin-B1 on Red Drum (Sciaenops ocellatus) and assessment of dietary supplementation of NovaSil for the prevention of aflatoxicosis. Toxins 5 (9) :1555-1573.