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The Impact of Mycotoxins on Humans, Animals and Control Strategies: A Review

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Abstract

Fusarium is mycelia fungi which can attack field crops and stored agricultural products. This fungus produces mycotoxins which can cause severe disease on cereal grains. The aim of this paper is to review the current status of fusarium, mycotoxins, diseases and control strategies of mycotoxins. First the paper describes about Fusarium mycotoxins and their Occurrence, Major mycotoxins produced by *Fusarium*, Diseases caused by Fusarium Biosynthesis of *Fusarium* mycotoxins Economical importance of *Fusarium* species and impacts of *Fusarium* mycotoxin on human and animal health. Then it presents about fusarium mycotoxins and also major mycotoxins produced by *Fusarium* species, such as trichothecens and fumonicins. The impacts of *Fusarium* mycotoxins on human and animal health and factor contributing for *Fusarium* invasion are described in detail. The step involved in the biosynthesis of *Fusarium* mycotoxins such as trichothecens and fumonicins is also outlined. Many control approaches for fusarium contamination such as chemical, biological, molecular and cultural practice explained briefly.

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Disease, Fungus, Fusarium, mycotoxin, Species.

Introduction

Fusarium is a fungus which belongs to the division *Ascomycota* and was first described by Link in 1809 as Fusisporium. However, major study for the classification was done by Wollenweber and Reinking (1935). The *genus Fusarium* belongs to the *Ascomycota phylum*, *Ascomycetes class*, *Hypocreales order*, while the teleomorphs of *Fusarium* species are mostly classified in the *genus Gibberella*, and for a smaller number of species, *Hemanectria and Albonectria genera*.

Innumerable members of this genus act as pathogens, endophytes and saprophytes and can be recovered from plants and soils worldwide (Geiser *et al.*, 2004). Macroscopic and microscopic features, such as color of the colony, length and shape of the macroconidia, the number, shape and arrangement of microconidia, and presence or absence of chlamydospores are key features for the differentiation of *Fusarium* species (Burges *et al.*, 1994; Larone, 1995; De Hoog *et al*., 2000). Molecular methods, such as 28S rRNA gene sequencing, may be used for rapid identification of *Fusarium* strains to species and sub species levels (Hennequin *et al.*, 1999).

Others are polymerase chain reaction (PCR) based rDNA detection method (Lacmanova *et al.*, 2009) and detection of protein banding patterns by SDS-PAGE and esterase isozyme electrophoresis (El-Kazzaz *et al.,* 2008). *Fusarium* is probably economically the most important phytopathogenic and toxigenic genus of filamentous fungi in cereals worldwide (McMullen *et al.*, 1997).

Fusarium species produce three types of spores called macroconidia, microconidia and chlamydospores (Burgess *et al.,* 1994). Most of the species produce all three types of spores, while some species do not. The macroconidia are produced in a specialized structure called a sporodochium. Sporodochium is a structure where the spore mass is supported by a superficial cushion-like mass of short monophialides which bear the microconidia. This large fungi group is the most common pathogens attacking crops. They infects mostly cereals (wheat, triticale, oat), but also other plants that are the basis of human and animal nutrition. *Fusarium* is able to attack a variety of plant organs, such as seedlings, heads, roots or stem-base and causes cereal diseases as, for example, *Fusarium* head blight (FHB), foot and root rot (FRR) and crown rot (CR) (Nelson *et al.*, 1994). The environmental conditions that promote *Fusarium* contamination are moderate temperatures in the presence of high humidity. In addition, it is favoured by rainfall during and after flowering.

The two main species responsible for FHB are *Fusarium graminearum*, a dominant species in warm and wet conditions, and *Fusarium poae*, which occurs under relatively warm and dry conditions (Backhous, 2014).

The species comprising a *Fusarium* community associate with each other and this cohabitation is particularly affected by climatic factors such as temperature and moisture at the stage of flowering, but also on agronomic factors, such as soil cultivation, nitrogen fertilization, fungicides, crop rotation, and host genotype (Placinta, 1999). Wet and warm weather during crop anthesis and maturation may favour FHB (McMullen *et al.*, 1997), and hot and dry conditions promote CR (Burgess *et al.*, 2001). All these fungal groups, occurring at high density, are suitable at conditions of low humidity and they are typically considered as storage fungi (Logrieco *et al.*, 2002).

The extensive distribution of *Fusarium* species has been attributed to the ability of these fungi to perform on a wide range of substrates and their well-organized mechanisms for spore dispersal (Nelson *et al.*, 1994).

According to Booth (1971), crown rot, head blight, and scab on cereal grains; vascular wilts on a wide range of horticultural crops (for example, tomato, cucurbits and banana), root rots; cankers; and other diseases such as pokkah-boeng on sugarcane and bakanae disease of rice are the major plant diseases mainly caused by *Fusarium* species.

Fusarium mycotoxins and their Occurrence

The term mycotoxin describes a chemically diverse group of secondary fungal metabolites mainly produced by species of the *Aspergillus, Penicillium or Fusarium genus* (Surai *et al.*, 2008). Some *Fusarium* strains associated with FHB produce many types of mycotoxin and the major ones trichothecenes (deoxynivalhe major oneenol-DON, nivalenol-NIV, T-2 and HT-2) and zearalenones (zearalenone-ZEA) (Bottalico and Perrone, 2002). Damaged grain is highly affected by mycotoxin contamination and therefore it is mandatory to avoid the damage before and during drying, and in storage. Field insect pests and some storage species harm grain on the head and stimulate fungal growth in the moist environment of the maturing grain. The activity of the insect species on the grain creates moisture and favorable conditions for the fungi. To avoid such moisture and mould, it is important that minimize the numbers of insects in stored grain by applying different techniques like adequate ventilation system, especially if the storage is metal containers. Ideally, all large-scale storage areas should be equipped with instruments for measuring humidity, so that air appropriate for ventilation can be selected (Olusegun *et al.*, 2013).

Major mycotoxins

The most common *Fusarium* mycotoxin groups are trichothecenes, zearalenones and fumonisins (Bottalico and Perrone, 2002; Jestoi, 2008). Based on the chemical features, trichothecenes can be divided in type A, including T-2 toxin, HT-2 toxin and type B, including deoxynivale- nol (DON, also called vomitoxin) and nivalenol (NIV) (Bottalico, 1998).

Trichothecenes

The trichothecenes are classified under the largest group of mycotoxins, containing of more than 150 chemically-related toxic compounds. It can produce by several species of *Fusarium*; mycotoxins are produced by several species of *Fusarium*, *Stachybotrys*, *Trichoderma*, and *Trichothecium*. Trichothecene mycotoxin isa common contaminant of wheat, barley, and maize in the United States also called vomitoxin because of its lethal effects on the digestive system of monogastric animals. Trichothecenes a huge group of metabolites comprise containing an epoxide, which is responsible for their toxicological activity. As described by Shank *et al.*, (2011), trichothecenes produced by *Fusarium* spp., are well-known in all cereal-growing areas of the world and they are divided into two groups: A and B, mainly characterized by the presence of different functional groups in the C-8 position of the trichothecene backbone. DON and NIV are the main type B trichothecenes found in Fusarium-infected kernels. A worldwide prevalence of DON-producers *Fusarium graminearum* complex species is known (Kelly *et al.,* 2015). Deoxynivalenol (DON), also known as vomitoxin, is the most frequently occurring trichothecene in small cereals and maize used for food and feed production (Gale *et al.,* 2011). T-2 and HT-2 toxins are type A trichothecenes produced by several Fusarium spp., mainly *Fusarium langsethiae, F. sporotrichioides and F. poae* in small grains and are most commonly present in oat. *F. langsethiae* and *F. sporotrichioides* are considered to be the main producers of T-2 and HT-2 toxins, especially in Northern Europe (Haratian *et al.*, 2008). T-2 is rapidly metabolized in vivo to HT-2, which induces adverse effects similar to T-2, with non- remarkable differences in terms of strength (Beyer *et al.,* 2014).

Zearalenones

Zearalenone (ZEN) is a secondary metabolite produced by a variety of Fusarium species. These include (*F. graminearum*, *F. verticillioides*, *F. culmorum*, *F.cerealis*, *F. crookwellense*, *F.equiseti* and *F. semitectum*) that are known to also produce other toxins including DON, NIV, and FUX (Frizzell *et al.,* 2011).This ZEN produced after the fungi contaminate crops in the field prior to harvest. However, production of ZEN during storage has equally been reported by Kuiper-Goodman *et al.,* (1987) ZEN is commonly found food products such as soybean products, dried fruit and vegetables, and cheese snacks have also been reported (Pineiro *et al.,* 1996; Oveisi *et al.,* 2005). ZEN contaminates crops such as corn, barley, oats, wheat, sorghum, millet, rice, flour, malt, soybeans, and beer. ZEN derivatives α-zearalenol (α-ZEN), β-zearalenol (β-ZEN), α- zearalanol (α-ZAL), β-zearalanol (β-ZAL), and zearalenone (ZAN) have been detected in corn stems, rice cultures, corn silage, corn products, and soya meal (Marin *et al.,* 2011). Seve- ral in vivo studies found that ZEN principally targeted the reproductive system.

Studies have reported the toxic effects included changes in reproductive tract, uterine enlargement, reduced fertility, increased embryo-lethal resorption, and changes in serum levels of progesterone and estradiol (Koraichi *et al.,* 2012). Furthermore, ZEN is immunotoxic, hepatotoxic, hematotoxic, nephrotoxic and enhances lipid peroxidation (Choi *et al.,* 2012).

Fumonisins

The fumonisins are a group of mycotoxins produced primarily by *Fusarium verticillioides* and *Fusarium proliferatum*, although a few other *Fusarium* species also may produce them. Fumonisins are a group of polyketide-derived mycotoxins that have a wide geographic distribution, and are consequently most commonly present on maize in many different regions. Although up to 13 *Fusarium* species are able to produce fumonisins (Wang *et al.,* 2013), *F. verticillioides* and *F. proliferatum* are the most important species related with fumonisin contamination. The fumonisins are a group of compounds initially isolated from *Fusarium moniliforme* (Gelderblom *et al.,* 1988).Ingestion of Fumonisins (FBs) has been associated with several human and animal ailments worldwide because of their hepatotoxicity, nephrotoxicity, neurotoxicity, immune stimulation, and immune suppression, causing several developmental abnormalities, and liver and kidney malfunctions (Harrison *et al.,* 1990; Howard *et al.,* 2001; Voss *et al.,* 2001). Diseases such as human abdominal pains and diarrhea were reported in India, resulting from consumption of moldy maize or sorghum containing high levels of FB (Bhat *et al.,* 1997).The incidence of FBs has been reported in several cereals, legume crops, spices, and food products all over the world. Maize and its products remain the most contaminated because of the susceptibility of the maize crop to FB-producing fungi (Shephard *et al.,* 2013).

Diseases caused by *Fusarium* mycotoxins

An array of diseases is caused by *Fusarium* species that affect agricultural and horti -cultural crops worldwide. Diseases such as, head blight of wheat (Windels, 2000) and panama disease of banana (Ploetz,1990), have huge sociological and economic impact on farmers and their communities who rely solely on the produce for their livelihood. Moreover, the pathogencity of *Fusarium species* in plants is not limited by regions or cropping patterns. The diseases that caused *Fusarium* are: Pokkah boeng in sugarcane, *Fusarium* crown and root rot, Stalk rot of maize, *Fusarium* head blight and Oil palm wilt.

Pokkah boeng in sugarcane

Sugarcane pokkah boeng is an economically important fungal disease globally. Pokkah boeng disease caused by the *Fusarium* species complex results in substantial yield losses in sugarcane. Thus, the rapid and accurate detection and identification of the pathogen is urgently required to manage and prevent the spreading of sugarcane pokkah boeng (Siddique, 2007). Pokkah boeng in sugarcane is mainly caused by *F.monoliforme*. Three to seven months old sugarcane plant is more prone to this infection. The infected leaves develop crumpled, twisted and shortened. Leaf sheaths also become chlorotic and irregular necrotic areas of reddish color develop and infection of the growing tip of plant is the most serious injury. It is referred to as top rot which results in the loss of the entire top of the plant. Lin *et al.*, (2014) reported the incidence and severity of disease from major sugarcane growing areas from China, during all seasons instead of only wet and hot summer seasons. Sugarcane stalk wilt and rot, caused by *F. sacchari*, is closely related to Pokkah Boeng disease and occasionally occurs on stems close to the top of plants (Lin *et al.*, 2014).

Oil palmwilt

The main fungal disease on Canary palm (Phoenix canariensis) is a *Fusarium* wilt caused by *Fusarium oxysporum f.* sp. *canariensis*. *F. oxysporum f.* sp. *elaeides* is the main causal agent for the oil palm wilt. Initial wilt follows dessication of the fronds, which finally break and hang around the trunk. Characteristic browning of the vascular elements internally is seen both in adult palms and in seedlings (Hernández-Hernández *et al.*, 2010). These diseases are caused by diverse species of *Fusarium* but the most important are *F. graminearum* in wheat, *F. verticillioids* in maize and *F. thapsinum* in sorghum. According to the report by Plyler *et al.*, (1999), the most distinctive symptom of this disease is an asymmetrical wilt of the leaflets on only one side of the rachis. The disease is usually harmful, but the time elapsed from first symptom appearance to final collapse and death of the palm tree differs.

Fusarium head blight

Fusarium head blight (FHB) or scab is mainly caused by *F. graminearum* group II, also known as Gibberella zeae (sexual stage of fungus). Other species of Fusarium like *F. poae*, *F. langsethiae*, *F. nivale* and *F.sporotrichioides* can also cause the disease. The disease usually attack head, grain and sometimes the neck of the plant. The first visible symptom is bleaching of some or all of the spikelets. As the fungus proceeds into the rachis, spikelets located above or below the initial site of infection also become bleached, whereas in barley, infection spikelets is located and do not proceed into rachis of spike. Pink to salmon-orange spore masses may be visible on infected spikelets during wet and humid conditions. Wet and warm conditions during crop growth and maturation may be favorable for FHB or scab (Windels, 2000).

Stalk rot of maize

Stalk rot is one of the major diseases of grain sorghum worldwide that damage to yield and quality becomes severe when disease development coincides with environmental stresses *Fusarium* stalk rot of maize caused by *F. verticillioides* in maize is one of the most serious and destructive disease which results in yield losses from 10 to 42% and as high as 100% in some areas in India as reported by Khokher *et al.*, (2014). The disease causes internal decay and discoloration of stalk tissue, reduces yield by blocking translocation of water and minerals, resulting in death and lodging of plant in the cropping season. According to Shin *et al.*, (2014) the stalk rot in maize in Korea is associated with *F. subglutinans* and *F. temperatum* and studied the fungicidal effects of fungicides on mycelial growth and colony formation (Jardine and Lesile, 1992). Maize (*Zea mays*) is one of the most important crops worldwide.

Fusarium crown and root rot

Fusarium crown and root rot (FCR) mainly caused by the members of *Fusarium* species include *F. culmorum and F. pseudograminearum*. Several species of Fusarium such as *F. avenaceum, F. acuminatum, F. equiseti, F. nivale, F. graminearum* group I, have been reported to cause FCR in cereals but are less virulent and more geographically and environmentally restricted than the main causal agents. The disease affects the stem base of barley and wheat resulting in necrosis and causes dry rot of the crown bases always brown, that often extends up to 2-4 nodes, root tissue and basal stem. Seasons with a wet start and dry climates lead to the formation of white head. FRR and CR are also a major challenge in wheat production. These diseases induce rotting of seeds, crowns and roots and lead to significant grain yield losses and quality reduction in each year (Smiley and Patterson, 1996).

Biosynthesis of fusarium mycotoxins

Mycotoxins are secondary metabolites produced by various phytopathogenic and food spoilage fungi including *Aspergillus, Fusarium and Penicillium* species. The biosynthetic genes involved in the fumonisin and trichothecene biosynthetic pathways are outlined. The potential benefits gained from an increased knowledge of the molecular organization of these pathways together with the mechanisms involved in their regulation are also discussed (Michael and Alan, 1999).

Trichothecenes

The trichothecene pathway begins with the cyclisation of farnesyl pyrophosphate (FPP) to trichodiene by the enzyme trichodiene synthase on (Figure 1) as described by Alexander *et al.*, (1998). This is the only enzyme in the biosynthetic pathway that has been characterized the macrocyclic biosynthetic pathway is much less understood; only the end products and late intermediates of the pathway have been identified and characterized (Jarvis *et al.*,1991).

Zearalenone

Zearalenone, phenolic resorcylic acid lactone, is a mycotoxin that may occur in the form of four hydroxyl derivatives (Placinta *et al.*, 1999). ZEA is of major interest because despite its low acute toxicity, it has proven to be hepatotoxic, immunotoxic, and carcinogenic to a number of mammalian species. The structures of ZEN and its derivatives are shown in (Figure 2). Also, ZEA and some of its metabolites have been shown to competitively bind to estrogen receptors in a number of different species and are responsible for hyper estrogenism and infertility in livestock (Cortinovis *et al.*, 2013). ZEA is mainly produced by *F. graminearum*, *F. culmorum*, *F. cerealis*, *F. equiseti* and F. *semitectum*(Glenn, 2007) and the contamination often co-occurs with DON. This toxin has a worldwide distribution with differences in the percentage and level of contamination, which are generally lower compared with the most representative trichothecenes (DON) (Yazar and Omurtag, 2008).

Fumonisins

Fumonisins are thought to be synthesised through the condensation of the amino acid alanine to an acetaste-derived precursor. Branched-chain methyl groups are added at C-12 and C-16 by an S-adenosyl methionine transferase. The subsequent biosynthetic stages involving oxygenation and esterification of the acetate-derived backbone areas yet unidentified. It is not clear whether oxygenation and methylation occur before or after condensation with alanine. But, it appears likely that less oxygenated trichothecenes such as FB2, FB3 and FB4 are precursors of the more highly oxygenated FB1 (Figure 3) (Desjardins *et al.*, 1996).

Economic importance of Fusarium species

The importance of *Fusarium* species is mostly assessed through damages that they cause either by destroying crops, grain, nursery plants, stored fruits, finished products, processed products, or by causing the decrease in the livestock production or death of animals, human diseases, etc. Many of the species of the genus *Fusarium* are capable of causing diseases (mycoses) in plants, animals and humans or mycotoxicoses in animals and humans. These fungal species parasitise on living cells, tissues or organs that are often weakened by other factors and cause infections of a mycosis type. These fungi form mycotoxins in infected plants and if these plants are introduced in a food chain they can cause intoxication of humans and animals known as mycotoxicoses. *Fusarium* is responsible for worldwide economic losses estimated at more than billion dollars annually. Yield losses are mostly caused by mycotoxins produced by *Fusarium*, which leads to a reduction of grain quality and quantity (Parry *et al.*, 1995).The distribution and predominance of a *Fusarium* species in a country seems to be determined by climatic factors like temperature, humid conditions, agronomic practices like cropping sequence, soil tillage, sowing on untilled soil, use of nitrogen fertilizers, as well as by competition from the *Fusarium* species (Parry *et al.*, 1995).The economic effects attributed to mycotoxin infection are widely felt in all sectors of the production and consumption of grain products. The damage can result in direct economic impact through limited yields, price discounts, restricted end markets and export rejections from importers. Mycotoxin contamination has an adverse economic effect in reducing the yield for food and fiber crops and food contamination with mycotoxin results in the huge and universal economic crisis (Geremew, 2015). The livestock industry is also mostly affected by mycotoxins. It makes animals more disposed to disease by weakening their immune system and decrease vaccination response. On the other hand, it may cause loss in productivity in the dairy cow industry, specifically in the case of aflatoxins, additional losses involve the clearance times farmers have to wait in order to allow animals to excrete all AFM1 from their schemes (Marroquín *et al.*, 2014).

Fig.1 Trichothecene biosynthetic pathway in Fusarium species

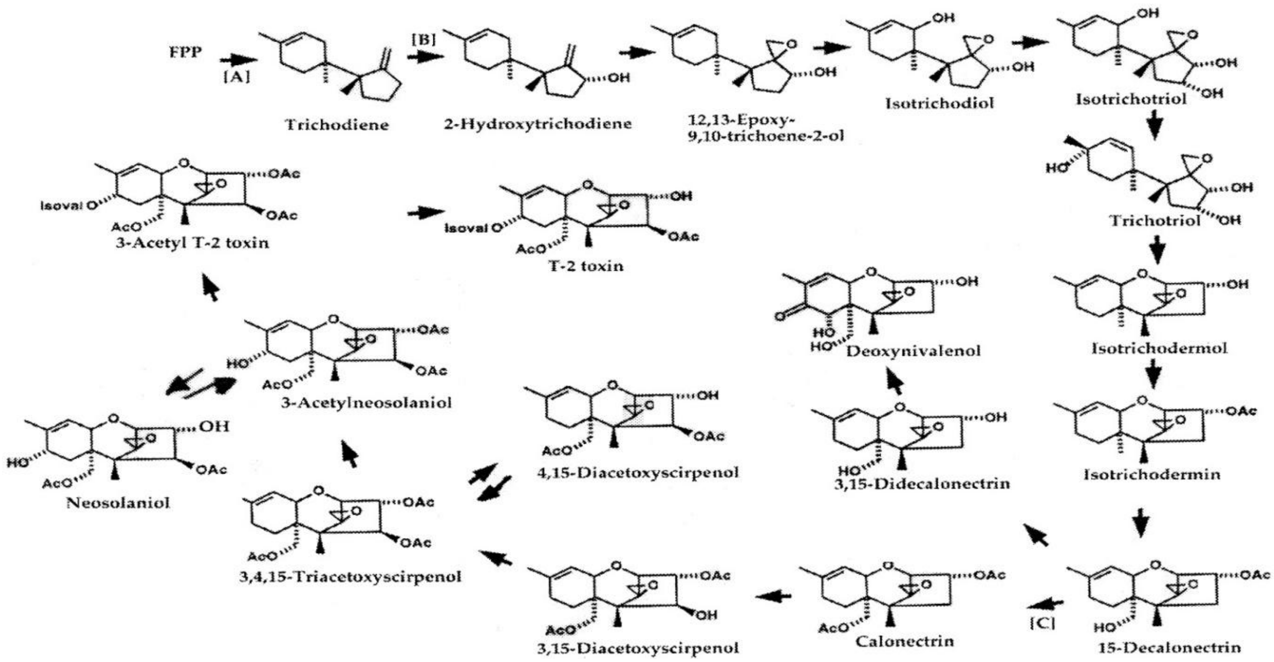


Fig.2 Chemical structures of ZEN and its derivatives: (a) zearalenone, (b) α-zearalenol, (c) β-zearalenol, (d) zearalanone, (e) α-zearalanol, and (f) β-zearalanol

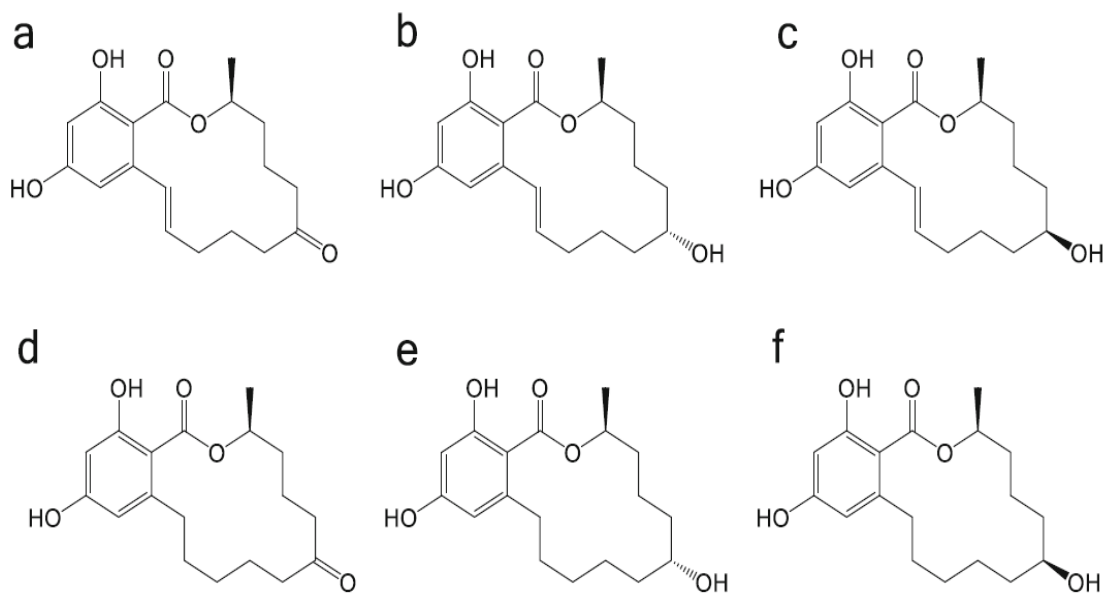
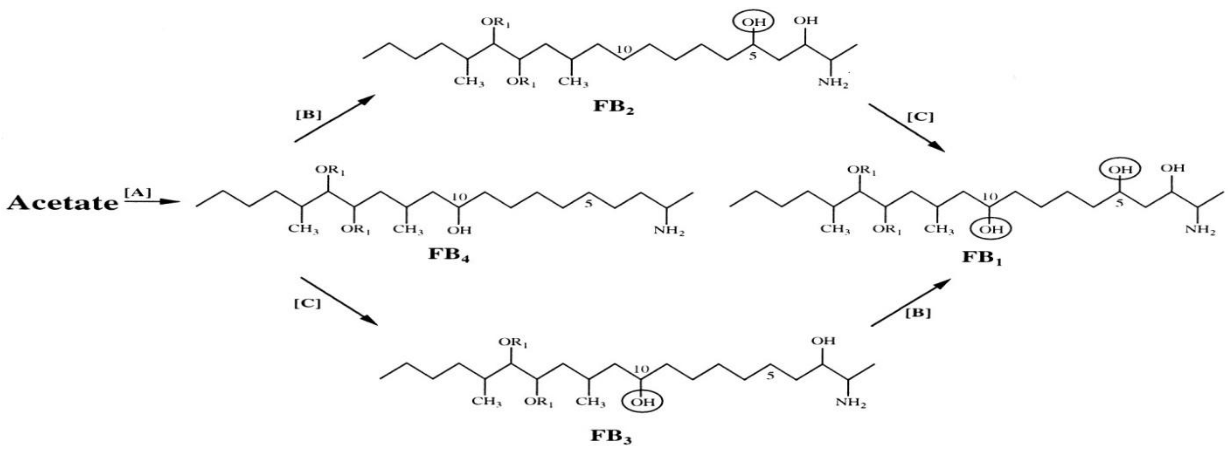


Table.1 Major *Fusarium mycotoxin* and their related fungi and toxicity to human and animal

Mycotoxin	Major Food	Mycotoxin producing fungal spp.	Toxicity to Human and Animal
Trichothecenes type B :Deoxynivalenol and nivalenol	All cereal grains	*Fusarium graminiarum*	Vomiting, feed refusal, kidney problem, immunosuppression
Trichothecenes type A : T-2 and HT-2	All cereal grains	*Fusarium* spp.	Weight loss, diarrhea, Allimentary toxic aleukia, decrease in immune responses, nausea, vomiting
Fumonisin	Maize, rice	*Fusarium moniliforme*	Liver and kidney tumors, Possible carcinogen for humans, esophageal carcinoma,
Zearalenone	Wheat, corn, rice	*Fusarium graminiarum*	Estrogenic not actually toxic, reproductive toxicity

Fig.3 Proposed pathway for fumonisin biosynthesis



Impacts of fusarium mycotoxin on human and animal health

Mycotoxins can induce health problems that are specific to each toxin or affect the immune status of animals, favouring infections. This is the major reason for the difficulty of diagnosing mycotoxicoses (Yiannikouris and Jonany, 2002). Mycotoxins produce a wide range of harmful effects in animals. The economic impact of reduced animal productivity, increased incidence of disease due to immunosuppression, damage to vital organs and interference with reproductive ability is many times better than the impact caused by death due to mycotoxin poisoning (Akande *et al.,* 2006). The economic impact of mycotoxins on humans and on animal agriculture can be assessing in different way with multiple criteria. Considerations may include loss of human and animal life, health care and veterinary care costs, loss of livestock production, loss of forage crops and feeds, regulatory costs and research cost focusing on relieving the impact and severity of the mycotoxin (Hussein and Brasel, 2001).Accordingly the formulas for worldwide economic impact have been difficult to develop and hence, most reports on economic impact are on a single aspect of mycotoxin exposure or contamination (Hussein and Brasel, 2001).

Trichothecene toxins are linked with aggressiveness of pathogens, influence on disease severity and mass control of plant tissues (Proctor *et al.*, 2002). T-2 and HT-2 toxins inducer of oxidative stress and an inhibitors of DNA, RNA, protein synthesis and mitochondrial function, T-2 and HT-2 toxins represent contaminants that are of considerable concern for human and animal health. Besides, T-2 and HT-2 contamination can arise with diacetoxyscirpenol (DAS) (Edwards *et al.,* 2012), that is expectable because DAS is biosynthesized at a side branch of the T-2 toxin pathway (Schuhmacher-

Wolz *et al.,* 2016). Dietary T-2 toxin has also been found to affect the nervous system by producing an irregular positioning of the wings. Furthermore, it can induce abnormal feathering, drastically decrease feed intake without impairing feed efficiency, less egg production and cause thinning of egg shells and destruction of the haemotopoietic system (Wyatt, 1979). In most animals fumonisin damages immune function, causes liver and kidney impairment, decreases weight gains and increases mortality rates as described on Table 1, by Peraica *et al.*, (1999).

Mechanism of Fusarium and their mycotoxins Control

Control of Mycotoxins is for the purpose of public health importance and economic improvement in the country. A number of strategies for reduction and control of mycotoxins have been considered in different areas of world. In control of mycotoxins there are several management practices that can be helpful in reducing losses caused by *Fusarium* contamination (McMullen *et al.*, 2012). These practices are aimed at reducing disease risk and include: Resistant cultivars, cultural practices, chemical controls. The production of mycotoxins in commodities depends on both the environmental conditions and the toxigenic species present. Hence, proper harvesting and processing practices and early detection of mycotoxigenic species are key aspects in any strategy to prevent or reduce mycotoxins in foods (Sardiñas *et al.*, 2011).

Chemical control

Fusarium contamination is currently treated with highly environmentally hazardous chemical fungicides that are effective only when used under specific conditions (Goswami and Kistler, 2004). Suppression of *Fusarium* disease can be achieved by the timely application of fungicidesto wheat and barley (McMullen *et al*., 2012).

A number of fungicides including carbendazim, hexaconazole, mancozeb, benomyl, prochloraz, propiconazole, tebuconazole and triadimenol are useful for *Fusarium* disease control. However, none of these chemicals has resulted in complete control.

Biological Control

Biocontrol agents also appear to be promising in controlling *Fusarium* contamination, but researchers usually indicate that they may be effective primarily as a means to lower the amount of chemical fungicide required to effectively control *Fusarium* disease (Xue *et al.*, 2009).The use of bio-control agents including bacteria and fungi has a great role in reduction of *F. graminearum* and associated toxin production. *Brevibacillus sp.*(strain BRC263), *Streptomyc- essp*. (BRC87B), and *Trichoderma gamsii* (6085) are suggested for testing as potential FHB bio-control agents (Matarese *et al.*, 2012).

Cultural Practices

Residue Management

Fusarium graminearum grows well on decaying plant residues, particularly that of corn, wheat, and barley. Tillage buries residues below the soil surface, allowing for their decomposition. In addition, burial of residues reduces the amount of inoculum available for spread (Dill-Macky, 2000). The increase in minimal tillage fields is believed to be a major contributor to recent regional scab epidemics. Although residue management may reduce local inoculum levels, spores dispersed from other fields may serve as a source of pathogen spores.

Crop Rotation

There is some studies report that *Fusarium graminearum* does not grow as well on residues of crops like soybean compared to corn, wheat, and barley (Dill-Macky, 2000). Planting wheat after soybean may help to reduce the level of local inoculums. As with residue management, aerial dispersal of spores from residues of nearby fields may serve as a source of disease.

Molecular approach

Fusarium disease resistance is a quantitative trait controlled by multiple genes, making it difficult to determine resistance mechanisms and breed resistant cultivars. A variety of *Fusarium oxysporum* f. sp. *Gladioli* resistance tests, based mainly on biological assays using cultivars and species of gladiolus have already been reported (Loffler *et al.*, 1997; Straathof *et al.*, 1998). However, the resistance mechanisms are still poorly understood (Remotti and Loffler, 1996). Qualitative trait loci (QTLs) for FHB resistance have been identified with the development of a molecular marker and marker map. Anderson and Buerstmary *et al.*, reviewed the stable QTLs for FHB resistance found by previous research (Buerstmary *et al.*, 2009). In recent years, plant pathologists have been interested in understanding the disease resistance pathways and the genes involved in providing resistance. These pathologists have started using various molecular techniques. Molecular markers such as allozymes, restriction fragment length polymorphisms (RFLP) and random amplified polymorphic DNA (RAPD) have been extensively used to characterize pathogen populations.

Mycotoxins are poisonous chemical compounds produced by various fusarium species fungi. Fusarium disease occurs in cereals when plants, fungal pathogens and environmental conditions are conducive for infection and cause substantial crop and yield losses. Mycotoxins are important contaminants with a several effects on both human and animal health, causing significant economic problems throughout the agri-food chain. Mycotoxin contamination in food might not be inevitable and its presence could threaten the food security of many countries especially developing ones. However, the implementation of proper methods from the beginning of the food chain until the end including all stages of production like planting, harvest, drying, storage, processing, packaging and transport helps to decrease the level of contamination and maintain it below the tolerable levels assigned by different countries. Effective management of *Fusarium* diseases in crops is not only essential for preventing crop losses but also needed to minimize mycotoxin production in food and feed products. Major strategies for preventing/minimizing mycotoxin production should be based on preventing growth of *Fusarium* in plants and therefore mycotoxin formation, reducing or eliminating mycotoxins from contaminated food and feed stuffs, or diverting contaminated products to low risk uses.

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