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Review

Occurrence *Fusarium species*, mycotoxins on cereal crops and their health implication

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Cereal crops are the most economically important grains in the world. These crops are not only used as a staple food for human consumption but also used as animal feed. The concept of *Fusarium* species causing diseases remains serious problem which severely affects cereal crop production and the grain quality. Mycotoxin produced by *Fusarium* species is considered to be a major contaminant of foods and feeds with health implications to farm animals and humans. Conventionally, control of *Fusarium* disease is achieved by chemical method. However, public concern about soil pollution and chemical residues in agriculture products lead to research of alternative methods. Among these methods, biocontrol seems to be a promising. The aim of this paper is to review some of researches on common *Fusarium* spp. of cereal crops, mycotoxins and their impact on farm animal and human health.

Keywords: Fusarium spp, Mycotoxins, Cereal crops

INTRODUCTION

Cereals are crops belonging to grass family (*gramineae*). The grains are edible; therefore cereals grains are the seeds of cultivated grasses. They are primarily rich source of energy for human and no ruminant animals. Cereals are widely cultivated and are the world's most important a staple food crops because of their agronomic significances and nutritional values(Anderson et al., 2004). The major production constraints to cereal crops are pests such sects and birds as well as diseases caused by bacteria, fungi, viruses and nematodes. Several studies have revealed that fungi particularly *Fusarium Spp*. that produce mycotoxins cause cereal contamination (Covarelli *et al.,* 2015). Mycotoxins are natural toxins elaborated by different fungal species growing in or on crops, food and feedstuffs. In most parts of the world, the major mycotoxins of concern are fumonisins, trichothecenes, and zearalenone, produced by *Fusarium spp*. They may be produced while the crop is growing or during grain transportation and storage. They are commonly found in cereal crops such as maize, wheat, sorghum and rice and also exist extensively in natural environment. Cereal crops are more prone to *Fusarium* diseases especially at flowering period up to ripening and maturity. Moreover, increased cereal crops farming and minimal tillage practices has increased inoculum availability because the crops remnants in field persist for certain period of time and produce huge amounts of inoculum (Jonathan et al., 2017). Common occurrence of mycotoxins in foods and

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feed stuffs poses a serious health risk to farm animals and humans. However, *Fusarium* toxins contamination in the various crops can be detected by Polymerase Chain reaction (PCR) or qPCR, mass spectrometer and high performance liquid chromatograph (HPLC) methods. In laboratory studies, qPCR is often the recommended method due to its accurate quantification allowing extracted DNA of the pathogen to be translated into a number of spores present in the sample and therefore the concentration of the spores per sample (Jonathan et al., 2017). This method can be used to identify specific *Fusarium* species. Therefore, the aim of this paper is to review some information availability on diseases of cereal crops caused by *Fusarium spp*. and their effects on farm animals and human health.

Occurrence of *Fusarium Species* causes diseases in cereal crops

Fungal diseases pose a threat to cereal crop production worldwide. These pathogenic fungi produce mycotoxins which reduce the production and contaminate grain with mycotoxins that pose health risk to farm animals and humans. Fungal diseases are soil borne which affect the different parts of the plant including root, stalk, kernel, ear and grains. Though several species of *Fusarium* can cause diseases, the most pathogenic agents and proficient soil inhabitants capable of saprophytic growth are *F. oxysporum, F. graminearum, F. fujikuroi ,F. verticillioides, F. moniliforme* and *F. solani* (Leslie and Summerell, 2013). These pathogens secrete mycotoxins, the most significant contaminants of cereal grain, foods and feedstuffs.

Maize

Maize (*Zea mays* L.) is a dicotyledonous angiosperm crop that belongs to the Poaceae family (Park, 2001). It is one of the important feed and food grain worldwide. Maize is a rich source of consumable calorie due to its high starch content. The crop is widely cultivated and can respond well to irrigation and fertilizers. However, maize is often prone to many fungal infections such as *Aspergillus Spp*., *Fusarium Spp*., *Rhizopus Spp.* and *Macrophomina Spp*. which are of concern in human foods and animal feeds (Malvika et al., 2016).The major fungi of concern with maize are *Fusarium Spp*. which produces mycotoxins posing serious health problem to both farm animals and humans.*Fusarium* ear rot and kernel which are caused by *F. moniliforme*, *F. graminearum* and *F. verticillioides* are the most devastating diseases of maize (Table 1).In a recent study in Brazil (Mauricio et al., 2017) reported that 54.2% of maize samples infected with *Fusarium spp* were found to be contaminated by at least ten different mycotoxins. This multi-mycotoxins contamination of maize suggests that *Fusarium Spp*. is widely distributed and is abundant in all climates where maize is grown. Nevertheless, susceptibility of maize to fungal diseases depends on the variety of the crop. Pastirčáka et al. (2002) reported highly significant differences in sensitivity to *Fusarium* ear rot between genotypes for twenty maize variants under mist irrigation and without mist irrigation.

Wheat

Wheat is one of the world's most important cereal crops. It is basically grown for human consumption and it is the preferred grain in many societies. Wheat belongs to the genus *Triticum*. A total wheat production in the world is estimated to be 500 million tons annually, with Russia the leading producer, followed by Ukraine, the United States of America, China, India and France (International Grain Council, 2009). However, wheat is more susceptible to fungal disease which hinders its production worldwide. *Fusarium Spp*. in particular is the main phytopathogen that produces mycotoxins and causes wheat disease known as *Fusarium* Head Blight (FHB). *Fusarium graminearum* is the common pathogen that frequently contaminates wheat and is associated with production of trichothecenes (Table 1). Trichothecenes are potent inhibitors of protein synthesis in eukaryotes, interfering at the initiation, elongation and termination stages. In study carried out in Brazil (Dos Santos et al., 2013) showed that trichothecenes (Deoxynivalenol) produced by *F. graminearum* was detected in 66.4% of wheat samples at levels ranging from 206.3 to 4732.3µg/kg (mean 1894.9µg/kg) and the total average daily intake of trichothecenes in bread and pasta was 1.13 µg/kg which exceeded tolerable limits. In another study, Spolti et al. (2014) reported three principle components-ascospore production on stalks, total trichothecene amount in wheat kernel, and incidence of diseased spikelets up from point inoculation- accounted for 29.4, 18.9 and 10.8% of the variation, respectively.

Sorghum

Sorghum is the major food grain in the semiarid tropics, an ecological zone encircling the globe and including Asia, Africa, South America and parts of the United States. It is a hardy, drought-resistant crop adaptable to a wide range of environmental conditions. Sorghum requires less water than maize and can survive dry environment and then resumes growth when moisture becomes available. However, many *Fusarium* species that produce mycotoxins cause serious sorghum diseases. *Fusarium* head blight (FHB) which is caused by *F. moniliforme* is a common sorghum disease (Table 1). In study conducted in the United States, Castor and Frederiksen (1980) reported 12 - 22% reduction in kernel weight and decreased in grain yield of sorghum due to FHB infection with *F. moniliforme*. In separate study Leslie et al. (1990) reported 71% and

Table 1. Diseases caused by different Fusarium species in cereal crop

Fungal spp	Mycotoxin	Crop	Disease	References
F. moniliforme, *F. graminearum* and *F. verticillioides*	Fumonisin (FB_1), trichothecene, Fumonisin	Maize	Ear rot and kernel	Malvika et al., 2016
Fusarium graminearum	Trichothecene	Wheat	Fusarium head bight (FHB)	Dos Santos et al., 2013
Fusarium fujikuroi	Fumonisins (B_1, B_2 and B_3)	Rice	Bakanae	Zainudin et al. 2008, Adam et al., 2018
F. moniliforme.	Fumonisin (FB_1)	Sorghum	FHB	Castor and Frederiksen, 1980

18% of sorghum tissues and debris were infected with *F. moniliforme* or *F. Proliferatum* respectively.

Rice

Rice also known as *Oryza sativa* belongs to the family Poaceae. It is a major food grain for a large population of people in the Europe, Africa, tropical and temperate zones, particularly in the Asian countries. The crop is almost exclusively cultivated as a human food. Processing rice for human consumption produces rice bran which can be used as livestock feed-stuff. Like other cereal crop, *Fusarium Spp*. is responsible for many rice diseases including bakanae disease. *Fusarium fujikuroi* is rice pathogen causing considerably production losses and produces mycotoxin fumonisins (B_1, B_2 and B_3)) which pose risk to livestock and human health.In reported from study carried out in Malaysia (Zainudin et al. 2008) showed that *F. Fujikuroi* was highly virulent and the only fungal species involved in causing bakanae disease in rice (Table 1). *Fusarium fujikuroi* produced gibberellic acid ranged from 450µg/g to 4361µg/g and had positively correlated with elongation symptoms of the disease (Bashyal et al., 2016). In recent study, Adam et al. (2018) reported more severe symptoms of bakanae disease in rice infected with a CarO-deficient *F. fujikuroi* strain than the reference strain. This demonstrates that *F. fujikuroi* is serious causal agent bakanae disease of rice.

Effects of *Fusarium* infection on cereal crops

There is no cereal crop totally immune to fungal diseases. The most visually symptoms of *Fusarium* infection are white, grayish or grayish-brown mold on the kernel, shrivelled, discolored and grains, rot root, kernels/stalks that may contain dark, grey perithecia, and pinkish. The fungi can invade plant kernel throught wounds and colonize the endosperm and parts of the embryo (Chelkowski et al., 1990). They can hinder development of kernel by interfering with the synthesis of the available food or by using up the stored carbohydrates and proteinsnecessary for the growth of the plant. *Fusarium* may affect seed physiology of plant so that kernel development starts sprouting early or the seed become unviable. Furthermore, the infection affects the crop yield by reducing the grain weight and subsequently decreasing the number of viable seeds for germination. *Fusarium* has been reported to caused significant production loss in some cereal ranged from 30 -100% depend on crop cultivar and the prevailing weather condition (Singh and Bandyopadhyay, 200)

Effects of *Fusarium* mycotoxins on farm animal and human health

Fusarium mycotoxins are fungaltoxins that can contaminate a wide range of human food and animal feed. There has been an increased concern about health risks associated with these fungal metabolites. Several studies have shown that consumption of feed and food contaminated with mycotoxins has negative effects on both farm animals and human health. Different *Fusarium* species produce various types of mycotoxins which can induce both acute and chronic toxic effects (Table 2). In human, consumption of mycotoxins contaminated food has been found to be associated with an increased risk of liver cancer and acute hepatitis (Mohamed et al., 2016). Grain contaminated with fumonisins produced by *F. verticillioides* and *F. proliferatum* has also been linked to oesophageal cancer in human (Jaskiewicz et al., 1987; Marasas, 2001; Gelineau-van Waes et al*.,* 2009; Bulder et al., 2012). Other symptoms of mycotoxins infection in adults include immune suppression or immune stimulation, digestive tract discomfort, diarrhea (Ukwuru et al., 2017), while in children aflatoxins poisoning is associated with hepatic cirrhosis. It is worth mentioning that human exposure to *Fusarium* mycotoxins can also be caused by residues of mycotoxins and their metabolites in animal products such as meat, milk and eggs (Ji et al., 2016).

Table 2. Diseases caused of different Fusarium species in human and livestock animals

Fungal spp.	Mycotoxin	Host	Disease	Reference
F. verticillioides and *F. proliferatum*	fumonisins	Human	Oesophageal and liver cancer, acute hepatitis	Mohamed et al., 2016
A. flavus	Aflatoxins	Cattle	aflatoxicosis	
F. moniliforme	Fumonisins	Horse	equine leukoencephalomalacia (ELM)	Gunther et al., 2014
F. graminearumF. graminearum, and *F. culmorum* and *F. culmorum*	Trichothecene and Zearalenone	Pigs	Pulmonary edema, vomiting, diarrhea, nausea and weight loss	Ji et al., 2016, Kriek *et al.,*1981a
F. graminearum and *F. culmorum*	Trichothecene and Zearalenone	poultry	oesophagus lesions	Ji et al., 2016

Cattle, horses and pigs are more susceptibility to Fusarium mycotoxins as well. Severe aflatoxicosis occurs in cattle consuming feeds contaminated with *A. flavus* aflatoxins (Ukwuru et al., 20017). Fumonisins produced by *F. moniliforme* are known to cause pulmonary edema in pigs (Kriek *et al.,* 1981a), while neurological disease called equine leukoencephalomalacia (ELM) that results from fatal degeneration of cerebellum in horses (Gunther et al., 2014). Zearalenone produced by *F. graminearum* and *F. culmorum* causes estrogenic effects in swine and can affect gilts and sows leading to swelling of external genital tracts and mammary glands. Ingestion of low to moderate amount of trichothecene and zearalenone cause vomiting, diarrhea, nausea and weight loss as well as feed refusal in pig and oesophagus lesions in poultry (Ji et al., 2016).

Factors influencing *Fusarium* infection

Several factors function together to affect *Fusarium* infection and production of the mycotoxins in cereal crops. Among them environmental conditions such as temperature, relative humidity and moisture that can affect crop physiology resulting in an increased *Fusarium* infection and contamination levels can exceed the maximum and tolerant limits especially in absence of appropriate management system. Furthermore, pathogenic fungi grow best under warm, humid and aerobic conditions. Disease control system plays crucial role in affecting cereal crop production. A wide range of chemicals have been used against *Fusarium* diseases. Fungicidal treatment applied to cereal crops against *Fusarium* diseases until anthesis or a day after anthesis. This practice has the greatest benefits for grains yield due to decrease in *Fusarium* infection. Nevertheless, insects can influence *Fusarium* colonization and mycotoxin contamination. Insects attack and harm crop causing wounds that are favourable entry sites for conidia already present on the ear tissues of the plants. Additionally, some *Fusarium* species are capable of producing more than one mycotoxin which increases contamination level.

Management of *Fusarium* diseases in cereal crops

Proper management system is necessary to increase crop yield and decrease *Fusarium* diseases. This includes proper fertilization, weed control, irrigation, tillage practices followed by crop rotation is essential. Rotation out of the crop will allow the crop residues that contain fungi to decompose, reducing the presence of the pathogens. Varieties of cereal crops differ in their susceptibility to *Fusarium* infection (Cleveland et al., 2003). Therefore, farming of the varieties that are resistant to fungal infection is recommended. In most cases when infection conditions of the crop become worse, farmers tend to use fungicide. However, extensive use of fungicide led to development of resistance against these chemicals among some fungal species. Moreover, there is an increased concern about soil pollution and chemical residues in agricultural products (Alabouvette et al., 2009). Among control methods, biological control system of fungal infection using endophytic bacteria spp seems to be a promising (Zalila-Kolsi et al., 2016; Grosu et al., 2015; Huang et al., 2012; Song et al., 2014; Bacon et al., 2001) . Bacteria produced inhibitors which acted against pathogen mycelial growth and production of pectinase which causes crop rot (Song et al., 2014). Numerous studies demonstrated that pathogen hyphae were twisted and shrivelled by the bacteria causing direct damage to the fungi resulted in 100% diseases suppression and no infection symptoms (Song et al., 2014; huang et al., 2012, Idris et al., 2007). The biocontrol method of fungal infection is believed to be more effective, sustainable and less cost.

CONCLUSION

Fusarium spp is wide spread and the most important pathogens of cereal crops worldwide. These pathogens cause several diseases in the crops resulting in yield reduction and poor grain quality. Mycotoxins produced by the *Fusarium spp* in the cereals can also have serious health implication to farm animals and humans. Control of *Fusarium* is commonly achieved by chemical methods. However, public concern about soil pollution and chemical residues in agriculture products lead to research of alternative methods. Among these methods, biocontrol seems to be a promising. Further studies to increase knowledge about occurrence of *Fusarium* infection and mycotoxins contamination of grain are necessary.

Conflict of interest

The authors of this work solely declared no conflict of interest.

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