SciMedCentral
Journal of Veterinary Medicine and Research

Review Article

Fusarium verticillioides, a Globally Important Pathogen of Agriculture and Livestock: A Review

N. Deepa and MY Sreenivasa*
Department of Studies in Microbiology, University of Mysore, India

***Corresponding author**
MY Sreenivasa, Department of Studies in Microbiology, University of Mysore, Manasagangotri, Mysore- 570 006, Karnataka, India, Tel: 91-821-2419733; Email: sreenivasamy@gmail.com; mys@microbiology.uni-mysore.ac.in

Submitted: 29 April 2017
Accepted: 09 May 2017
Published: 11 May 2017
ISSN: 2378-931X

Keywords
- Fumonisins
- Pathogenic
- Metabolites
- Effects
- *Fusarium verticillioides*

Abstract

Fusarium verticillioides is a multi-phytopathogenic fungi widely distributed throughout the world in association with cereals and cereal based food products. Cereals are the basic staple food which provides much of the energy and protein for many populations, where 2534MT consumed as food by Humans and animals. In some developing nations, grain in the form of rice, wheat or maize constitutes a majority of daily substance. In developed nations, cereal consumption is more moderate and varied as using cereal based products like corn flakes, oats, Poultry and animal feeds etc. Due to poor agricultural practices and intermittent rain at the time of harvest cereals are prone to contamination by number of fungi and it has become unavoidable and a worldwide problem. *Fusarium* species are the most common fungi associated with cereals all over the world. Among which *F. verticillioides* is the most frequently isolated species. FAO estimated that around 25-50% of cereals have been contaminated by mycotoxins. *F. verticillioides* produces secondary metabolites such as Fumonisins, trace level of fusaric acid, beauvericin, fusarin C, moniliformin, gibberiliformin in very low amount. Fumonisins receive the most attention as it is a potential carcinogen of global concern because they are the common contaminants of cereals and cereal-based foods. The International Agency for Research on Cancer (IARC) evaluated the toxin fumonisin as human carcinogen.

ABBREVATIONS

IARC: International Agency for Research on Cancer; FAO: Food and Agriculture Organization; PROMEC: Programme on Mycotoxins and Experimental Carcinogenesis; MRC: Medical Research Council; CSIR: Council for Scientific and Industrial Research.

INTRODUCTION

Fusarium verticillioide (Saccardo) Nirenberg (telomorph *Gibberellamoniliformis* Wineland) is an important plant pathogen with a wide range of hosts such as maize, sorghum, rice, millet, infecting plants in all stages of development, from the early hours of kernel germination to the time of harvest, including post-harvest deterioration of grains [1]. Seed infection by *F. verticillioides* is of major concern because it can reduce seed quality and result in contamination of grain with mycotoxins. *Fusarium verticillioides* infection of kernels occurs after flowering and is favored by hot and dry conditions. The fungus is distributed throughout the world, but predominant in humid tropical and subtropical regions and also present in the temperate regions [2,3]. In addition to causing plant diseases, infection by *F. verticillioides* can also result in contamination of kernels by fumonisins which can cause food safety problems for humans and animals and these fumonisins cannot easily be detoxified or removed from the grains [4,5].

TAXONOMY AND MORPHOLOGY

Fusarium verticillioides belongs to the section *Liseola* of *Fusarium* genus. In 1976, Helgard Nirenberg rejected *F. moniliforme* and transferred *Oospora verticillioides* to *F. verticillioides* (Sacc.) Nirenberg, while retaining Saccardo as the original author, and the epithet "*verticillioides*" which described the whorled nature (i.e., verticillate or cyclic) of the conidiophores [6] and it has been defined as mating population A of the *Fusarium fujikuroi* species complex (formally known as *Gibberellafujikuroi* species complex) [7].

The taxonomical relationship of *Fusarium verticillioides*is as follows: Kingdom Fungi, Class Deuteromycetes, Order Moniliales, Family Tuberculariaceae and genus *Fusarium*. Name of the taxon was highly controversial among the taxonomists as *F. moniliforme* and *F. verticillioides.* Presently the name *F. verticillioides* has been generally accepted and been in practise in the routine days [7]. The name *F. verticillioides* should be used only for strains that have the *G. monoliformis* (*Gibberellafujikuroi* mating population) telomorph and not simply as a replacement for *F. moniliforme*(Synder and Hansen). *F. moniliforme* is now likely called as *F. thapsinum* from sorghum, *F. sacchari* from sugar cane, *F. mangiferae* from mango, *and F. fujikuroi* from rice [5].

Fusarium verticillioides produces initially white mycelia but later develop into violet pigments with age. Macroconidia are long, slender, straight, thin walled, apically curved and notched basally with 3 to 5 septate and difficult to find. Abundant Microconidia are oval in shape, 0 septate, long chains of microconidia arise from monophialides and occasionally produces pair of rabbit ear shape of spores are observed. Chlamydospores are absent, swollen cells in some isolated species will be mistaken as pseudochlamydospores [5].

Fusarium verticillioides is morphologically similar to *Fusarium thapsium* which do not produce yellow pigment and *Fusarium proliferatum* which produce short chain of microconidiacan be differentiated by molecular markers, production of spores and pigments. *F. verticillioides* is very similar to *F. andiyazi*but does not form pseudochlamydospores. *F. verticillioides* is similar in some respects to *F. nygamai* which forms microconidia in short chains or false heads from monophialides, abundant macroconidia in sporodochia and chlamydospores in the aerial hyphae in older cultures [8].

HOST AND DISTRIBUTION

Fusarium verticillioides is widely distributed throughout the world and is particularly associated with Maize [9,10], rice [11-13], sugarcane [14], wheat [15], banana [16], asparagus[17,18] and sorghum [19]. High incidence of *F. verticillioides* was found in poultry feed mixtures and in animal feeds based on maize pellets and wheat bran [20]. A total of 51 cereal samples were found to be associated with *F. Verticillioides* with 33.12% of percent incidence in maize [21]. *F. verticillioides* were particularly associated with maize causes stalk rot and cob rot with drastic decrease of grain quality resulting in yield loss. The brutality of the rottness is affected by mode of inoculation systemically initiating from different routes such as seed or kernel through wounds in plant or infections of silks reciting disease symptoms [22,23].

The resistant genotypes are studied by the molecular mechanisms of the host response to infection which have been recently elucidated in maize and the identification of resistant genotypes will contribute to reduce fumonisin contamination. Developing Genetic resistance in maize to *F. Verticillioides* is of high priority in which sources of resistance has been identified and incorporated into public and private breeding programs [3]. Lanubile et al. [24], reported transcriptional changes were studied by next-generation RNA-sequencing for the first time with *F. verticillioides* in resistant C0441 and susceptible C0354 maize genotypes which revealed 6,951 differently expressed genes. Very recently Ju et al.[25], in Aprildocumented 8 quantitative trait loci (QTLs) and 43 genes associated with 57 SNPs correlated with *F. verticillioides* stalk rot resistance through linkage mapping and genome wide association analysis respectively. Similarly, Maschietto et al. [26], accelerated the resistance of maize lines by using identified set of QTLs and candidate genes for reducing disease severity and lowering mycotoxin contamination by *F. verticillioides*.

The quantity of stalk rot usually increases by drought stress and is reassured by irrigation. Many plants have at least one *Fusarium* associated diseases. Ear rot severity highness is due to disordered husk [27]. *F. verticillioides* infection is more susceptible among High lysine corn, brown midrib corn and sweet corn lines causing root rot with decreased root growth in maize seedlings [28,29]. *F. verticillioides* causes foot rot disease in rice; crown rot among asparagus and top rot in sugar cane and also infects many plant species, and has been reconfirmed that the infection is by *F. verticillioides* but not by the other *G. fujikori* species complex [30] (Table 1).

PHYSIOLOGY AND BIOCHEMISTRY

F. verticillioides growth is reported to occur at 25°C and an osmotic potential of -1.0 MPa with the best growth occurring on wounded immature reproductive tissues. Fumonisin B1 production will also be high at this condition in the laboratory [31-33]. Biochemically many number of enzymes from *F. verticillioides* have been examined like ß-d-Galactosidase [34], Dextranase [35], D-lactonohydrolase [36], pectate lyase [37,38], peptidase [39], phosphatases [40], polygalacturonase [41-43], oxygenase [44], proteases [45], ribonucleases [46] and ß-xylosidase [47]. *F. verticillioides* strains are commercially used to resolve DL-pantolactone mixtures since some strains can degrade lactic acid containing polymers [48,49]. Gonzalez-Jaen et al. [50], demonstrated that genes Fum1 (=Fum5), Fum6, and Fum8 were only present in *F. verticillioides* and other *Fusarium* species as the principle producers of fumonisins within the *G. fujikuroi* complex. Sanchez-Rangel et al. [51], reported similar results with a different pair of primers with presence or absence of the Fum1 gene which is the principle ability of a *F. verticillioides* isolate to produce fumonisin. Ramana et al. [52], system was based on the Fum1 and Fum13 gene sequences of *F. proliferatum* and *F. verticillioides* and was applied to the detection of the fungi in artificially contaminated cornmeal in a multiplex PCR assay.

Table 1: *Fusarium verticillioides* infection causing diseases in the crop.

Sl. No.	Crop	Disease	Reference
1.	Coconut palm (*Cocos nucifera*)	Bud rot	Ploetz R et al., 1999
2.	Corn/Maize (*Zea mays*)	*Fusarium* ear rot, stalk rot, kernel rot, root rot, seed rot, Seedling blight, seed-ling root rot	Shurtleff M.C et al., 1993
3.	Pearl millet (*Pennisetum-glauccum*)	Top rot	Wilson J.P et al., 1996
4.	Sorghum (*Sorghum bicolor*)	*Fusarium* wilt head blight, root rot, stalk rot, Seedling blight and seed rot	Horne C.W et al., 1993
5.	Sugarcane (*Saccharum spp.*)	*Fusarium* stem rot and twisted top	Ferreira S.A. et al., 1993
6.	Sunflower (*Helianthus an-nus*)	*Fusarium* stalk rot	Gulya T.J et al., 1993

Source: www. apsnet.org/online/common/search.asp

Ma et al. [53], studied the genome statistics of *F. verticillioides* strain 7600 with NCBI accession number of AAIM02000000 and genome size of 41.7Mb comprising of 8 sequence coverage folds, 11 chromosomes, 31 scaffolds, 14,179 coding genes with 1,397bp median gene length and 0.36Mb repetitive sequence, 0.14% of transposable elements.

SECONDARY METABOLITES

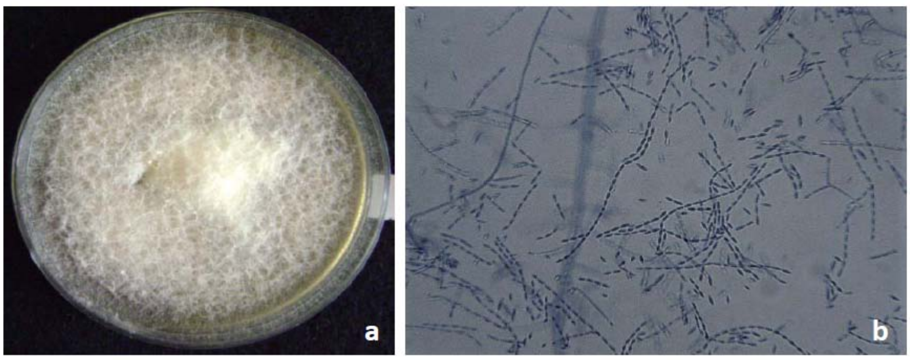
Secondary metabolites are generally produced by all *Fusarium* species, but some mycotoxins are toxic to humans and animals. To date, 28 structurally related fumonisin analogues have been identified, only three of them fumonisin B1 (FB1), B2 and B3 occur abundantly, Fusaric acid and fusarin C is produced in very sensitive levels as of zinc and manganese occurs at fermentation time, trace levels of beauveriacin, Gibberellin and moniliformin are produced not more than trace levels by *F. verticillioides* [54]. Among the *Fusarium* species *F. verticillioides* is the most prominent *Fusarium* species that produces the most important toxins fumonisins, discovered in the cultures of *F. moniliforme* (= *F. verticillioides*) [55,2].

FUMONISINS AND ITS TYPES

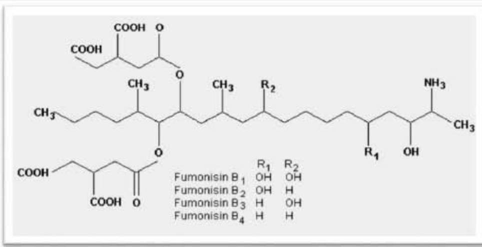
During the mid-1980s, although their effects on horses had been recognized for at least 150 years before with a significant risk of contamination to the association of *F. verticillioides* species with cereals and cereal based feeds [57,58]. During the last two and half decade, fumonisins have received worldwide attention. In 1988, the fumonisins were first isolated at the Programme on Mycotoxins and Experimental Carcinogenesis (PROMEC) of the Medical Research Council (MRC) in Tygerberg, South Africa, by Gelderblomet al [55]. Also in the same year, the structures of the fumonisins were also elucidated in a collaborative effort between the PROMEC and the Council for Scientific and Industrial Research (CSIR) in Pretoria [59]. Fumonisins are a group of 15 closely related mycotoxins that frequently occur in maize and other cereal based foods produced by 15 *Fusarium* species such as *F. verticillioides, F. proliferatum, F. subglutinans, F. thapsinum, F. anthophilum, F. globosum, F. fujikuroi, F. sacchari. F. nygami, F. dlamini, F. napiforme, F. andiyazi, F. pseudonygami, F. oxysporum* and *F. Polyphialidicum* [56].

Fumonisins receive the most attention because they are the common contaminants of cereals and cereal-based foods. They are ubiquitous in distribution and are found frequently on freshly harvested and stored agricultural commodities such as cereals in all stages of their production, processing and storage. Fumonisins are divided into four groups: A, B, C and G, with the B-type fumonisins being the most toxic. There are more than 10 fumonisins, but only three, FB_1, FB_2 and FB_3, occur naturally [60]. Fumonisin B_1 is considered as the most serious threat to human and animal health and has been reported that FB1 makes up approximately 70%, and FB2 and FB3 each make up about 10–20% of the total fumonisin content [57,61]. The International Agency for Research on Cancer (IARC) evaluated the fumonisins as Group 2B carcinogens i.e. possibly carcinogenic to humans [62,63].

The chemical structure of fumonisins (Figure 1) was elucidated and named them as fumonisin B_1 (FB_1) and fumonisin B_2 (FB_2) respectively [55,59]. The fumonisin optimally produces at moderate water activity and with nitrogen limited and usually its production doubles roughly for every 48 hrs with increase in mycelial dry weight. Cultures of *F. moniliforme* MRC 826 on maize were used to isolate and to study the structure of the fumonisins. A few years later FB_3 and FB_4 were also isolated



Fumonisin	Formula	MW [g/mol]
FB_1	$C_{34}H_{59}NO_{15}$	721.8
FB_2	$C_{34}H_{59}NO_{14}$	705.8
FB_3	$C_{34}H_{59}NO_{14}$	705.8
FB_4	$C_{34}H_{59}NO_{13}$	689.8



Chemical structure, Formula and molecular weight of Fumonisins

Figure 1 Morphological features of *Fusarium verticillioides.*
A. Colony morphology,obverse; **B.** Micro-morphological features showing monophialides and long conidial chains

Email: sreenivasamy@gmail.com; mys@microbiology.uni-mysore.ac.in

and characterized [64,65]. Fumonisin B_1 is a white hydroscopic powder that is soluble in water, acetonitrile-water or methanol and has the empirical formula $C_{34}H_{59}NO_{15}$ (relative molecular mass: 721). Fumonisins B_1 and B_2 are stable in methanol if stored at –18°C but steadily degrade at 25°C and above. However, they are reported to be stable over a 6- month period at 25°C in acetonitrile-water (1:1). Fumonisin B_1 is the diester of propane-1, 2, 3-tricarboxylicacid and 2S-amino-12S, 16R-dimethyl-3S, 5R, 10R, 14S, 15R-pentahydroxyeicosane in which the C-14 and C-15 hydroxy groups are esterified with the terminal carboxy group of propane-1, 2, 3-tricarboxylic acid. FB_2 to FB_4 show different hydroxylation patterns.

FUMONISIN DISTRIBUTION, METABOLISM AND ITS AFFECTS

Fumonisins appears to be wide spread in U.S. maize [66]. Surveys of 1,300 maize samples collected in the central United States from 1988 through 1995 indicated low levels of FB_1[67]. Cereals and cereal based products from maize source are the main commodities with natural FB1 occurrence have been reported from all parts of the world such as Brazil, Asia, Italy, Costa Rica and Hungary respectively [68-72]. In India, high levels of FB_1 were reported in maize kernels infected with *F. moniliforme* [73,74]and in maize as well as poultry feeds [75]. Fumonisin B1 contamination of maize and poultry feeds was high in Haryana, with 91 out of 100 maize samples and 42 out of 50 poultry feed samples were found to be contaminated with fumonisin B1. Fumonisins were considered as their occurrence was only confined to maize and later their presence was noted in a range of products, which include rice [76,77], sorghum [75,78,79] and low levels in wheat, barley, soybean [80] and at very low level in beer [81,82]. Recently fumonisin producing *F. verticillioides* was detected and differentiated from non fumonisin producing strains through nested and multiplex PCR as an early detection methods [83,84].

The secondary metabolite fumonisins include the polyketide pigment bikaverin, the terpenoid plant growth regulators gibberellic acids (GAs), and multiple mycotoxins. Nelson et al. [31], reported that Fumonisin toxicity is thought to result from the blockage of sphingolipid biosynthesis [85]. Sphingolipids have a complex role in cell function by affecting a number of metabolic processes due to fumonisins. Accumulation of sphingolipid bases leads to inhibition of growth cells resulting in cytotoxicity. They can inhibit protein kinase-C, activate phospholipase D, activate or inhibit enzymes involved in lipid signalling pathways, inhibit Na+/K+ ATPase, and induce dephosphorylation of retinoblastoma protein. All of these processes may increase cancer risk via loss of regulation of differentiation, apoptosis and lipid mediators that control cell proliferation [86-88]. Ceramide synthase inhibition generally results in accumulation of free sphinganine in liver, lung and kidney.Sphinganine, as a hydrophobic compound, can cross cell membranes and occur in blood and in urine if the kidneys are affected [89,87]. As the proposed mechanisms of action involve alterations in *de novo* synthesis, nutritional factors might be important in toxic end-points. The liver is the target for FB_1 in all animals and the kidney is also a target in many animals. Initially fumonisin B induced toxicity is characterized by increase in apoptotic, oncotic necrosis and regeneration in kidney and bile duct hyperplasia is reported in liver. Fumonisin B1 toxicity depends on strain and sex of the rodents [31].

Marasaset al. [90], reported the first syndrome of fumonisins, ELEM, equine leukoencephalomalacia, in 1980s characterized by fatal necrotic lesions in the cerebrum in horses. Smith et al. [91], reported that fumonisins induce cardiovascular dysfunction in horses with decreased heart rates, lower cardiac output, and right ventricular contractibility which may be involved in the pathogenesis of the lesions in the central nervous system. The symptoms in swine have been referred to as Porcine Pulmonary Edema (PPE) characterized by pulmonary, cardiovascular and hepatic symptoms as a "mystery swine disease" with diarrhea, weight loss, increased liver weight and poor performance [92] (Table 2).

Toxicity of FB1 has been implicated affecting alligators [93], fresh water fish [94] causing hepatotoxicity in rats [95] with skin lesions [96], wounds [97], keratitis [98],Polycystic kidney disease (PKD)mainly affecting liver, kidney and lungs in animals and life threatening cancer disease in humans [55](Table 2). Subsequent studies have also shown that fumonisins are toxic to plants causing root rot, stem rot, seed rot, seedling blight, head blight diseases which has been explained in table one [77]. It is known to be allergic to humans systematically infecting cancer and HIV patients and not associated with hospital settings but nosocomial diseases do occur [99-102,109]. *F. verticillioides* is resistant to most clinical antifungals like itraconazole, miconazole, amphotericin B [103] and flucytosine [104] reported as most effective.

CONCLUSION

Fusarium verticilliodes is genetically the most intensively studied species in the section of *Fusarium*. This fungus is primarily a pathogen of maize and other crops like sorghum and largely responsible for important economic losses worldwide. *F. verticillioides* is mainly known to produce fumonisins which is well studied in terms of its synthesis, its effects on animals and humans that consumes contaminated grains its association

Table 2: Effects of fumonisins on humans and animals.

Affected	After effects	Source
Horse	CNS, ELEM (Equine Leukoencephalomalacia)	Smith et al., [90]
Swine	PPE, Hepatotoxicosis, lesions in liver, lung targets to Pancreas, heart, oesophagus	Hollinger &Ekperigin [92]
Rats	Hepatic nodules, adenofibrosis, hepatocellular carcinoma, cholangiocarcinoma, hepatotoxins	Gross et al.,[105]
Rabbit	Anorectic, lethargic, injures liver and kidney	Gumprechtet al., [106]
Chicken	Erythrocyte formation, lymphocyte cytotoxic effects, weight reduction, hepatic necrosis, biliary hyperplasia, thymic cortical atrophy.	Javid et al., [107]
Primates	Oesophagal cancer, reduction in WBC and RBC	Gelderblomet al., [108]
Humans	Esophageal cancer, skin lesions, wounds, keratitis.	Kyung et al., [109]

with disruption of sphingolipid metabolism and folate transport which is a potential risk factor for human neural tubes. Hence it is a thrust area in food safety research for its prevention.

ACKNOWLEDGEMENT

We wish to thank Indian Council of Medical Research (ICMR) for awarding Senior Research Fellowship (SRF)as financial support to carry out the research work on *Fusarium verticillioides* and its management.

REFERENCES

1. Sreenivasa MY, Jaen MTG, Dass RS, Charith Raj AP, Janardhna GR. A PCR based for the detection and differentiation of potential fumonisin-producing *Fusarium verticillioides* isolated from Indian Maize kernels. Food biotechnol. 2008; 22: 160-170.
2. Marasas WFO, Kriek NPJ, Fincham JE, Van Rensburg SJ. Primary liver cancer and oesophageal basal cell hyperplasia in rats caused by *Fusarium moniliforme.* Int J Cancer. 1984; 34: 383-387.
3. Munkvold GP. Cultural and genetic approaches to managing mycotoxins in maize. Ann. Rev. Phytopathology. 2003; 41: 99-116.
4. Nayaka CS, Udaya Shankar AC, Niranjana SR, Wulff Ednar G, Mortensen C N, Prakash HS. Detection and quantification of fumonisins from *Fusarium verticillioides* in maize grown in Southern India. World J Microbiol Biotechnol. 2010; 26: 71-78.
5. Leslie JF, Summerell BA. The *Fusarium* Laboratory Manual. Blackwell Publishing, Ames, Iowa, USA. 2006.
6. Nirenberg HI. Untersuchungen uber die morphologische und biologische Differenzierung in der *Fusarium*-Sektion Liseola. Mitt. Biol. Bundesanst. Land-u. Forstwirtsch. Berlin-Dahlem.169: 1-117. 1976.
7. Seifert KA, Aoki T, Baayen RP, Brayford D, Burgess LW, Chulze S, et al. The name Fusarium moniliforme should no longer be used. Mycol Res. 2003; 107: 643-644.
8. Burgess LW, Trimboli D. Characterization and distribution of *Fusarium nygamai*, sp. nov. Mycol. 1986; 78: 223-229.
9. Oren L, Ezrati S, Cohen D, Sharon A. Early events in the *Fusarium verticillioidies* - maize interaction characterized by using a green fluorescent protein-expressing transgenic isolate. Appl Envi Microbiol. 2003; 69: 1695-1701.
10. Alberts JF, Van zyl WH, Gelderblom WCA. Biologically Based Methods for Control of Fumonisin-Producing Fusarium Species and Reduction of the Fumonisins. Frontiers in microbiology 2016; 7: 548.
11. Desjardins AE, Manandhar GG, Plattner RD, Maragos CM, Shrestha K, Mc-Cormick SP. Occurrence of *Fusarium* species and mycotoxins in Nepalese maize and wheat and the effect of traditional processing methods on mycotoxin levels. J Agri Food Chem. 2000; 48: 1377-1383.
12. Ghiasian SA, Rezayat SM, Kord-Bacheh P, Maghsood AH, Yazdanpanah H, Shepard GS, et al. Fumonisin production by *Fusarium* species isolated from freshly harvested corn in Iran. Mycopathol. 2005; 159: 31-40.
13. Munkvold G, Stahr HM, Logrieco A, Moretti A, Ritieni A. Occurrence of fusaproliferin and beauvericin in *Fusarium*-contaminated livestock feed in Iowa. Appl Envi Microbiol. 1998; 64: 3923-3926.
14. Mohammadi A, Nejad RF, Mofrad NN. *F.verticillioides* from sugarcane, vegetative compatability groups and pathogenecity. Plant Prot Sci. 2012; 48: 80-84.
15. Desjardins AE, Busman M, Proctor RH, Stessman R. Wheat kernel black point and fumonisin contamination by *Fusarium proliferatum*. Food Addit Cont. 2007; 24: 1131-1137.
16. Anthony S, Abeywickrama K, Dayananda R, Wijeratnam SW, Arambewela L. Fungal pathogens associated with banana fruit in Sri Lanka, and their treatment with essential oils. Mycopathol, 2004; 157: 91-97.
17. Stephens CT, Vries-de RM, Sink KC. Evaluation of Asparagus species for resistance to *Fusarium oxysporoum* and *Fusarium verticillioides*. Horti. sci. 1989; 24: 365-368.
18. Corpas-Hervias C, Melero-Vara JM, Molinero-Ruiz ML, Zurera-Muñoz C, Basallote-Ureba MJ. Characterization of isolates of *Fusarium* spp. obtained from asparagus in Spain. Plant Dis. 2006; 90: 1441-1451.
19. Tesso T, Claflin LE, Tuinstra MR. Estimation of combining ability for resistance to *Fusarium* stalk rot in grain sorghum. Crop Sci. 2004; 44: 1195-1199.
20. Regina SD, Sreenivasa MY, Janardhana GR. High incidence of Fusarium verticillioides in Animal and Poultry feed mixtures produced in Karnataka, India. Plant Pathol J. 2007; 6: 174-178.
21. Deepa N, Nagaraja H, Sreenivasa MY. Prevalence of fumonisin producing *Fusarium verticillioides* associated with cereals grown in Karnataka (India). FSHW. 2016; 5: 156-162.
22. Stewart DW, Reid LM, Nicol RW, Schaafsma AW. A mathematical simulation of growth of Fusarium in maize ears after artificial inoculation. Phytopathol. 2002; 92: 534-541.
23. Yates IE, Arnold JW, Hinton DM, Basinger W, Walcott RR. *Fusarium verticillioides* induction of maize seed rot and its control. Can J Bot. 2003; 81: 422-428.
24. Lanubile AL, Ferrarini A, Maschietto V, Delledonne M, Marocco A, Bellin D. Functional genomic analysis of constitutive and inducible defense responses to Fusarium verticillioides infection in maize genotypes with contrasting ear rot resistance. BMC Genomics. 2014; 15: 710.
25. Ju M, Zhou Z, Mu Cong, Zhang X, Gao J, Liang Y, et al. Dissecting the genetic architecture of *Fusarium verticillioides* seed rot resistance in maize by combining QTL mapping and genome-wide association analysis. 2017; 7: 46446.
26. Maschietto V, Colombi C, Pirona R, Pea G, Strozzi F, Marocco A, et al. QTL mapping and candidate genes for resistance to *Fusarium* ear rot and fumonisin contamination in maize. BMC plant Bio. 2017; 17-20.
27. Warfield CY, Davis RM. Importance of the husk covering on the susceptibility of corn hybrids to *Fusarium* ear rot. Plant Dis. 1996; 80: 208-210.
28. Warren HL. Comparison of normal and high lysine maize in breds for resistance to kernel rot caused by *Fusarium moniliforme*. Phytopathol. 1978; 68: 1331-1335.
29. Soonthornpoct P, Trevathan LE, Ingram D. The colonization of maize seedling roots and rhizosphere by *Fusarium* spp. in Mississippi in two soil types under conventional tillage and no-tillage systems. Phytoprot. 2000; 81: 97-106.
30. Bacon CW, Porter JK, Norred WP, Leslie JF. Production of fusaric acid by *Fusarium* species. Appl Envi Microbiol. 1996; 62: 4039-4043.
31. Nelson PE, Desjardins AE, Plattner RD. Fumonisins, mycotoxins produced by *Fusarium* species: Biology, chemistry, and significance. Annu Rev Phytopathol. 1993; 31: 233-252.
32. Yates IE, Hiett KL, Kapczynski DR, Smart W, Glenn AE, Hinton DM, et al. GUS transformation of the maize fungal endophyte *Fusarium moniliforme*. Mycol Res. 1999; 103: 129-136.
33. Bourett TM, Sweigard JA, Czymmek KJ, Carroll A, Howard RJ. Reef

coral fluorescent proteins for visualizing fungal pathogens. Fun Gene Biol. 2002; 37: 211-220.

34. Macris BJ, Markakis P. Characterization of extracellular β-D-galactosidase from *Fusarium moniliforme* grown in whey. App Environ Microbiol. 1981; 41: 956-958.

35. Marin S, Albareda X, Ramos AJ, Sanchis V. Impact of environment and interactions of *Fusarium verticillioides* and *Fusarium proliferatum* with *Aspergillus parasiticus* on fumonisin B1 and aflatoxins on maize grain. J Sci Food Agri. 2001; 81: 1060-1068.

36. Liu Z, Sun Z. Cloning and expression of Dlactonohydrolase cDNA from Fusarium moniliforme in *Saccharomyces cerevisiae*. Biotechnol Lett. 2004; 26: 1861-1865.

37. Dixit VS, Kumar AR, Pant A, Khan M.I. Low molecular mass pectate lyase from *Fusarium moniliforme*: Similar modes of chemical and thermal denaturation. Biochem Bioph Res Commu. 2004; 315: 477-484.

38. Rao MN, Kembhavi AA, Pant A. Role of lysine, tryptophan and calcium in the β-elimination activity of a low-molecular-mass pectate lyase from *Fusarium moniliforme*. Biochem J. 1996; 319: 159-164.

39. Rodier MH, El-Moudni B, Kauffman-Lacroix C, Jacquemin JL. Purification of an intracellular metallopeptidase of M-r 45 000 in *Fusarium moniliforme*. Mycol Res. 1997; 101: 678-682.

40. Kanaya S, Yoshida H. Phosphodiesterase phosphomonoesterases from *Fusarium moniliforme*: Separation and properties for four isozymes. J Biochem. 1979; 85: 791-798.

41. Bonnin E, Le Goff A, Körner R, Van Alebeek GW, Christensen TM, Voragen AG , et al. Study of the mode of action of endopolygalacturonase from Fusarium moniliforme. Biochim Biophys Acta. 2001; 1526: 301-309.

42. Bonnin E, LeGoff A, Korner R, Vigouroux J, Roepstorff P, Thibault JF. Hydrolysis of pectins with different degrees and patterns of methylation by the endopolygalacturonase of Fusarium moniliforme. Biochem Biophys acta. 2002; 1596: 83-94.

43. Bonnin E, Legoff GJ, Alebeek WM, Voragen AGJ, Thibault JF. Mode of action of Fusarium moniliforme endopolygalacturonase towards acetylated pectin. Carbo Polymers. 2003; 52: 381-388.

44. Uzura A, Katsuragi T, Tani Y. Stereoselective oxidation of alkylbenzenes by fungi. J Biosci Bioeng. 2001; 91: 217-221.

45. Chrzanowska JM, Kolaczkowska, Polanowski A. Proteolysis of casein by a proteinase from Fusarium moniliforme in solution and in Emmental cheese. Milchwi. 1990; 45: 164-167.

46. Nakai T, Yoshikawa W, Nakamura H, Yoshida H. The three-dimensional structure of guanine-specific ribonuclease F1 in solution determined by NMR spectroscopy and distance geometry. Eur J Biochem. 1992; 208: 41-51.

47. Saha BC. Purification and characterization of an extracellular beta-xylosidase from a newly isolated Fusarium verticillioides. J Ind Microbiol Biotechnol. 2001; 27: 241-245.

48. Torres A, Li SM, Roussos S, Vert M. Screening of microorganisms for biodegradation of poly(lactic-acid) and lactic acid-containing polymers. Appl Environ Microbiol. 1996; 62: 2393-2397.

49. Tang YX, Sun ZH, Hua L, Lv CF, Guo XF, Wang J. Kinetic resolution of DL-pantolactone by immobilized Fusarium moniliforme SW-902. Proc Biochem. 2002; 38: 545-549.

50. Gonzalez-Jaen MT, Mirete S, Patino B, Lopez-Errasquin E, Vazquez C. Genetic markers for the analysis of variability and for production of specific diagnostic sequences in fumonisin-producing strains of Fusarium verticillioides. Eur J Plant Pathol. 2004; 110: 525-532.

51. Ramana MV, Balakrishna K, Murali HCS, Batra HV. Multiplex PCR based stratergy to detect contamination with mycotoxigenic Fusarium species in rice and fingermillet collected from southern India. J Sci Food Agri. 2011; 91: 1666-1673.

52. Sanchez-Rangel D, Sanjuan-Badillo A, Plasencia J. Fumonisin production by Fusarium verticillioides strains isolated from maize in Mexico and development of a polymerase chain reaction to detect potential toxigenic strains in grains. J Agri Food Chem. 2005; 53: 8565-8571.

53. Ma LJ, Does HCVD, Borkovich KA, Coleman JJ, Daboussi MJ, Pietro AD, et al. Comparative genomics reveals mobile pathogenicity chromosomes in Fusarium. Nature. 2010; 464: 367-373.

54. Ghiasian SA, Kord-Bacheh P, Rezayat SM, Maghsood AH, Taherkhani H. Mycoflora of Iranian maize harvested in the main production areas in 2000. Mycopathologia. 2004; 158: 113-121.

55. Gelderblom WCA, Jaskiewicz K, Marasas WFO, Thiel PG, Horak MJ, Vleggaar R, et al. Fumonisins-novel mycotoxins with cancer promoting activity produced by Fusarium moniliforme. Appl Environ Microbiol. 1988; 54: 1806-1811.

56. Rheeder JP, Marasas WF, Vismer HF. Production of fumonisin analogs by Fusarium species. Appl Environ Microbiol. 2002; 68: 2101-2105.

57. Nelson PE, Burgess LW, Summerell BA. Some morphological and physiological characters of Fusarium species in sections Liseola and Elegans and similar new species. Mycolo. 1990; 82: 99-106.

58. Navi SS. Fungi associated with sorghum grain in rural Indian storages. J New Seeds. 2005; 7: 51-68.

59. Bezuidenhout SC, Gelderblom WCA, Gorst-Allman CP, Horak RM, Marasas WFO, Spiteller G, et al. Structure elucidation of the fumonisins, mycotoxins from Fusarium moniliforme. J Chem Soc Chem Comm. 1988; 743-745.

60. Richard JL, Bennett GA, Ross PF, Nelson PE. Analysis of naturally occurring mycotoxins in feedstuffs and food. J Anim Sci. 1993; 71: 2563-2574.

61. Dawlatana M, Coker R, Nagler MJ, Blunden G. A normal phase HPTLC method for the quantitative determination of fumonisin B1 in rice. Chromato. 1995; 41:187-190.

62. Toxins derived from Fusarium moniliforme: fumonisins B1 and B2 and fusarin C. IARC Monogr Eval Carcinog Risks Hum. 1993; 56: 445-466.

63. Fandohan P, Hell K, Marasas WFO, Wingfield MJ. Infection of maize by Fusarium species and contamination with fumonisin in Africa. Afri J Biotechnol. 2003; 2: 570-579.

64. Cawood ME, Gelderblom WCA, Vleggaar R, Behrend Y, Thiel PG, Marasas WFO. Isolation of the fumonisins mycotoxins: a quantitative approach. J Agri Food Chem. 1991; 39: 1958-1962.

65. Plattner RD, Weisleder D, Shackelford DD, Peterson RP, Powell RG. A new fumonisin from solid cultures of Fusarium moniliforme. Mycopathologia. 1992; 117: 23-28.

66. Bullerman. Fusaria and toxigenic molds other than Aspergilli and Penicillia. pp. 481-497. In: Food Microbiol. Fundamentals and frontiers, eds. Doyle MP, Beuchat LR, Montville TJ. ASM. Washington, DC. 2001.

67. Munkvold GP, Desjardins AE. Fumonisins in maize: can we reduce their occurrence. Plant Dis. 1997; 81: 556-565.

68. Sydenham EW, Marasas WFO, Shephard GS, Thiel PG, Hirooka EY. Fumonisin concentrations in Brazilian feeds associated with field outbreaks of confirmed and suspected animal mycotoxicoses. J Agri Food Chem. 1992; 40: 994-997.

69. Ueno Y, Aoyama S, Sugiura Y, Wang DS, Lee US, Hirooka EY, et al. A limited survey of fumonisins in corn and corn-based products in Asian countries. Mycotoxin Res. 1993; 9: 27-34.

70. Ritieni A, Moretti A, Logrieco A, Bottalico A, Randazzo G, Monti SM, et al. Occurrence of fusoproliferin, fumonisin B1 and beauvericin in maize from Italy. J Agri Food Chem. 1997; 45: 4011-4016.

71. Viquez OM, Castell-Perez ME, Shelby RA. Occurrence of fumonisin B1 in maize grown in Costa Rica. J Agri Food Chem. 1996; 44: 2789-2791.

72. Fazekas B, Bajmócy E, Glávits R, Fenyvesi A, Tanyi J. Fumonisin B1 contamination of maize and experimental acute fumonisin toxicosis in pigs. Zentralbl Veterinarmed B. 1998; 45: 171-181.

73. Chhatterjee D, Mukherjee SK. Contamination of Indian maize with fumonisin B1 and its effects on chicken macrophage. Lett Appl Microbiol. 1994; 18: 251-253.

74. Chourasia HK, Shelby RA. Production of fumonisin by Fusarium moniliforme and Fusarium proliferatum isolated from Indian corn samples. Indian J Expt Biol. 1996; 34:103-106.

75. Shetty PH, Bhat RV. Natural occurrence of fumonisin B1 and its co-occurrence with aflatoxin B1 in Indian sorghum, maize and poultry feeds. J Agri Food Chem. 1997; 45: 2170-2173.

76. Desjardins AE, Plattner RD, Nelson PE. Production of Fumonisin B (inf1) and Moniliformin by Gibberella fujikuroi from Rice from Various Geographic Areas. Appl Environ Microbiol. 1997; 63: 1838-1842.

77. Abbas HK, Cartwright RD, Shier WT, Abouzied MM, Bird CB, Rice LG, et al. Natural occurrence of fumonisins in rice with Fusarium sheath rot disease. Plant Dis. 1998; 82: 22-25.

78. Da Silva JB, Dilkin P, Fonseca H, Correa B. Production of aflatoxin by Aspergillus flavus and fumonisin by Fusarium species isolated from Brazilian sorghum. Braz J Microbiol. 2004; 35: 182-186.

79. da Silva JB, Pozzi CR, Mallozzi MA, Ortega EM, Corrêa B. Mycoflora and occurrence of aflatoxin B(1) and fumonisin B(1) during storage of Brazilian sorghum. J Agric Food Chem. 2000; 48: 4352-4356.

80. Castellá G, Bragulat MR, Cabañes FJ. Surveillance of fumonisins in maize-based feeds and cereals from spain. J Agric Food Chem. 1999; 47: 4707-4710.

81. Scott PM, Lawrence GA. Analysis of beer for fumonisins. J Food Protc. 1995; 58: 1379-1382.

82. Shephard GS, Vander-Westhuizen L, Gatyeni PM, Somdyala NIM, Burger HM, Marasas WFO. Fumonisin mycotoxins in traditional Xhosa maize beer in South Africa. J Agric Food Chem. 2005; 53: 9634-9637.

83. Deepa N, Charith Raj AP, Sreenivasa MY. Nested PCR method for early detection of fumonisin producing *Fusarium verticillioides* in Pure Cultures, Cereal Samples and Plant parts. Food Biotechnol. 2016; 30: 18-29.

84. Deepa N, Charith Raj AP, Sreenivasa MY. Multiplex PCR for the early detection of fumonisin producing *Fusarium verticillioides*. Food Biosci. 2016; 13: 84-88.

85. Enongene EN, Sharma RP, Bhandari N, Voss KA, Riley RT. Disruption of sphingolipid metabolism in small intestines, liver and kidney of mice dosed subcutaneously with fumonisins B1. Food Chem Toxicol, 2000; 38: 793-799.

86. Merrill AH, Wang ET, Vales R, Smith ER, Schroeder JJ, Menaldino DS, et al. Fumonisin toxicity and sphingolipid biosynthesis. Adv Exp Med Biol. 1996; 392: 297-306.

87. Riley RT, Wang E, Schroeder JJ, Smith ER, Plattner RD, Abbas H, et al. Evidence for disruption of sphingolipid metabolism as a contributing factor in the toxicity and carcinogenicity of fumonisins. Nat Tox. 1996; 4: 3-15.

88. Lee JY, Leonhardt LG, Obeid LM. Cell-cycle dependent changes in ceramide levels preceding retinoblastoma protein dephosphorylatin in G2/M. Biochem J. 1998; 344: 457-461.

89. Hannun YA, Jr-Merrill AH, Bell RM. Use of sphingosine as an inhibitor of protein kinase C Meth Enzymol. 1991; 201: 316-328.

90. Marasas WFO, Kellerman TS, Gelderblom WCA, Coetzer JAW, Thiel PG, Van der Lugt JJ. Leucoencephalomalacia in a horse induced by fumonisin B1 isolated form *Fusarium moniliforme*. Ondersteport J Vet Res. 1988; 55: 197-203.

91. Smith GW, Constable PD, Foreman JH, Eppley RM, Waggoner AL, Tumbleson ME, et al. Cardiovascular changes associated with intravenous administration of fumonisin B1 in horses. Ame J Vet Res. 2002; 63: 538-545.

92. Hollinger K, Ekperigin HE. Mycotoxicosis in food producing animals. Veterinary Clinics of North America. Food Animal Prac. 1999; 15: 133-165.

93. Frelies PF, Sigles L, Nelson PE. Mycotic pneumonia caused by *Fusariummoniliforme* in an alligator. Sabour. 1985; 23: 399-402.

94. Bisht W, Bisht GS, Khuble RD. *Fusarium*: A new threat to fish population in reservoirs of kumaun, India. Current Science. 2000; 78: 1241-1245.

95. Gelderblom WCA, Kriek NPJ, Marasas WFO, Thiel PG. Toxicity and carcinogenecity of the *Fusarium moniliforme* metabolite, fumonisin B_1, in rats. Carcinogenesis. 1991; 12: 1247-1251.

96. Ajello L, Padhye AA, Chandler FW, Mc Girmis MR, Morganti L, Alberici F. *Fusariummoniliforme* a new mycetoma agent restudy of a European case. Euro. J Epid. 1998; 1: 5-10.

97. Pineiro MS, Miller J, Silva G, Musser S. Effect of commercial processing on fumonisin concentrations of maize-based foods. Mycotox Res. 1999; 15: 2-12.

98. Perkins DD. How should the interfertility of interspecies crosses be designated? Mycologia. 1994; 86: 758-761.

99. Castagnola EA, Garaventa A, Conte M, Barretta A, Faggi. E, Viscoli C. Survival after fungaemia due to *Fusariummoniliforme* in a child with neuroblastoma. Europ J Clini Microbio Inf Dis. 1993; 12: 308-309.

100. Verma J, Sridhara S, Rai D, Gangal SV. Isolation and immunobiochemical characterization of a major allergen (65 kDa) from *Fusarium equiseti*. Aller. 1998; 53: 311-315.

101. Grigis A, Farina C, Symoens F, Nolard N, Goglio A. Nosocomial pseudo-outbreak of *Fusariumverticilloides* associated with sterile plastic containers. Infect Cont Hosp Epidemiol. 2000; 21: 50-52.

102. Bodey GP, Boktour M, Mays S, Duvic M, Kontoyiannis D, Hachem R, et al. Skin lesions associated with *Fusarium* infection. J Ame Acad Dermatol. 2002; 47: 659-666.

103. Pujol I, Guarro J, Gene J, Sala F. Invitro antifungal susceptibility of clinical and environmental *Fusarium* species strains. J Antimicr Chemother. 1997; 39: 163-167.

104. Reuben AE, Anissie PE, Nelson PE, Hashem R, Legrand C, Ho WH, et al. Antifungal susceptibility of 44 clinical isolates of *Fusarium* species by using a broth microdilution method Antimicrob Agents Chemother. 1989; 33: 1647-1649.

105. Gross SM, Reddy RV, Rottinghaus GE, Johnson G, Reddy CS. Development effects of fumonisin B1 containing *Fusarium moniliforme* culture exstracts in CD1 mice. Mycopathol. 1994; 128: 111-118.

106. Gumprecht LA, Beaslet VR, Weigel RM, Parker HM, Tumbleson ME, Bacon CW, et al. Development of fumonisin-induced hepatoxicity

and pulmonary edema in orally dosed swine: morphological and biochemical alterations. Toxicol Pathol. 1998; 26: 777-788.

107. Javed T, Richard JL, Bennett GA, Dombrink-Kurtzman MA, Bunte RM, Koelkebeck KW, et al. Embryopathic and embryocidal effects of purified fumonisin B1 or *Fusarium proliferatum* culture material extract on chicken embryos. Mycopathol. 1993; 123: 185- 193.

108. Gelderblom WCA, Seier JV, Snijman PW, Van Schalkwyk DJ, Shepard GS, Marasas WFO. Toxicity of culture material of *Fusarium verticillioides* strain MRC 826 to nonhuman primates. Envi Health Perspect. 2001; 109: 267-276.

109. Kyung M, Shaojie L, Robert AE, Butchko MB, Robert HP, Mark B. FvVE1 regulates biosynthesis of the mycotoxins fumonisin *F. verticillioides*. J agri Food Chem. 2009; 57: 5089-5094.

Cite this article

Deepa N, Sreenivasa MY (2017) Fusarium verticillioides, a Globally Important Pathogen of Agriculture and Livestock: A Review. J Vet Med Res 4(4): 1084.