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Review Article

Fumonisins: A Review on its Global Occurrence, Epidemiology, Toxicity and Detection

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Abstract

Fumonisins are the phytotoxic mycotoxins mainly synthesized by species of *Fusarium* such as by *F. verticillioides* (formerly *Fusarium moniliforme=Gibberella fujikuroi*), *F. proliferatum*, *F. anthophilum*, *F. nygamai*, *F. oxysporum*, *F. globosum* and other species like *Alternaria alternate* among which *F. verticillioides* is the worldwide recognized species in production of fumonisin in association with cereals and cereal based food products. Worldwide contamination of foods and feeds with mycotoxins is a significant problem. Corn based foods and animal feeds are mainly associated with fumonisins due to N-fatty acylated fumonisin estimating free FB1 and total bound FB1 in corn foods and thebinding of fumonisins to cholestyramine which is a potential means of detoxification of animal feed. The economic impact of mycotoxins includes loss of human and animal life, increased health care and veterinary care costs, reduced livestock production, disposal of contaminated foods and feeds. Fumonisins arehighly carcinogenic, hepatotoxic, nephrotoxic and embryotoxic in animals and in humans fumonisins are associated with oesophageal cancer and neural tube defects.

ABBREVATIONS

ELEM: Equine Leukoencephalomalacia; ELISA: Enzyme Linked Immuno Sorbent Assay; RFLP: Restriction Fragment Length Polymorphism; RAPD: Random Amplified Polymorphic DNA; PROMEC: Programme on Mycotoxins and Experimental Carcinogenesis; IARC: International Agency for Research on Cancer; FAO: Food and Agriculture Organization; MRC: Medical Research Council; CSIR: Council for Scientific and Industrial Research; FB: Fumonisins; HPLC: High Performance Liquid Chromatography; TLC: Thin Layer Chromatography; LC: Liquid Chromatography; GC: Gas Chromatography; DESI: Desorption Electrospray Ionization; LCMS: Liquid Chromatography – Mass Spectrometers

INTRODUCTION

Fumonisins were first discovered in 1988 at Programme on Mycotoxins and Experimental Carcinogenesis (PROMEC) of the Medical Research Council (MRC) in Tygerberg, South Africa [1] and its chemical structure was first elucidated by Bezuidenhout et al. [2], in a collaborative effort between PROMEC and Council for Scientific and Industrial Research (CSIR) in Pretoria. Fumonisins are mainly associated with corn and corn based foods [3]. Till today 28 fumonisins have been isolated which further divides into four series such as A, B, C and P among which Fumonisin B found to be the major contaminant in cereals which subdivides into FB1, FB2, FB3 and FB4. Recently during food processing concerning to heat FB1 usually binds to proteins and other components in which the bound fumonisins were found to be common in processed corn foods, rice flour, corn starch and corn meal. *Aspergillus niger* was found to be the producer of FB2 from coffee and grapes, and FB4from coffee. Coffee beans, wine and beer were found to be the source of FB2 other than maize and sorghum [4].

FUMONISINS AND THEIR OCCURRENCE

FB1 comprises of 70% and found to be the most prominent worldwide attention seeking fumonisins compared to other FB2, FB3 and FB4 [5,6]. Fumonisins are ubiquitous in distribution and are found frequently on freshly harvested and stored agricultural commodities from many parts of the world. FB1 is not only associated with maize and corn based foods, but also found to be allied in rice, sorghum, pearl millet, beans, wheat noodles, curry, chili pickle, cowpea, triticale, asparagus [7], soya beans in japan [8], beer [9], red wine in Italy [10,11], cassava products in Tanzania [12], garlic [13,14], onion [13], black radish [15], black tea [16,17], figs in Turkey [18,19], peanuts in Ivoire, Cameroon in china [20], cow's milk in Italy, milk [21,22], eggs [23], meat [24] dietary and medicinal plants in South Africa, orange leaves, flowers of linden and chamomile in Portugal [16], mint, stinging nettle in Turkey [17], sage leaves, valerian root in Spain [25], and corn based brewing adjuncts.

Fumonisins contamination in maize has been increasing day to day since they are omnipresent in all the maize and maize based products like cereals, cornmeal, corn flakes [26], tortillas, tortilla chips in Italy [27], popcorn [28], sweet corn in Italy [29]. In India, certain reports documented FB1 contamination in maize and poultry feeds infected with *F. moniliforme* was found to be high in Haryana [30]. A study from Karnataka reported 59.20% of relative density with association of *F. verticillioides* from cereal samples collected in which 29 maize samples were infected with the *F. verticillioides* out of 61 maize samples [31].

STRUCTURE AND MECHANISM OF FUMONISINS

In 1988, chemical structure of fumonisins was explained and named as fumonisin B_1 (FB_1) and fumonisin B_2 (FB_2) respectively by Bezuidenhout et al.,[2]; Gelderbloom et al.[32]. *F. verticillioides* cultures were used to study the structure of fumonisins and later FB3 and FB4 were characterized [33,34]. Fumonisin B1 is white in color with the molecular formula $C_{34}H_{59}NO_{15}$, molecular weight 721g/mol and it is a hydroscopic powder soluble in water or methanol [Table 1]. Fumonisins due to its 4 carboxyl groups derived from glutamic acid, hydroxyl groups and amino group derived from serine and methyl groups derived from methionine are soluble in polar solvents and insoluble in organic solvents like chloroform and hexane [35]. FB1 and FB2 remain stable in methanol at –18°C and in acetonitrile-water (1:1) at 25°C for over a period of 6 months but degrades at 25°C and above.

Fumonisin B_1 resembles lipid sphingosine with 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 and has hydroxyl groups at C-3, C-5, C-10. FB_2 to FB_4 show different hydroxylation patterns. FB2 and FB3 exhibits isomers along with the hydroxyl groups at C-3, C-5 and C-3, C-10 and FB4 is similar to FB2 and FB3 except one lesser number of hydroxyl group [Figure 1]. Fumonisins A_1 and A_2 are N-acetyl derivates of FB_1 and FB_2 and FC_1 differs from FB_1 with lack of methyl group at C-1. Iso-FB1 was isolated from *F. moniliforme* NRRL 13613 which varies with FB1 in the location of hydroxyl group at C-4 instead of C-5 [36]. FB1 production occurs at the favorable conditions of polyketides and sesquiterpenes which imitates the synthesis of FB1 and FB2 backbones from independent polyketide. Fumonisins optimum production requires moderate water activity, limited nitrogen, high oxygen and low pH and its production doubles for every 48 hrs with increase in the mycelial dry weight [37].

Fumonisins structurally resembles sphingosine with its polyhydric alcohol moiety and its mechanism of action is mediated through inhibition of ceramide synthesis being a key enzyme disrupts entire sphingolipid metabolism in cells,

Table 1: Molecular weight and formula of Fumonisins.

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

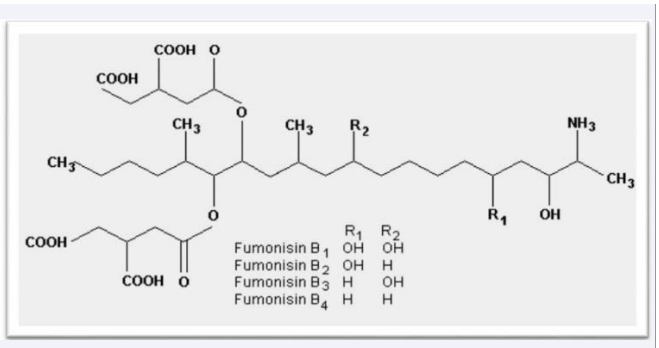

Figure 1 Chemical structure of Fumonisins.

tissues, hepatocytes, neurons and renal cells [38]. Sphingolipids biosynthesis occurs in endoplasmic reticulum by hydrolysis of complex sphingolipids to ceramides, and then to sphingosine, which is phosphorylated and cleaved to a fatty aldehyde and ethanolamine phosphate which is incorporated into phosphatidyl-ethanolamine [37]. This mechanism effects protein kinase activity on cell differentiation, cell growth, apoptosis and carcinogenicity. Sphingolipid biosynthesis can be altered since it leads an important role in diseases and carcinogenesis in DNA damage for FB1 [39].

TOXICITY AND EFFECTS OF FUMONISINS

Fumonisins causes toxicological effects in animals and humans since, sphingolipids exhibit complex role in cell function by affecting a great number of processes. Spingoid bases accumulation in cells causes inhibition of normal cells growth leading to cytotoxicity. They also inhibit protein kinase C, Na^+/K^+ ATPase and activate phospholipase D, activates or inhibits the enzymes involved in lipid signaling pathways and induce dephosphorylation of retinoblastoma protein. The above said processes generally increase the risk of cancer through apoptosis and lipid mediators that regulates cell proliferation [40]. Inhibition of ceramide synthesis resulted in accumulation of free sphingamine in liver, lung and kidney which is a hydrophobic compound that crosses cell membranes and will be present in blood and urine [38] [Figure 2]. The mechanism of FB1 in cell generally targets the liver and kidney in many of the animals by increased apoptotic and oncotic necrosis, regeneration and bile duct hyperplasia in case of liver.

Feeding horses with FB by intravenous injection and orally or with naturally contaminated corn, corn screenings and corn based feeds causes leukoencephalomalacia (LEM) in horses [41]. FB1 causes pulmonary edema syndrome (PES) and hydrothorax in pigs via intravenous injections or through the consumption of contaminated corn screenings [42]. During 1989-1990 PES in corn screenings outbreaks was reported in US with <1-330µg/g fumonisin B1 and <1-48µg/g of fumonisin B2 [43] [Table 2]. FB1 is classified as Group 2B carcinogen compound by International Agency for Research on Cancer (IARC) in 2002.Voss et al. [44], reported the HFB1 hydrolysis product of FB1 exhibiting sphingolipid metabolism without causing any neural tube defects in mouse model. Blood-brain barrier was permeated in young carp reporting the neurotoxicity of FB1 [45]. Oxidative stress genotoxicity in rats was mediated in the culture material with

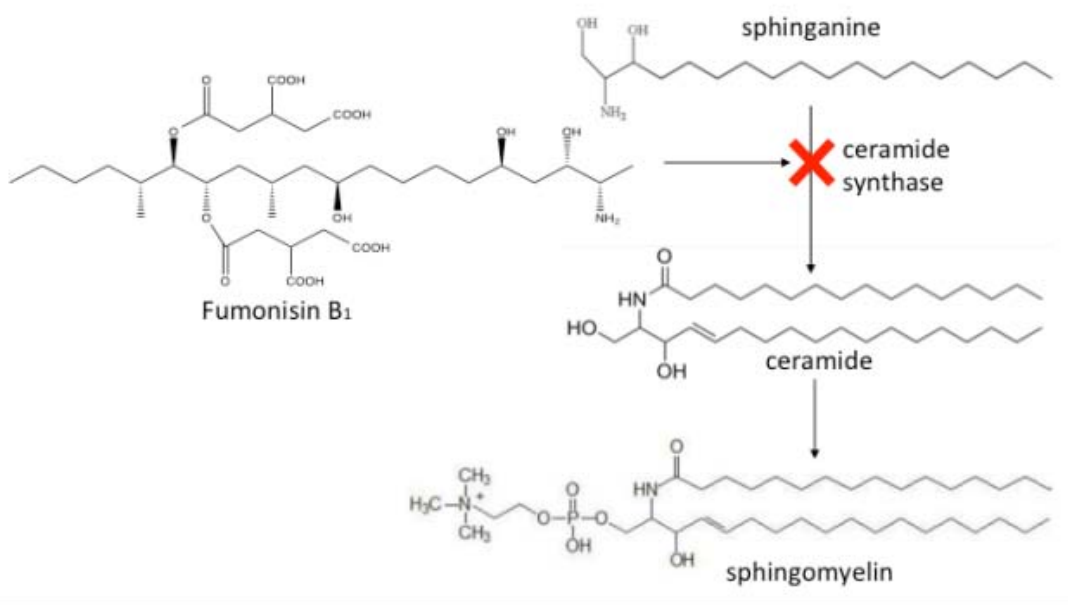

Figure 2 Representation of inhibition of ceramide synthase by Fumonisin B1 leading to accumulation of sphinganine.

Table 2: After effects of fumonisins on humans and animals.

Affected	After effects	Source
Horse	CNS, ELEM (Equine Leukoencephalomalacia)	Smith et al. [59],
Swine	PPE, Hepatotoxicosis, lesions in liver, lung targets to Pancreas, heart, oesophagus	Hollinger & Ekperigin [60]
Rats	Hepatic nodules, adenofibrosis, hepatocellular carcinoma, cholangiocarcinoma, hepatotoxins	Gross et al. [61],
Rabbit	Anorectic, lethargic, injures liver and kidney	Gumprecht et al. [62],
Chicken	Erythrocyte formation, lymphocyte cytotoxic effects, weight reduction, hepatic necrosis, biliary hyperplasia, thymic cortical atrophy.	Javid et al. [63],
Primates	Oesophagal cancer, reduction in WBC and RBC	Gelderblom et al. [64],
Humans	Esophageal cancer, skin lesions, wounds, keratitis.	Kyung et al. [65],

FB1 [46]. Two papers reported on the protective effects of teas and natural health products: royal jelly had protective effects against fumonisin toxicity in rats [47], and herbal teas (rooibos and honeybush) as well as black and green teas protected against cancer promotion by FB1 in rat liver [48].

In humans, corn associated with fumonisins or contaminated with *F. verticillioides* documents the high incidence of esophageal cancer in Transkei region of South Africa [49], Northern Italy [50], Linxhian region of China [51] and in South-eastern United and Golestan, a province in Iran [52]. Though the causal effects of oesophageal cancer are unknown, epidemiological studies suggests that FB1 is in association with neural tube defects by disrupting the folate receptors on membrane causing reduction in folate absorption among infants in Eastern Cape Province of South Africa, the Northern provinces of China and along the Texas-Mexico border in Northern America [53]. FB1 is hepatotoxic, nephrotoxic, hepatocarcinogenic and cancer promoting and initiating in rats and also found to be cytotoxic in mammalian cell [32,54-56] [Table 2].

Consumption of fumonisin has been associated with elevated human oesophageal cancer incidence in various parts of Africa, Central America, and Asia and among the black population in Charleston, South Carolina, USA. Since, fumonisin B1 reduces uptake of folate in different cell lines, fumonisin consumption has been implicated in neural tube defects in human babies. Some correlation studies have suggested a link between the consumption of maize with high incidence of *F. verticillioides* and fumonisins and the high incidence of human oesophageal carcinoma in certain parts of South Africa [57]. Fumonisins are also phytotoxic in which certain studies reported that FB1 were toxic at low concentration to broad leaf weeds including black nightshade, redroot, pigweed, duck weed, pricky sida, jimsonweed, sunflower, common cocklebur, hemp sesbania, soybean, venice mallow and spurred anode exhibiting chlorosis, necrosis, stunting, chlorophyll loss, growth inhibition and mortality symptoms [58].

DETECTION OF FUMONISINS

Most of the analytical and traditional methods were practiced for the detection of fumonisins such as chromatographic methods, immunological methods and molecular methods. Chromatographic methods involved Thin Layer Chromatography (TLC), Liquid Chromatography (LC) and Gas Chromatography

Table 3: List of Primers and genes targeted with its sequences.

Sl. No.	Primer Name	Sequence	Size (bp)	References
1	FUM1 F FUM1 R	5`- GTCGAGTTGTTGACCACTGCG3` 5`-CGTATCGTCAGCATGATAGC-3`	800	Bluhm et al. [84],
2	VER1 VER2	5′-CTTCCTGCGATGTTTCTCC 5′-AATTGGCCATTGGTATTATATATCTA	578	Mule et al. [91],
3	VERT-1 VERT-2	5'-GTCAGAATCCATGCCAGAACG-3' 5'-CACCCGCAGCAATCCATCAG-3'	800	Patino et al. [92],
4	VERTF-1 VERTF-2	5'-GCGGGAATTCAAAAGTGGCC-3' 5'-GAGGGCGCGAAACGGATCGG-3'	400	Patino et al. [92], Sreenivasa et al. [93],
5	FUM1F FUM1R	GAGCCGAGTCAGCAAGGATT AGGGTTCGTGAGCCAAGGA	90	Lopez – Errasquin et al. [94],
6	FUM1F FUM4R	GAGGCCCGAGCGAGCACTGG CCAGCCGCGGAAATTAGGGATGTG	1456	Baird et al. [87],
7	FUM5F FUM6R	GTCCTACGCGATACATCCCACCACAAT GATCAAGCTCGGGGCCGTCGTTCATAG	419	
8	FUM5F FUM4R	GTCCTACGCGATACATCCCACCACAAT CCAGCCGCGGAAATTAGGGATGTG	534	
9	FUM1F FUM6R	CGAGGCCCGAGCGAGCACTGG GATCAAGCTCGGGGCCGTCGTTCATAG	1340	
10	FV-F1 FV-R	5′-GTACAATCCCCCTGTTAAGG 5′-CACCCTGAGTGCCCTTGGTG	649	Faria et al. [88],
11	FV-F2 FV-R	5′-CACTGGTGGTAACGATGCG 5′-CACCCTGAGTGCCCTTGGTG	370	
12	FUM3F FUM3R	CTTGGCGGTGCCCATACTA GGACCAAGAGCGTGGATG	60	Rocha et al. [89],
13	FUM6F FUM6R	GATAGACTCGGGGCTGAGA AGCTCGCCGACAGAATC	100	
14	FUM7F FUM7R	CATCGTATCTACATTGTCGCATC TGTACTCTCCAACAATATGAATGAGTC	100	
15	FUM8F FUM8R	CAACAGAAATACGCAATGACG TGCTCGACCACTACATCAGG	99	
16	FUM13F FUM13R	GCCTTTGGTCTTGTTCTCTCA CGTCAATTATTGCCTCTTTCAA	100	
17	FUM14F FUM14R	TAGGTCCAGGTCGAGATGCT GGAAGCCAAGAACCCAATCT	99	
18	FUM15F FUM15R	TGCCATCCAGAATGACGATA GAGTCTCAGGAGAGCGAGGA	94	
19	FUM19F FUM19R	ATCAGCATCGGTAACGCTTATGA CGCTTGAAGAGCTCCTGGAT	88	

(GC) for separation and quantification [66,67]. The most common extraction method followed for fumonisins was High Performance Liquid Chromatography (HPLC) with fluorescent detection, separation and quantification based on intensity of fluorescence observed [68,69]. From past two decades' advancement in detection method was followed by introducing Liquid Chromatography – Mass Spectrometers (LC-MS) which was more sensitive and specific for detection and quantification with limit as low as 0.001µg/g of fumonisins along with disadvantage of high running and maintenance costs and the same instrumentation method has been followed in our present study. Developed analytical method such as a membrane-based colloidal gold immunoassay lateral flow test for the detection of FB1 was applied to govern the sum of all three FB1, FB2 and FB3 toxins in maize [70,71]. Molecularly imprinted Polymer (MIP) was developed to analyze FB1, FB2 and FB3 in pepper, rice and corn flakes and determined by LC-MS [72]. Desorption electron Spray Ionisation (DESI) is a mass spectrometric technique applied for analysis of FB1 from maize [73]. Fumonisins continue to be frequently associated as multi-mycotoxin assays in food and other commodities and were detected by LC-MS/MS [74].

The popular immunological method carried out commercially for screening fumonisins contamination is mainly by Enzyme Linked Immuno Sorbent Assay (ELISA) even though antibodies used here are raised against FB1 they show very low cross reactivity with FB2 and FB3 [75]. Dipstick, Biosensor and Immunoaffinity columns were the other immunological methods that were in practice for rapid detection of total fumonisins by direct fluorometric method [76].

Since the detection of *Fusarium* species itself is a very critical step, the prediction of its mycotoxigenic level in the isolates found to be more serious, hence the need for accurate and early detection of fumonisin producing *F. verticillioides* is more important with rapid, sensitive and reliable methods. Therefore, improved and quick methods such as DNA based identification methods and species-specific PCR assay for identifying fumonisin forming *Fusarium* species from cereals has become important, since fumonisins are now being implicated in diseases and cancer of animals [77,78], Ramana et al. [79], 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.

Between each copy of the 18S-5.8S-28S ribosomal DNA sequence within an intra-chromosomal repeat unit are non-transcribed spacers. The sequence of these segments is entirely free of selective constraint (ITS must continue to fold in such a way that nucleases can cut the transcript at the appropriate points). For this reason, the non-transcribed spacers (NTS), otherwise known as intergenic spacers (IGS) are sensitive markers of evolutionary change, tracking drift more rapidly than

the ITS. As with ITS they are thought to be under the constraint of concerted evolution, and so rapid change can only follow disruption of panmixis in a population. In their first study, Collins & Cunningham [80] amplified a range of fragments from the IGS. This makes it impossible to be sure how long the IGS is the longest fragment is 2.62 Kb but it is not clear how the fragments relate to each other, and it is possible that IGS of different lengths exist within the cassette.

Biochemical studies designated fumonisins as a product of polyketide synthase (PKS) gene FUM1 previously which was represented as FUM5 [81]. Gonzalez-Jaen et al. [82], demonstrated that genes Fum1 (=Fum5), Fum6, and Fum8 were only present in *F. verticillioides* and other *Fusarium* species asthe principle producers of fumonisins within the *G. fujikuroi* complex. Sanchez-Rangel et al. [83], 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. Fum1 gene with 7.8kb coding region or IGS located between 16S-23S rRNA genes for distinguishing between fumonisn producing and non-producing strains of *F. verticillioides* was successfully developed by multiplex PCR assay [84,85]. Multiplex PCR based methods was evaluated for potential fumonisin producing *Fusarium* species from traditional Morongo leafy vegetables in south Africa using a Fum1 gene encoding polyketide synthase for fumonisin B1 production along with EF-1 primer and was a potential method to obtain three fragments of appropriate sizes by multiplex PCR [86].

Baird et al. [87], tested 24 strains of *F. verticillioides* and other *Fusarium* species for its fumonisin production with four different sets of synthesized oligonucleotide primers such as Fum1F/ Fum4R, Fum5F/Fum6R, Fum5F/Fum4R/ Fum1F/Fum6R, among which primer Fum5F/Fum6R being a sensitive and accurate detector consistently amplified 419bp fragment from 96% DNA of all the *F. verticillioides* strains and 83% from *F. proliferatum*. Multiplex PCR method was developed to simultaneously detect *F. verticillioides* and *F. subglutians* in Brazil by developing a primer targeting gaoB gene coding for galactose oxidase and detected DNA from infected maize samples [88]. FB1 and FB2 production by *F. verticillioides* and its FUM genes Fum1, Fum3, Fum6, Fum7, Fum8, Fum13, Fum14, Fum15, Fum19 expression on *Bacillus thuringiensis* (Bt) and non-Bt maize during different periods of incubation was studied and all the FUM genes found to be expressed by *F. verticillioides* in all the tested samples indicating lower expression and weak association of FB1 in few Fum genes of Bt hybrids [89]. Recently a novel gene Fungal Unknown Gene 1 (FUG1) in *F. verticillioides* was reported through functional genetics which shows the deletion of FUG1 impairs the maize kernel colonization and fumonisin biosynthesis and also increases sensitivity to 2-benzoxazolinone and hydrogen peroxide indicating FUG1 key role in mitigating stress with host defence mechanism [90] [Table 3].

Molecular methods for the detection of fumonisins plays a wide key role since the industries demands for results in a minute which is an impossible request to be followed by conventional methods by taxonomists. Important methods followed for detection of toxigenic fumonisins producing *F. verticillioides* are polymerase chain reaction (PCR), Restriction fragment length polymorphism (RFLP) and Randomly Amplified Polymorphic DNA (RAPD) [95]. The use of PCR approaches has been already useful in epidemiological analyses [77] and are widely used in fungal taxonomy [87,96] and more recently they have been used for the detection of fungal pathogens in plant tissues [97]. PCR based methodology reported the genetic diversity and detected fumonisin producing *F. verticillioides* from Philippines using 800bp VERT1/VERT2 and 400bp VERTF-1/VERTF2 primers documenting 38 fumonisin producing *F. verticillioides* and five more isolates claimed to be *F. verticillioides* through TEF sequences, morphology and sexual crosses, were negative by Universally Primer-PCR (UP-PCR) [98]. Several other researchers have also employed DNA based techniques for the detection of *Fusarium* species [81,92,99-102,]. Many numbers of genus specific, species specific and fumonisin specific primers were used to detect *F. verticillioides* through PCR assays was developed [77,85,95,100-104].

Some conventional qualitative PCR approaches for detection of *Fusarium* species have been reported [91,105,106]. *F. culmorum* was specifically detected in cereal samples by nested PCR [107] in a single closed tube with OPT18F/R describing it was approximately 100 times more sensitive than another PCR method. Similarly, many researchers have been conducted for detection of *Fusarium solani* in soybean roots with single or in combination of primers FSg1/FSg2, FsgEF1/FsgEF2 primers [108], in ocular samples using Fusofor/Fusorev primers [109], *F. oxysporum* in artificial and natural soil by using WiltNF-1/ WiltNR-1 primers [110], in basil [111] and *F. niveum* in soil and infected plant tissues using Fn-1/Fn-2 set of primers [112] by nested PCR method. Among the four targeted genes norI, Tri6, Fum13, Otanps; norI found to be stable intermediate that encodes for norsolorinic acid reductase involved in aflatoxin biosynthesis by multiplex PCR [112]. In recent days multiplex PCR assay could be a supplementary strategy to current conventional mycotoxin analytical techniques such as TLC, HPLC and a reliable tool for high throughput monitoring of major mycotoxin producing fungi during processing steps of food and feed commodities [113]. Real-Time PCR is more sensitive and specific for the detection and quantification of toxigenic fungi. The real-time PCR could detect as little as 300fg of genomic DNA It can also identify symptomless infections with higher sensitivity than conventional PCR [114]. However, real time PCR assay is not so cost effective and needs costly equipment as well as reagents. A PCR method was developed by Murillo et al. [115], to detect *F. verticillioides* from naturally infected maize seeds directly. PCR method found to be important since the killed fungi can also be detected as an advantage. Since a decade Real-time PCR, a new method which is more sensitive and specific for detection and quantification of toxigenic fungi [116]. In a study two new PCR methods have been developed such as nested PCR and multiplex PCR from the *F. verticillioides* isolates and sensitivity test for the developed kits were carried out directly from the cereals and its plant parts for the early detection of fumonisin producing *F. verticillioides* [117,118].

Mycotoxicological and pathogenic characterization of fungal plant pathogens can be complemented by fingerprinting. Wide range of pathogenicity in terms of effect on seed germination, seedling development and of symptoms produced on detached

leaves, which were not correlated with the different *in vitro* fumonisin production. Amplified Fragment Polymorphisms Analysis (AFLP) analysis indicated the presence of genetic diversity not only between Italian strains and the American reference but also among the Italian isolates [119]. Restriction Fragment Length Polymorphism (RFLP) and Random Amplified Polymorphic DNA (RAPD) can also reveal genetic variability between different species and within the same species, giving us information about genetic differences which could correspond to different mycotoxicological or pathogenic profiles [120,121]. Visentin et al. [122], described the ITS-RFLP discrimination between *F. verticillioides* and *F. proliferatum*. Schlacht et al. [123], analyzed the DNA of members of *Fusarium* species belonging to mating populations A, D, and E, the teleomorphs of *F. verticillioides*, *F. proliferatum* and *F. subglutinans*, respectively. RFLP reports the intraspecific variability in Intergenic spacer regions (IGS) and based on specific sequences of RAPD fragments specific primers were developed for *F. verticillioides* [84,124]. A total of 33 *F. verticillioides* strains from different origin and hosts were analyzed for fumonisin production and characterized by PCR-RFLP to detect variations and to discriminate among isolates [92]. Kerengy [125] in their study through RFLP studies reported that groups of fumonisin non - producing strains had less variations than the fumonisin producing group of strains.

RAPD has been reported to be an intense method to identify the genotypic differences using short oligodeoxynucleotides primersamong the fungal species [126]. RAPD was mainly used to correlate taxa based differences among its morphology, physiology, its toxin production and to distinguish fungal species and its pathogenicity variations within the species [127]. RAPD was not sensitive enough to detect fumonisin producing fungi hence, specific primers from known sequences of genes producing fumonisin was investigated and compared DNA based strategies for identification of fumonisin producing and non-producing strains [128,84]. Moeller et al. [124], reported the identification *F. verticillioides* and *F. subglutinans* based on sequences of RAPD fragments that were successively applied for the analysis of infected maize kernels. However, although RAPDs have been widely used as diagnostic tools in many laboratories for the identification of *Fusarium* species [129] they are considered not very reliable because of the lack of reproducibility of the technique. Among 3840 maize kernels tested in southern Brazil 77% were contaminated with *Fusarium* species in which *F. verticillioides* was the most prevalent species with 98% infection and approximately 95% of *F. verticillioides* isolates found to harbor the essential genes for fumonisin biosynthesis (FUM1 and FUM8) also its genetic structure was also investigated by AFLP revealing high genetic variability [130]. To avoid these cumbersome methods faster diagnostic method such as polymerase chain reaction (PCR) protocols have emerged as useful and rapid techniques.

CONCLUSION

Mycotoxins usually enter the body through ingestion of contaminated foods, but inhalation of toxigenic spores and direct dermal contact are also important routes to enter the body. Cereals and cereal based food products are significant in our food chain. Cereal grains are grown in greater quantities and provide more food energy worldwide than any other type of crop. Worldwide cereal production is of 2534MT in which Indian production is 245.5MT among which 1104MT cereals are consumed as food by Humans and 876 MT in the form of feed for animals which finally in turn will be consumed as meat by humans. The significant risk of contamination of such cereal based foods and feeds by fumonisins receives the most attention as it is a potential carcinogen of global concern. On consumption of such contaminated cereals mainly affects or targets liver, lung and kidney in animals and skin lesions, wounds and life-threatening cancer to humans. Well-developed methods have been followed for the early and rapid detection of toxigenic fumonisins to monitor the occurrence of these mycotoxins. Only the continued research on understanding the effects and modes of mycotoxin action in various species, have regulations been forthcoming.

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REFERENCES

1. Marasas WFO. Discovery and occurrence of the fumonisins: a historical perspective. Environ Health Perspect. 2001; 109: 239–243.
2. 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 Commun. 1988; 743-745.
3. Weidenborner M. Foods and fumonisins. Eur Food Res Technol. 2001; 212: 262-273.
4. Scott PM. Recent research on fumonisins: a review. Food Addit Cont. 2012; 23: 242-248.
5. Soriano JM, Gonzalez L, Catala AI. Mechanism of action of splingolipids and their metabolites in the toxicity of fumonisin B1. Prog Lipid Res. 2005; 44: 345-356.
6. Wang J, Zhou Y, Liu W, Zhu X, Du L, Wang Q. Fumonisin level in corn-based food and feed from Linxian Country, a high-risk area for esophageal cancer in China. Food Chem. 2008; 106: 241-246.
7. Soriano JM, Dragacci S. Occurrence of fumonisins in foods. Food Res Int. 2004; 37: 985-1000.
8. Aoyama K, Nakajima M, Tabata S, Ishikuro E, Tanaka T, Norizuki H, et al. Four-year surveillance for ochratoxin A and fumonisins in retail foods in Japan. J Food Prot. 2010; 73: 344-352.
9. Shephard GS, Vander-Westhuizen L, Gatyeni PM, Somdyala NIM, Burger HM, Marasas WFO. Fumonisin mycotoxins in traditional Xhosa maize beer in South Africa. J Agri Food Chem. 2005; 53: 9634-9637.
10. Logrieco A, Ferracane R, Haidukowsky M, Cozzi G, Visconti A, Ritieni A. Fumonisin B2 production by Aspergillus niger from grapes and natural occurrence in must. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 2009; 26: 1495-1500.
11. Logrieco A, Ferracane R, Visconti A, Ritieni A. Natural occurrence of fumonisin B2 in red wine from Italy. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 2010; 27: 1136-1141.
12. Manjula K, Hell K, Fandohan P, Abass A, Bandyopadhyay R. Aflatoxin and fumonisin contamination of cassava products and maize grain from markets in Tanzania and republic of the Congo. Toxin Rev. 2009; 28: 63-69.

13. Boonzaaijer G, van Osenbruggen WA, Kleinnijenhuis AJ, van Dongen WD. An exploratory investigation of several mycotoxins and their natural occurrence in flavouringredients and spices, using a multi-mycotoxin LC-MS/ MS method. World Mycotoxin J. 2008; 1: 167-174.

14. Seefelder W, Gossmann M, Humpf HU. Analysis of fumonisin B1 in Fusarium proliferatum-infected asparagus spears and garlic bulbs from Germany by liquid chromatography-electrospray ionization mass spectrometry. J Agric Food Chem. 2002; 50: 2778-2781.

15. Di Mavungu JD, Monbaliu S, Scippo ML, MaghuinRogister G, Schneider YJ, Larondelle Y, et al. LC-MS/ MS multi-analyte method for mycotoxin determination in food supplements. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 2009; 26: 885-895.

16. Martins ML, Martins HM, Bernardo F. Fumonisins B1 and B2 in black tea and medicinal plants. J Food Prot. 2001; 64: 1268-1270.

17. Omurtag GZ, Yazicioglu D. Determination of fumonisins B1 and B2 in herbal tea and medicinal plants in Turkey by high-performance liquid chromatography. J Food Prot. 2004; 67: 1782–1786

18. Senyuva HZ, Gilbert J. Identification of fumonisin B2, HT-2 toxin, patulin, and zearalenone in dried figs by liquid chromatography-time-of-flight mass spectrometry and liquid chromatography-mass spectrometry. J Food Prot. 2008; 71: 1500–1504.

19. Karbancioglu-Gu ler F, Heperkan D. Natural occurrence of fumonisin B1 in dried figs as an unexpected hazard. Food ChemToxicol. 2009; 47: 289–292.

20. Njobeh PB, Dutton MF, Koch SH, Chuturgoon AA, Stoev SD, Mosonik JS. Simultaneous occurrence of mycotoxins in human food commodities from Cameroon. Mycotoxin Res. 2010; 26: 47–57.

21. Gazzotti T, Lugoboni B, Zironi E, Barbarossa A, Serraino A, Pagliuca G. Determination of fumonisin B1 in bovine milk by LC-MS/MS. Food Control. 2009; 20: 1171–1174.

22. Richard JL, Meeridink G, Maragos CM, Tumbleson M, Bordson G, Rice LG, et al. Absence of detectable fumonisins in the milk of cows fed with *Fusarium proliferatum* (Matsushima) Nirenberg culture material. Mycopathologia. 1996; 133: 123-126.

23. Vudathala DK, Prelusky DB, Ayround M, Trenholm HL, Miller JD. Pharmacokinetic fate and pathological effects of ^{14}C-fumonisin B_1 in laying hens. Nat Toxins. 1994; 2: 81-88.

24. Prelusky DB, Miller JD, Trenholm HL. Disposition of ^{14}C-derived residues in tissues of pigs fed radiolabelled fumonisin B1. Food Addit Contam. 1996; 13: 155-162.

25. Santos L, Marın S, Sanchis V, Ramos AJ. Screening of mycotoxin multicontamination in medicinal and aromatic herbs sampled in Spain. J Sci Food Agric. 2009; 89: 1802–1807.

26. Stack ME. Analysis for fumonisin B1 in Tortillas and Tortilla chips using immunoaffinity column and liquid chromatography. J Assoc Off Anal Chem Int. 2009; 75: 634-640.

27. Doko MB, Visconti A. Occurrence of fumonisin B1 and B2 in corn and corn-based human food stuff in Italy. Food Addit Contamin. 1994; 11: 433-439.

28. Bullerman LB, Tsai WYJ. Incidence and levels of *Fusarium moniliforme*, *Fusarium proliferatum*, and fumonisins in corn and corn-based foods and feeds. J Food Prot. 1994; 57: 541-546.

29. Trucksess MW, Stack ME, Allen S, Barrion N. Immunoaffinity column coupled with liquid chromatography for the determination of fumonisin B1 in canned and frozen sweet corn. J AOAC Int. 1995; 78: 705-710.

30. Jindal N, Mahipal SK, Rottinghaus GE. Occurrence of fumonisin B1 in maize and poultry feeds in Haryana, India. Mycopathologia. 1999; 148: 37-40.

31. Deepa N, Nagaraja H, SreenivasaMY. Prevalence of fumonisin producing *Fusarium verticillioides* associated with cereals grown in Karnataka (India). FSHW. 2016; 5: 156-162.

32. 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 Envion Microbiol. 1988; 54: 1806-1811.

33. Plattner RD, Weisleder D, Shackelford DD, Peterson R, Powell RG. A new fumonisin from solid cultures of *Fusarium moniliforme*. Mycopathologuia. 1992; 117: 23-28.

34. Blackwell BA, Miller JD, Savard ME. Production of carbon 14-labelled fumonisin in liquid culture. J AOAC Int. 1994; 77: 506-511.

35. Mackenzie SE, Blackwell BA, Miller JD, Apsimon JW. Isolation of a new fumonisin from *Fusarium moniliforme* grown in liquid culture. J natu prod. 1998; 61: 367-369.

36. Miller JD, Savard ME, Rapior S. Production and purification of fumonisins from a stirred jar fermentor. Nat Toxins. 1994; 2: 354-359.

37. 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. Natutox. 1996; 4: 3-15.

38. Smith ER Jr, Merrill AH. Differential roles of de novo sphingolipid biosynthesis and turnover in the "burst" of free sphingosine and sphinganine, and their 1-phosphates and n-acyl-derivates, that occurs upon changing the medium of cells in culture. J Biol Chem. 1995; 270: 18749-18758.

39. Domijan AM, Zeljezic D, Milic M, Peraica M. Fumonisin B1: Oxidative status and DNA damage in rats. Toxicology. 2007; 232: 163-169.

40. 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.

41. Ross PF, Ledet AE, Owens DL, Rice LG, Nelson HA, Osweiler GD, et al. Experimental equine leukoencephalomalacia, toxic hepatosis, and encephalopathy caused by corn naturally contaminated with fumonisins. J Vet Diagn Invest. 1993; 5: 69-74.

42. Colvin BM, Harrison LR. Fumonisin-induced pulmonary edema and hydrothorax in swine. Mycopathologuia. 1992; 117: 79-82.

43. Ross PF, Rice LG, Osweiler GD, Nelson HA, Richards JL, Wilson TM. A review and up-date of animal toxicoses associated with fumonisin contaminated feeds and production of fumonisins by *Fusarium* isolates. Mycopathologuia. 1992; 117: 109-114.

44. Voss KA, Riley RT, Snook ME, Waes JG. Reproductive and sphingolipid metabolic effects of fumonisin B1 and its alkaline hydrolysis product in LM/Bc mice: hydrolyzed fumonisin B1 did not cause neural tube defects. Toxicol Sci. 2009; 112: 459-467.

45. Kovacic S, Pepeljnjak S, Petrinec Z, Klaric MS. Fumonisin B1 neurotoxicity in young carp (Cyprinus carpio L.). Arh Hig Rada Toksikol. 2009; 60: 419-426.

46. Theumer MG, Canepa MC, Lopez AG, Mary VS, Dambolena JS, Rubinstein HR. Subchronicmycotoxicoses in wistar rats: assessment of the invivo and invitro genotoxicity induced by fumonisins and aflatoxin B (1), oxidative stress biomarkers status. Toxicol. 2010; 268: 104-110.

47. El-Nekeety AA, El-Kholy W, Abbas NF, Ebaid A, Amra HA, Abdel-Wahhab MA. Efficacy of royal jelly against the oxidative stress of fumonisin in rats. Toxicon. 2007; 50: 256-269.

48. Marnewick JL, van der Westhuizen FH, Joubert E, Swanevelder S, Swart P, Gelderblom WC. Chemoprotective properties of rooibos (Aspalathuslinearis), honeybush (Cyclopia intermedia) herbal and green and black (Camellia sinensis) teas against cancer promotion induced by fumonisin B1 in rat liver. Food ChemToxicol. 2009; 47: 220–229.

49. Thiel PG, Marasas WFO, Sydenham EW, Shephard GS, Gelderblom WCA. The implications of naturally occurring levels of fumonisins in corn for human and animal health. Mycopathologuia. 1992; 117: 3-9.

50. Fransceschi, Bidoldi SE, Baron AE, La Vecchia, C. Maize and risk of cancers of the oral cavity, pharynx, and oesophagus in Northeastern Italy. J Natl Cancer Inst. 1990; 82: 1407-1411.

51. Chu FS, Li GY. Simultaneous occurrence of fumonisin B_1 and other mycotoxins in moldy corn collected from People's Republic of China in regions with high incidence of esophageal cancer. Appl Environ Microbiol. 1994; 60: 847-852.

52. Alizadeh AM, Rohandel G, Roudbarmohammadi S, Roudbary M, Sohanaki H, Ghiasian SA, et al. Fumonisin B1 contamination of cereals and risk of esophageal cancer in a high risk area in north eastern Iran. Asian Pac J Cancer Prev. 2012; 13: 2625-2628.

53. Missmer SA, Suarez L, Felkner M, Wang E, Merrill AH Jr, Rothman KJ, et al. Exposure to fumonisins and the occurrence of neural tube defects along the Texas–Mexico border. Environ Health Perspect. 2006; 114: 237–241.

54. Gelderblom WCA, Cawood ME, Snyman SD, Marasas WFO. Fumonisin B1 dosimetry in relation to cancer initiation in rat liver. Carcinogenesis. 1994; 15: 209-214.

55. Voss KA, Chamlerlain WJ, Bacon CW, Norred WP. A preliminary investigation on hepatic toxicity in rats fed purified fumonisin B_1. Nat Toxins. 1993; 1: 222-228.

56. Voss KA, Chamberlain WJ, Bacon CW, Herbert RA, Walters DB, Norred NP. Subcronic feeding study of the mycotoxin fumonisin B1 in B6C3F1 mice and Fischer 344 rats. Fundam Appl Toxicol. 1995; 24: 102-110.

57. Marasas WFO, Riley RT, Hendricks KA, Stevens VL, Sadler TW, Gelineau-van Waes J, et al. Fumonisins disrupt sphingolipid metabolism, folate transport, and neural tube development in embryo culture and in vivo: a potential risk factor for human neural tube defects among populations consuming fumonisin contaminated maize. J Nutr. 2004; 134: 711-716.

58. Abbas HK, Ocamb CM, Xie W, Mirocha CJ. First report of Fumonisn B_1, B_2 and B_3 production by *Fusarium oxysporum var. redolens*. Plant Dis. 1995; 79: 968.

59. 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. Am J Vet Res. 2002; 63: 538-545.

60. Hollinger K, Ekperigin HE. Mycotoxicosis in food producing animals. Veterinary Clinics of North America. Vet Clin North Am Food Anim Pract. 1999; 15: 133-165.

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

62. 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.

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

64. 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. Environ Health Perspect. 2001; 109: 267-276.

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

66. Musser SM, Eppley RM, Trucksess MW. Electrospray mass spectrometry for fumonisin detection and method validation. Adv exp medic biol. 2002; 504: 95-105.

67. Anonymous. Council for Agricultural Science and Technology (CAST). Mycotoxins: Risks in plant, animal, and human systems, Ames, USA. 2003.

68. Trucksess MW. Mycotoxins. J Assoc off Anal Chem Int. 1998; 81:128-137.

69. Trucksess MW. General Referee Replicateorts: Committee on Natural Toxins and Food Allergens: Mycotoxins. J Assoc off Ana Chem Int. 2003; 86: 1-10.

70. Wang S, Quan Y, Lee N, Kennedy IR. Rapid determination of fumonisin B1 in food samples by enzyme-linked immunosorbent assay and colloidal gold immunoassay. J Agri Food Chem. 2006; 54: 2491-2495.

71. Molinelli A, Grossalber K, Krska R. A rapid lateral flow test for the determination of total type B fumonisins in maize. Anal Bioanal Chem. 2009; 395: 1309-1316.

72. De smet D, Dubruel P, Van Peteghem C, Schacht E, De Saeger S. Molecularly imprinted solid-phase extraction of fumonisin B analaouges in bell pepper, rice and corn flakes. Food Addit Contam. 2009; 26: 874-84.

73. Maragos CM, Busman M. Rapid and advanced tools for mycotoxin analysis: a review. Food Addit Contam A. 2010; 27: 688-700.

74. Zachariasova M, Lacina O, Malachova A, Kostelanska M, Poustka J, Godula M, et al. Novel approaches in analysis of Fusarium mycotoxins in cereals employing ultra performance liquid chromatography coupled with high resolution mass spectrometry. Anal Chim Acta. 2010; 662: 51-61.

75. Kulisek ES, Hazebroek JP. Comparison of extraction buffers for the detection of fumonisin B_1 in corn by immunoassay and high-performance liquid chromatography. J Agric Food Chem. 2000; 48: 65-69.

76. Mullett W, Lai EPC, Yeung JM. Immunoassay of fumonisins by a surface plasmon resonance biosensor. Anal Biochem. 1998; 258: 161-167.

77. Jurado M, Vazquez C, Marin S, Sanchis V, Gonzalez-Jaen MT. PCR-based strategy to detect contamination with mycotoxigenic *Fusarium* species in maize. Syst Appl Microbiol. 2006; 29: 681-689.

78. Petrovic T, Walsh JL, Burgess LW, Summerell BA. *Fusarium* species associated with stalk rot of grain sorghum in the northern grain belt of eastern Australia. Australas Plant Pathol. 2009; 38: 373-379.

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

80. Collins CM, Cunningham CO. Characterization of the *Gyrodactylus salaris* Malmberg, 1957 (Platyhelminthes: Monogenea) ribosomal intergenic spacer (IGS) DNA. Parasitology. 2000; 121: 555-563.

81. Proctor RH, Brown DW, Plattner RD. Desjardins AE. Co-expression of 15 contiguous genes delineates a fumonisin biosynthetic gene cluster

in *Gibberella moniliformis*. Fungal Genet Biol. 2003; 38: 237-249.

82. 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*. Euro J Plant Pathol. 2004; 110: 525-532.

83. 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.

84. Bluhm BM, Cousin MA, Woloshuk CP. Multiplex real-time PCR detection of fumonisin producing and trichothecene-producing groups of *Fusarium Spp*. J Food Prot. 2004; 67: 536-543.

85. Patino B, Mirete S, González-Jaen MT, Mule G, Vázquez C. PCR detection assay of fumonisin-producing *Fusarium verticillioides* stains. J Food Protect. 2004; 67: 1278-1283.

86. Bezuidonhout SC, Prinsloo M, Vanderwalt AM. Multiplex PCR-based detection of potential fusarium producing Fusarium in traditional African vegetables. Environ Toxicol. 2006; 21: 360-366.

87. Baird R, Abbas HK, Windham G, Williams P, Baird S, Ma P, et al. Identification of Select Fumonisin Forming *Fusarium* Species Using PCR Applications of the Polyketide Synthase Gene and its Relationship to Fumonisin Production *in vitro*. Int J Mol Sci. 2008; 9: 554-570.

88. Faria CB, Abe CAL, Novais da- silva C, Tessmann DJ, Barbosa-Tesmann LP. New PCR Assays for the Identification of *Fusarium verticillioides*, *Fusarium subglutinans*, and Other Species of the *Gibberella fujikuroi* Complex. Int J Mol Sci. 2012; 13: 115-132.

89. Rocha LO, Barroso VM, Andrade LJ, Pereira GHA, Ferreira-Castro FL, Duarte AP, et al. FUM Gene Expression Profile and Fumonisin Production by *Fusarium verticillioides* Inoculated in Bt and Non-Bt Maize. Front microbiol. 2016; 6: 1503

90. Ridenour JB, Bluhm BH. The novel fungal-specific gene FUG1 has a role in pathogenicity and fumonisin biosynthesis in *Fusarium verticillioides*. Mol Plant Pathol. 2017; 18: 513-528.

91. Mule G, Susca A, Stea G, Moretti A. A species-specific assay based on the calmodulin partial gene for identification of *Fusarium verticillioides*, *Fusarium proliferatum* and *Fusarium subglutinans.* Eur J Plant Pathol. 2004; 110: 495-502.

92. Patino B, Mirete S, Vazquez C, Jimenez M, Rodriguez MT, Gonzalez-Jaen MT. Characterization of *F. verticillioides* strains by PCR-RFLP analysis of the intergenic spacer region of the rDNA. J Sci Food Agri. 2006; 86: 429-435.

93. Sreenivasa MY, Jaen MTG, Dass RS, Charith Raj AP, Janardhana GR. A PCR based for the detection and differentiation of potential fumonisi n-producing *Fusarium verticillioides* isolated from Indian Maize kernels. Food Biotechnol. 2008; 22: 160-170.

94. Lopez-Errasquin E, Vazquez C, Jimenez M, Gonzalez-Jaen MT. Real-TimeRT-PCR assay to quantify the expression of FUM1 and FUM19 genes from the fumonisin-producing *Fusarium verticillioides.* J Microbiol Met. 2007; 68: 312-317

95. Nicholson P, Chandler E, Draeger RC, Gosman NE, Simpson DR, Thomsett M, et al. Molecular tools to study epidemiology and toxicology of *Fusarium* head blight of cereals. Eur J Plant Pathol. 2003; 109: 691-703.

96. Chandra NS, Udaya Shankar AC, Niranjana SR, Prakash HS. Molecular detection and characterisation of *Fusarium verticillioides* in maize (*Zea mays*. L) grown in southern India. Annals of Microbiol. 2008; 58: 359-367.

97. Chandra NS, Udaya Shankar AC, Niranjana SR, Wulff EG, Mortensen CN, Prakash HS. Detection and quantification of fumonisins from *Fusarium verticillioides* in maize grown in southern India. World J Microbiol Biotechnol. 2010; 26: 71-78.

98. Magculia NJF, Cumagun JR. Genetic diversity and PCR-based identification of potential fumonisin-producing *Fusarium verticillioides* isolates infecting corn in the Philippines. Trop Plant Pathol. 2011; 36: 225-232.

99. Abd-Elsalam KA, Aly NI, Abdel-Satar AM, Khalil SM, Verreet AJ. PCR identification of *Fusarium* genus based on nuclear ribosomal-DNA sequence data. Afr J Biotechnol. 2003; 2: 82-85

100. Mishra PK, Fox RTV, Chulham A. Inter-simple sequence repeat and aggressiveness analyses revealed high genetic diversity, recombination and long-range dispersal in *Fusarium culmorum.* Annals Appl Biol. 2003; 143: 291-301.

101. Mirete S, Vazquez C, Mule G, Jurando M, Gonzalez-Jaen MT. Differentiation of *Fusarium verticillioides* from banana fruits by IGS and EF-1α sequence analyses. Eur J Plant Pathol. 2004; 110: 515-523.

102. 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.

103. Grim C, Geisen R. A PCR-ELISA for the detection of potential fumonisin-producing *Fusarium* species. Lett Appl Microbiol. 1998; 26: 456-462.

104. Jurado M, Vazquez C, Patiño B, Gonzalez Jaen MT. PCR detection assays for the trichothecene-producing species *Fusarium graminearum*, *Fusarium culmorum*, *Fusarium poae, Fusarium equiseti* and *Fusarium sporotrichioides*. Syst Appl Microbiol. 2005; 28: 562-568.

105. Sreenivasa MY, Dass RS, Charith Raj AP, Janardhana GR. PCR method for the detection of genus *Fusarium* and Fumonisin producing isolates from freshly harvested sorghum grains grown in Karnataka, India. J Food Saf. 2008; 28: 236-247.

106. Klemsdal SS, Elen O. Development of a highly sensitive nested PCR method using a single closed tube for detection of *F. culmorum* in cereal samples. Lett Appl Microbiol. 2006; 42: 544-548.

107. Li S, Haitman GL. Molecular detection of *F. solani* f. sp. Glycines in soyabean roots and soil. Plant Pathol. 2003; 52: 74-83.

108. Emma EMJ, Nora MC, Sarah C, Anthony ASD, Hamish MAT, Melville MM, et al. Rapid detection and identification of *Candida*, *Aspergillus* and *Fusarium* species in ocular samples using nested PCR. J Clini Microbiol. 2000; 38: 2902.

109. Garcia P, Bainbridge BW, Heala JB, Perez AE, Jimenez DRM. A simple PCR based method for the detection of the chickpea-wilt pathogen *Fusarium oxysporum* f.sp. *ciceris* in artificial and natural soils. Euro J Plant Pathol. 1999; 105: 251-259.

110. Chiocchetti A, Sciaudone L, Durando F, Garibaldi A, Migheli Q. PCR detection of Fusarium oxysporum f. sp. basilici on basil. Plant Dis. 2001; 85: 607-611.

111. Zhenggang Z, Jingyu Z, Yucoo W, Xiaobo Z. Molecular detection of *F. oxysporum, F. niveum* and*Mycospaerellameloxis* in infected plant tissues and soil. FEMS Microbiol Lett. 2005; 249: 39-47.

112. Rashmi R, Ramana MV, Shylaja R, Uppalapati SR, Murali HS, Batra HV. Evaluation of a multiplex PCR assay for concurrent detection of four mycotoxigenic fungi from foods. J Appl Microbiol. 2013; 114: 819-827.

113. Ginzinger DG. Gene quantification using real-time quantitative PCR:

An emerging technology hits the mainstream. Exp Hematol. 2002; 30: 503-512.

114. Schaad NW, Frederick RD. Real-time PCR and its application for rapid plant disease diagnostics. Cana J Plant Pathol. 2002; 24: 250-258.

115. Murillo I, Cavallarin L, San Segundo B. The development of a rapid PCR assay for detection of *Fusarium moniliformae*. Eur J Plant Pathol. 1998; 104: 301-311.

116. Schena L, Nigro F, Ippolito A, Gallitelli D. Real-time quantitative PCR: A new technology to detect and study phytopathogenic and antagonistic fungi. Eur J Plant Pathol. 2004; 110: 893-908.

117. Deepa N, Charith Raj Adkar-Purushothama, SreenivasaMY. 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.

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

119. Covarelli L, Stifano S, Beccari G, Raggi L, Veronica Maria Teresa, Lattanzioc, Emidio Albertinib. Characterization of *Fusarium verticillioides* strains isolated from maize in Italy: fumonisin production, Pathogenecity and genetic variability. Food Microbiol. 2012; 31: 17-24.

120. Moretti A, Mule G, Susca A, Gonzalez-Jaen MT, Logrieco A. Toxin profile, fertility and AFLP analysis of *F. verticillioides* from banana fruits. Eur J Plant Pathol. 2004; 110: 601-609.

121. Reynso NN, Chulze SN, Zeller KA, Torres AM, Leslie JF. Genetic structure of *F. verticillioides* populations isolated from maize in Argentina. Eur J Plant Pathol. 2009; 123: 207-215.

122. Visentin I, Tamietti G, Valentino D, Portis E, Karlovsky P, Moretti A, et al. The ITS region as a taxonomic discriminator between Fusarium verticillioides and Fusarium proliferatum. Mycol Res 2009; 113: 1137-1145.

123. Schlacht UF, Moller EM, Geiger HG. Genetic diversity of *Gibberella fujikuroi* isolates from different geographic origins. Proceedings of the 5th European *Fusarium* seminar. Cereal Res Commun. 1997; 25: 557-600.

124. Moeller EM, Chelkowski J, Geiger HH. Species-specific PCR assays for the fungal pathogens *Fusarium moniliforme* and *Fusarium subglutinans* and their application to diagnose maize ear rot. J Phytopathol. 1999; 147: 497-508.

125. Kerengy Z, Zeller K, Hornok L, Leslie JF. Molecular standardization of mating type terminology in the *Gibberella fujikuroi* species complex. Appl Envi Microbiol. 1999; 65: 4071-4076.

126. Williams JGK, Kubelik AR, Rafalski JA, Tingey SV. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucleic Acids Res. 1990; 18: 6531-6535

127. Zhang AW, Riccioni GL, Chen L, Ma WD, Petersen WL. Using PCR to distinguish Diaporthephaseolorum and Phompsislongicolla from other soybean fungal pathogens and to detect them in soybean tissues. Plant Dis. 1997; 81: 1143-1149.

128. Waalwijk C, Van der Heide R, deVries I, Van der Lee T, Schoen C, Costrel-de Corainville G, et al. Quantitative detection of Fusarium species in wheat using TaqMan. Eur J Plant Pathol. 2004; 110: 481-494.

129. Blackwell BA, Gilliam JT, Savard ME, David Miller J, Duvick JP. Oxidative deamination of hydrolyzed fumonisin B(1) (AP1) by cultures of Exophiala spinifera. Nat Toxins. 1999; 7: 31-38.

130. Silva JJ, Viaro HP, Ferranti LS, Oliveira AIM, Ferreira JM, Ruas CF, et al. Genetic structure of Fusarium verticillioides populations and occurrence of fumonisins in maize grown in southern Brazil. Crop pro. 2017; 99: 160-167.

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