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# Fumonisin: a Potential Mycotoxin Produced by Fusarium Verticellioides and it's Impact on Human and Animal Health

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## Abstract

Fumonisin are considered as agriculturally important mycotoxin produced by Fusarium verticillioides and F. proliferatum which frequently contaminate the maize and its products worldwide.They can be divided into four main series (A, B, C and P) with the B series, mainly FB1, FB2 and FB3 as most abundant naturally occurring fumonisin. FB1 is the most prevalent and toxic fumonisin compound and chemically described as a diester of propane-1, 2, 3-tricarboxylic acid (TCA) and 2-amino-12, 16-dimethyl -3, 5, 10, 14, 15-penta hydroxylcosane. These are polar soluble in water and aqueous solutions such as methanol and acetonitrile. Fumonisin, the potent mycotoxin causes several diseases in animals such as blind staggers and leukoencephalomalacia in horses, pulmonary oedema in swine and hepatic cancer in rat, nephrotoxicity and hepatotoxicity in cattle, whereas oesophageal cancer and neural tube defects in humans. There is also suggestive evidence that mycotoxins modulate human immunity and may contribute to growth impairment in children In this review fumonisin extraction, purification, toxicity as well as it's impacts on animal and human health will be studied in light of the almost recent literature.

**Keywords:** Animal; Fumonisin; Fusarium Verticillioides; Human Being; Maize; Mycotoxin

**Abbreviations:** FB: Fumonisin; FAO: Food and Agricultural Organisation; *FV: Fusarium Verticillioides;* TCA: Tricarboxylic Acid; LC: Liquid Chromatography; MS: Mass Spectrometry; Cers: Ceramide Synthase; ELEM: Equine Leukoencephalomalacia; BW: Body Weight; FI: Feed Intake; FCR: Feed Conversion Ratio; RWL: Relative Weight Of Liver; NTD: Neural Tube Defect; USFDA: United States Food And Drug Administration; MG: Microgram; KG: Kilogram.

## Introuction

Fumonisins are considered as agriculturally important mycotoxin produced by *Fusarium verticillioides* and *F. proliferatum* during pre-harvest as well as post-harvest, which frequently contaminate the maize and its products worldwide [1], it alsooccurs as a contaminantin other crops such as sorghum, white beans, mung bean, wheat, barley and soybean. Fumonisins were first isolated in 1988 by Gelderblom and colleagues from cultures of *F. moniliformae* strain MRC 826 at "South African Medical Research Council". Fumonisin causes several diseases in animals such as blind staggers and leukoencephalomalacia in horses, pulmonary oedema in swine and hepatic cancer in rat, nephrotoxicity and hepatotoxicity in cattle, whereas oesophageal cancer and neural tube defects in humans. Experts at Food and Agricultural Organization (FAO) have estimated that



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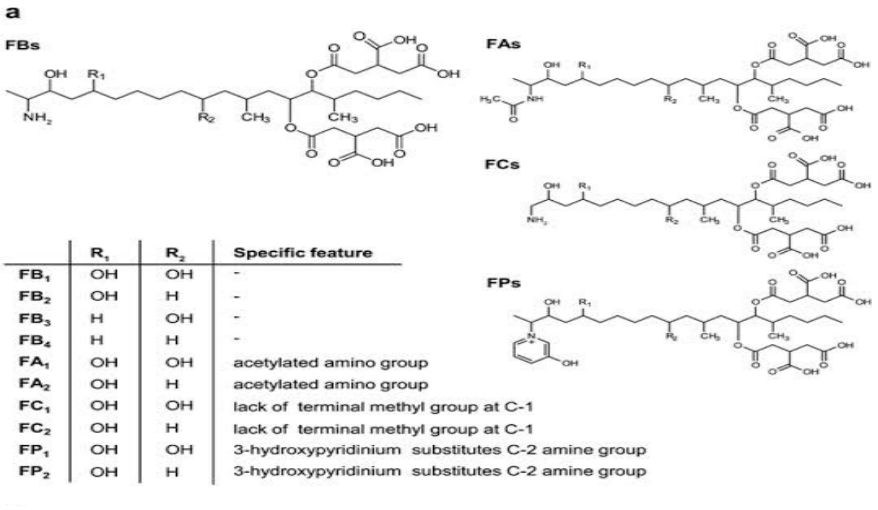
25-50 per cent of world's food crops are lost each year due to mycotoxin contamination, with Fusarium species contributing substantially to food contamination.

In Karnataka the contamination of fumonisin in food and feed products of maize was up to 59 per cent [2]. In the European Union, the maximum permitted levels for fumonisins (sum of FB1 and FB2) in maize and derived products range from 200 to 4000 µg/kg. *F. verticillioides* (Sacc.) Nirenberg (Telomorph: Gibberella moniliformis Wineland; synonym: *F. monilformis*) is both saprophyte and parasite on maize. F. verticillioides is commonly associated with maize causing root rot, stalk rot, ear rot, seed rot and kernel rot is one of the most common plant pathogenic fungi affecting maize [3,4]. It can be found as a systemic endophyte in the symptomless biotrophic state or as a hemibiotrophic pathogen depending on the environmental conditions [5]. *F. verticillioides* initially produces white mycelia but later develops into pink to violet pigments with age. Macroconidia are long, slender, straight, thin walled, apically curved and notched basally with three to five septate and difficult to find. Abundant oval shaped, zero septate, long catenate chains of microconidia arise from monophialides and chlamydospores are absent, swollen cells in some isolated species will be mistaken as pseudochlamydospores [4].

## Chemical and Physical Properties of Fumonisins

Fumonisins are chemically described as a diester of propane-1, 2, 3-tricarboxylic acid (TCA) and 2-amino, 12, 16-dimethyl, 3, 5, 10, 14, 15-penta hydroxylcosane. The C-14 and C-15 hydroxyl groups are involved in ester formation with the terminal carboxyl group of TCA. They can be divided into four main series (A, B, C and P), with the B series, mainly FB1, FB2 and FB3, of which FB1 is the most prevalent and toxic fumonisin compound. Fumonisin B1 is also known as macrofusin which accounts for 70-80 per cent fallowed by FB2 (15-20 %) and FB3 (3-8 %) of the total fumonisin content Figure 1. The A series of fumonisins, differs from B series by the presence of a N-acetyl amide group rather than amine group at C-2 position, whereas C series lack terminal methyl group and P series has 2-hydroxy pyridine at C-2 position. These are polar compounds soluble in water and aqueous solutions such as methanol and acetonitrile, but they are not soluble in non-polar solvents [6].




| | $R_1$ | $R_2$ | Specific feature |
|---|---|---|---|
| $FB_1$ | OH | OH | - |
| $FB_2$ | OH | H | - |
| $FB_3$ | H | OH | - |
| $FB_4$ | H | H | - |
| $FA_1$ | OH | OH | acetylated amino group |
| $FA_2$ | OH | H | acetylated amino group |
| $FC_1$ | OH | OH | lack of terminal methyl group at C-1 |
| $FC_2$ | OH | H | lack of terminal methyl group at C-1 |
| $FP_1$ | OH | OH | 3-hydroxypyridinium substitutes C-2 amine group |
| $FP_2$ | OH | H | 3-hydroxypyridinium substitutes C-2 amine group |

**Figure 1:** Chemical structures of fumonisins [7].

## Extraction and Purification of Fumonisin

The isolates will be artificially inoculated with the 1ml of $10^6$ spores /ml into 5g autoclaved samples in culture tubes and incubated for 27 days. The samples will be finely ground using sterile pestle and mortar used for fumonisin extraction. Ground sample (0.4 g) will be taken in a sterile glass vial and suspended with 2 ml acetonitrile/water (1:1, v/v) extraction solvent and allowed for equilibration overnight in a gel rocker at 28 ± 2 °C. The extracts will be syringe filtered using 0.45 µm nylon membrane filters. Liquid chromatography/ mass spectrometry (LC/MS) will be used for characterization of the extracted fumonisin. A column C18 will be used at 50 °C with sample temperature being 24 °C for a run time of 8 min and mobile phase was water / acetonitrile. MassLynx SCN781 software will be used to validate the results [8]. Further purification can do by subjecting 10 ml of extract to Bond-Elute SAX cartridges and eluted with 14 ml of acidified methanol Figure 2.

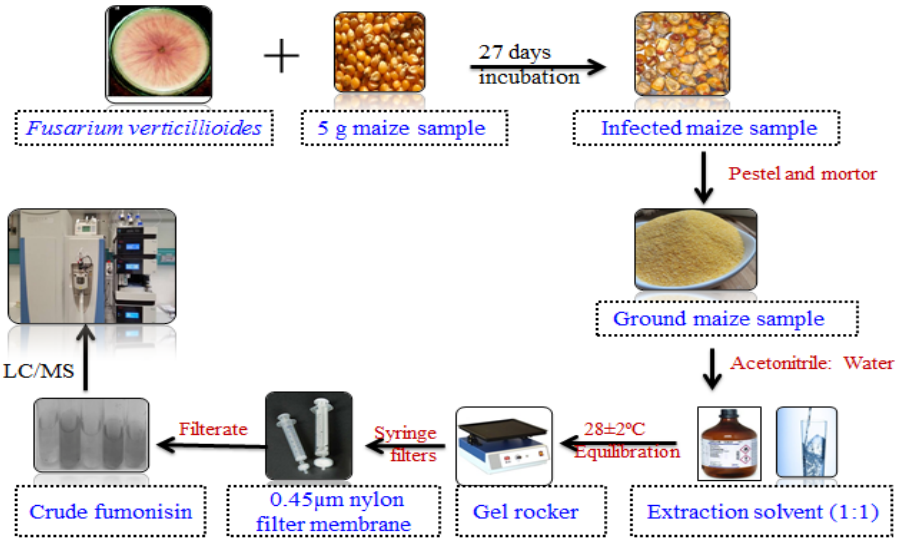



**Figure 2:** Extraction of fumonisin [9].

About 135 cereal samples (61 maize, 42 paddies, 24 sorghum and 8 pearlmillet) were collected from different districts of Karnataka of which 69 samples were infected with Fusarium species. Among these, 51 samples were contaminated with *F. verticillioides* infection and 42 samples were positive for fumonisin production. Per cent incidence and frequency was high in maize samples with 33.12 and 47.54, respectively followed by paddy and sorghum, while pearlmillet was free from *F. verticillioides* [9] Figures 3 & 4, Table 1.

| Cereal Samples Screened | Infected with Fusarium Sp. (%) | Infected With F. Verticillioides (%) | Infected with Fumonisin Producing F. Verticillioides (%) |
|---|---|---|---|
| Maize | 60.65 | 47.54 | 40. 98 |
| Paddy | 52.38 | 42.85 | 33.33 |
| Sorghum | 37.5 | 16.66 | 12.5 |
| Pearl millet | 12.5 | Not detected | Not detected |

**Table 1:** Frequency of cereal samples infected with Fusarium and its species with fumonisin production.

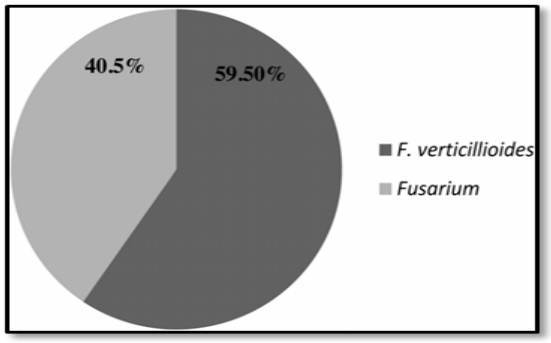



**Figure 3:** Relative density of the F. verticillioides isolated from cereal samples [9].

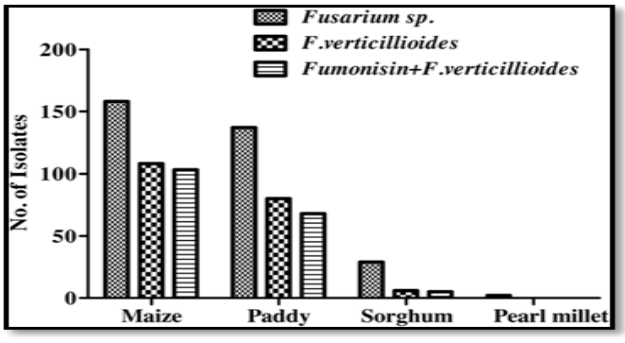



**Figure 4:** Incidence of Fusarium and its species with fumonisin production based on PCR confirmation [9].

## Mechanism of Fumonisin Toxicity

The only clearly defined target of fumonisins in animals is the inhibition of the enzyme ceramide synthase (CerS: also known as spingosine N-acyltransferase) which is involved in sphingolipids metabolism. Sphingolipids are an important family of lipids in the emerging field of lipodomics. Sphingolipids are vital in regulating important cellular processes such as cell growth, apoptosis, inflammation and migration. Sphingolipids are further modified to become complex sphingolipids which are important functional membrane components. Fumonisin toxicity is therefore thought to be due to the disruption of sphingolipid metabolism. This distuption typically includes elevations of both sphinganine and sphingosine has repeatedly correlated with FB toxicity in animals [10].

### Sphingolipids

These are metabolically-linked signalling molecules having sphingoid base backbone (1,3-dihydroxy, 2-aminoalkane) typified by sphingosine. They are hydrophobic in nature. The brain sphingolipid "spingosin" was the first sphingolipid, which was described in 19$^{th}$ century.

### Spingolipid Biosynthesis

Sphingolipid synthesis starts with the joining of serine with palmitoyl-CoA to form 3-keto-dihydrosphingosine (also known as 3-ketosphinganine) catalysed by the enzyme serine palmitoyl transferase in the endoplasmic reticulum. The 3-keto-dihydrosphingosine is then reduced to form dihydrosphingosine (also known assphinganine) by an NADPH-dependent reductase followed by the addition of an acyl chain of variable length via amide formation by CerS. This reaction can be reversed by one of several ceramidases which exhibit organelle specific expression and various pH optimums. The resulting molecule is known as dihydroceramide and is normally converted by the addition of a double bond in the 4-5 position bydihydroceramide desaturase to form ceramide, which can be further phosphorylated via ceramide kinase after transportation to the golgi apparatus to form ceramide-1-phosphate and this reaction can also be reversed by ceramide-1-phosphate phosphatase. Ceramide is the main entry point to complex sphingolipid production which also occurs principally in the endoplasmic reticulum or Golgi apparatus.

Ceramide is very hydrophobic and needs to be transported to the Golgi apparatus either via vesicular transport or by binding to the ceramide transfer protein (CERT). Once in the Golgi apparatus various "headgroups" such as glucose, galactose or phosphocholine can be added to the C1 position via the action of glucosylceramide synthase, ceramide galactosyl transferase or sphingomyelin for example is broken down first to ceramide via the action of one of several sphingomyelinases each with a different optimum pH and location on the plasma sphingomyelin synthase to form complex sphingolipids. Complex sphingolipids are degraded via various hydrolases to release ceramide back into the sphingolipid pool and then to sphingosine via ceramidase. Sphingosine can also be phosphorylated, via sphingosine kinases to produce sphingosine-1-phosphate which is also an important messenger molecule. Sphingosine-1-phosphate is also the so-called "exit" from sphingolipid metabolism as the action of sphingosine-1-phosphate lyase irreversibly degrades it into ethanolamine phosphate and hexadecenal Figure 5.

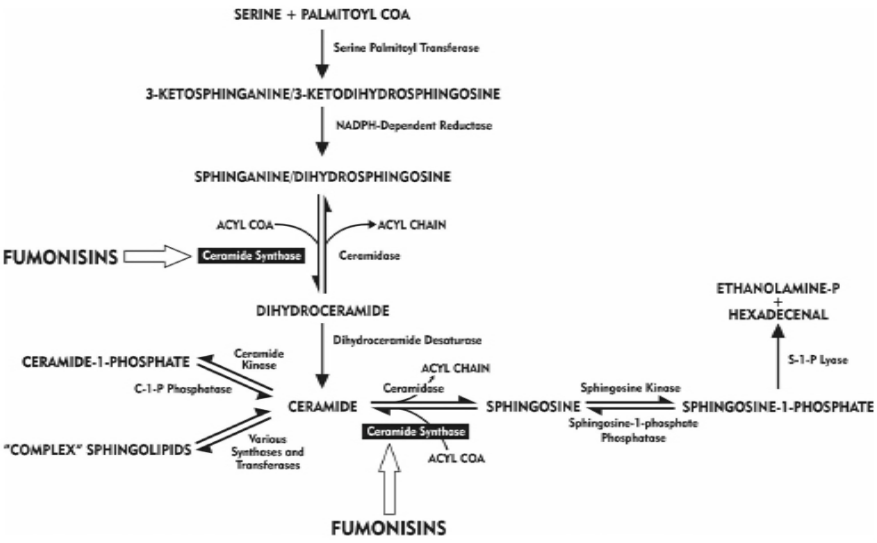



**Figure 5:** Mechanism of sphingolipid biosynthesis and fumonisin toxicity [10].

### Complex Sphingolipids

Complex sphingolipids can be divided into 3 categories depending on which head group is initially added to the C1 position of ceramide; this results in the production of glucosphingolipids, galactosphingolipids (collectively known as glycosphingolipids) and sphingomyelin respectively. These are synthesized either in the endoplasmic reticulum or Golgi apparatus and can exhibit great diversity. Which head group is added depends on which of three enzymes are utilized for the synthesis of these complex sphingolipids; these include glucosylceramide synthase, ceramide galactosyltransferase and sphingomyelin synthase adding glucose, galactose or phosphocholine, respectively. These are involved in cell to cell recognition and signal transduction.

## Impact of Fumonisin on Animal and Human Health

### Equine Leukoencephalomalacia (Elem)

Fumonisin exposure has been shown to cause equine leukoencephalomalacia in horses which is commonly called as "moldy corn poisoning", is a disease of central nervous system that affects horses, donkeys and mules. It is commonly associated with feeding of moldy corn over several days to weeks. The fungus that is most commonly isolated is *F. moniliformae* which produces three toxins, fumonisin B1, B2 and B3 [11]. FB1 is highly toxic associated with both central nervous system and liver damage. The clinical signs associated with the neurologic form of ELEM in horses includes apathy, drowsiness, pharangeal paralysis, blindness, circling, difficulty backing, staggering, hyperexcitability, seizures and recumbency Figure 6. On post-mortem examination, the classic finding is gray to brown areas of malacia and cavitation of white matter of the cerebral hemisphere. In the hepatic form, there may be diffuse vacuolization of hepatocyte, fatty degeneration, centrilobular necrosis with inflamatery cell infilterate, bile duct proliferation, bile stasis, increased mitotic figures within the hepatocytes. Marasas, et, al. [12] studied the impact of fumonisin on horses, where the cultural material of *F. moniliforme* strain MRC 826 was dosed through stomach tubes of two horses with 2.5 g and 1.25 g of culture material /kg body mass/day for seven days, respectively and a third horse was injected intravenously seven times with 0.125 mg of fumonisin B1/kg body mass/day for nine days. First horse developed severe hepatosis and mild oedema, the second horse developed mild hepatosis and moderate oedema of the brain after six doses and a third horse developed severe oedema of brain, necrosis in the medulla oblongata.

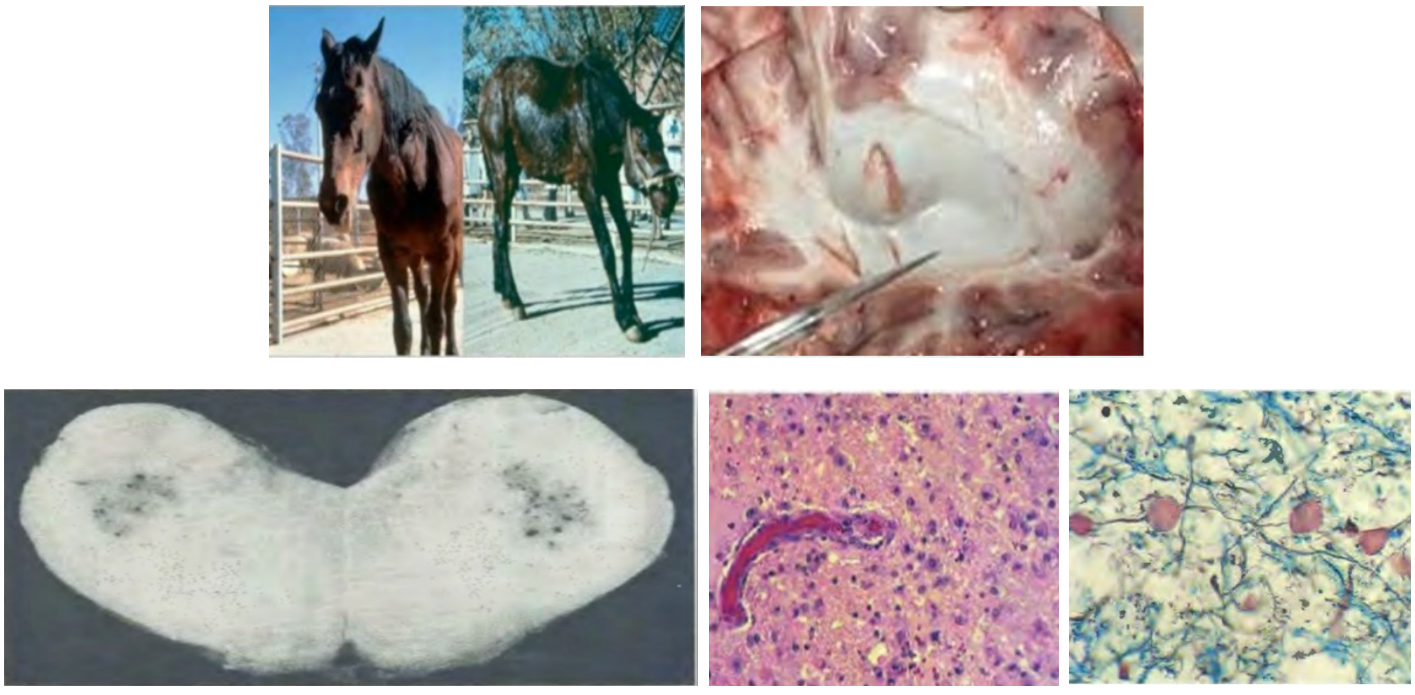


**Figure 6:** A. blind staggers (uncoordinated movement) B. Liquifactive necrosis of white matter of brain area of. C. haemorrhage in medullaoblongata, D. Necrotic area infiltrated by few neutrophils and macrophages, E. Segmented, ovoid swelling ofaxons. Marasas, et al. [12].

## Porcine Pulmonary Oedema

It has been documented that fumonisin consumption causes pulmonary edema in swine. In 1989, the Iowa State University Veterinary Diagnostic Laboratory received reports of an outbreak of acute fatal porcine pulmonary edema syndrome with clinical signs of lethargy, dyspnea, cyanosis, and death. Corn screenings from the swine outbreak revealed the presence of fumonisin B1. FB1 concentration in most corn samples was found to be between 20-330 μg/g. The hepatic injury was found to precede the appearance of pulmonary edema and, therefore, has been hypothesized that liver membrane fragments are released into the bloodstream causing a macrophage response in the lung and increased pulmonary capillary permeability. However, others have found no increase in pulmonary capillary permeability upon fumonisin exposure rather, pulmonary edema was found to be due to fumonisin-induced left ventricular failure via altered cardiac myocyte calcium handling.

Thus, fumonisin B1 is a causative agent inducing pulmonary edema in swine, possibly as a consequence of hepatic injury and/or myocardial failure. However, others have found no increase in pulmonary capillary permeability upon fumonisin exposure rather, pulmonary edema was found to be due to fumonisin-induced left ventricular failure via altered cardiac myocyte calcium handling. Thus, fumonisin B1 is a causative agent inducing pulmonary edema in swine, possibly as a consequence of hepatic injury and/or myocardial failure. The fumonisin toxicosis in swine was studied Hascheck, et al. [13] by which focused on immune effects and the pathogenesis of pulmonary oedema observed that fumonisin didn't affect any specific immune system but it inhibited phagocytosis and spingolipid biosynthesis in pulmonary macrophages. Fumonisin induced acute left-sided heart failure mediated by altered spingolipid biosynthesis Figures 7 & 8.

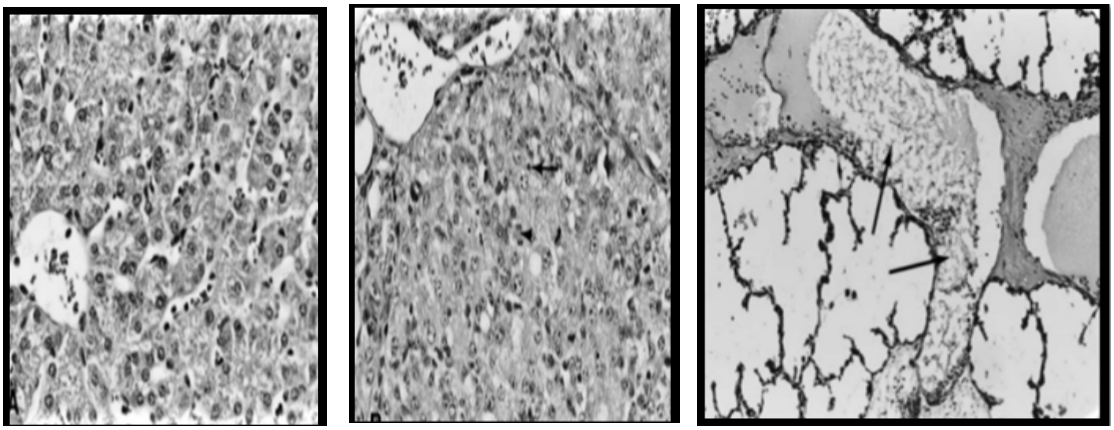


**Figure 7:** Liver from (A) control pig liver, the central vein (lower left) is surrounded by hepatocytes arranged in cords separated by sinus kids. (B) fumonisin treated pig, the hepatic cords are disorganized, and hepatocytes contain vacuoles and apoptotic bodies (arrow). A hepatocyte is undergoing mitosis (arrowhead). Hematoxylin and eosin × 300. (C)Lung from a pig that died from porcine pulmonary edema is characterized by massive dilation of lymphatics within the interlobular septa (arrows) [13].

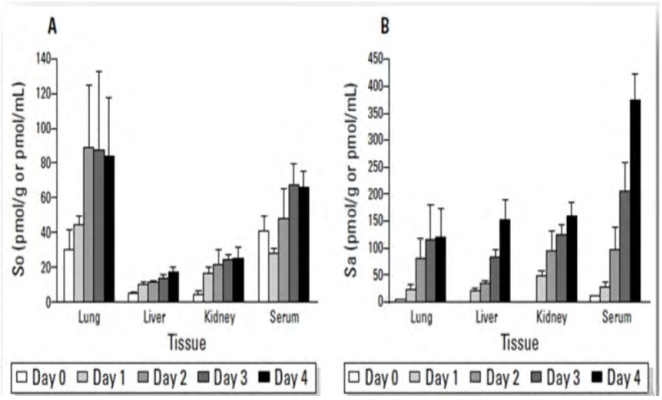



**Figure 8:** Sphinganine (A) and sphingosine (B) concentrations in tissues and serum of pigs fed fumonisin containing culture material at a dose of 20 mg FB1/kg/day Table 2 [13].

| Horse | | | | Dosing regime | | | | Clinical signs | Principal lesion |
|---|---|---|---|---|---|---|---|---|---|
| No. | Sex | Live mass (kg) | Age (yrs) | Dose (g/kg x n) | Days on which dosed | Total dose (g) | Day of euthanasia | | |
| 1 | Mare | 425 | 15 | 2.5 x 5<br>2.5 x 1 | 0-4, 7 | 6375 | 11 | Apathy, inappetance, icterus & constipation (day 8-11) | Severe hepatotis and mild odema of the brain stem |
| 2 | Mare | 385 | 15 | 2.5 x 5<br>2.5 x 1 | 0-4, 7 | 2902 | 12 | Slight nervousness, paralysis of lower lip, unable to walk | Mild hepatotis and moderate odema of the brain stem |
| 3 | Mare | 315 | 15 | 2.5 x 5<br>2.5 x 1 | 0-4,7,9 | 276 | 10 | Severe apathy, reluctance to move, dysponea, convulsive seizure | Early, bilaterally distributed leukoencephalomalacia in the brain stem |

**Table 2:** Toxicity to horses of fumonisin B1 isolated from F. moniliformae MRC 826 culture material.

## Hepatotoxicity and Neurotoxicity in Cattle

Hepatotoxicity refers to liver dysfunction or liver damage, which includes clinical symptoms such as icterus appearance causing yellowing of skin, eye and mucous membranes due to high level of bilirubin in the extracellular fluid and weight loss. In case of nephrotoxicity renal lesions which consist of apoptosis, proliferation of proximal renal tube, as well as dilation of proximal renal tube. The hepatotoxicity and nephrotoxicity effect of fumonisin B1 on milk-fed calves was examined where 10 milk-fed male Holstein calves aged from 7 to 14 days were instrumented to obtain blood and urine. Results concluded that the sphinganine and sphingosine concentrations in liver, kidney, lung, heart and skeletal muscle were increased in FB1 treated calves, in addition hepatic and renal lesions were also observed in [14] Figures 9-11.

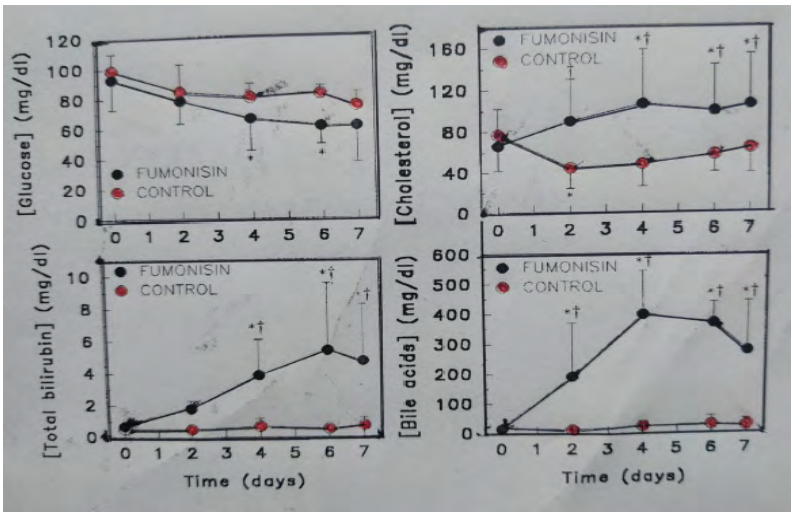



**Figure 9**: Effect of intravenous administration of fumonisin B1 (fumonisin, n = 5) or isotonicsolution (control, n = 5)on serum biochemical indices of hepatic function. *p< 0.05 compared with base line value. †p < 0.05 compared with control calves [14].

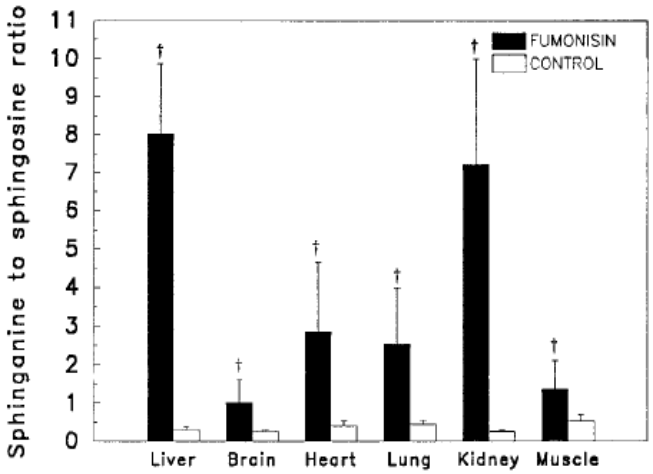



**Figure 10**: Effect of intravenous administration of fumonisin B1 (fumonisin, n = 5) or isotonicsolution (control, n = 5)on sphinganine to sphingosine ratio in selected organs. †p < 0.05 compared with control calves [14].

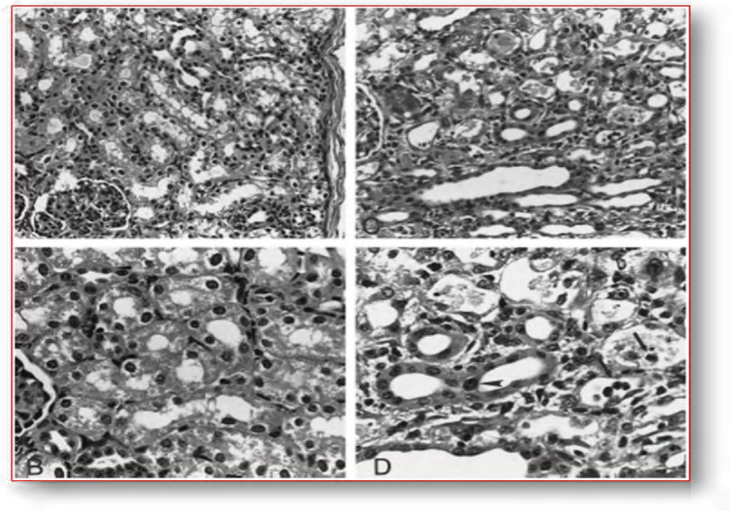



**Figure 11:** Kidney cortex from the control and fumonisin B1- treated calves at day 7. In the control kidney (A and B), normal glomeruli and proximal tubules are present. In the treatedkidney (C and D), there is tubular dilation with loss of proximal tubular epithelium and presence of cellular and protienaceous casts, in the D, higher magnification of C, apoptotic tubular epithelial cells (arrows) and cellular debris arepresent within dilated tubules that are lined by few epithelial cells. Other tubules are lined by basophilic epithelial cells with occasional karyomegaly [14].

## Impact of Fumonisin on Poultry

The main consumer of maize in India is the poultry industry with 47 per cent. Clinical signs includes decrease in feed intake and body weight, diarrhoea, hepatotoxicity (decrease in liver, proventriculus, gizzard weight, multifocal hepatic necrosis, biliary hyperplasia) and Thymic cortical atrophy (decrease in thymus size). Rauber, et al. [15] conducted a study to determine the effects of three doses of fumonisin B (FB) 1 (0, 100 and 200mg/kg of feed) on biological variables, histological evaluation and on performance of broiler chickens. Significant effects of FB were observed on body weight (BW), feed intake (FI) and feed conversion ratio (FCR) of broiler chicken. Both body weight (BW) and feed intake (FI) were reduced (P < 0.01) as the inclusion of FB was increased Table 3.

| FB[a] | Body weight [b](CV[c]) | | Feed intake [d] (CV) | | Feed Converstion rate[e] (CV) | |
|---|---|---|---|---|---|---|
| | 14 days | 28 days | 14 days | 28 days | 14 days | 28 days |
| 0 | 523.49 [A](8.8) | 1450.08[A](7.5) | 645.90[A](2.8) | 2375.77[A](3.1) | 1.23[A](2.5) | 1.64[B](3.4) |
| 100 | 452.58[B] (15.4) | 1225.59[B](11.7) | 586.40[B] (7.8) | 2205.5[B] (3.7) | 1.30 [A](4.6) | 1.81 [A](4.9) |
| 200 | 420.73 [C] (14.4) | 1189.59 [B](14.5) | 532.62[C] (3.7) | 2137.5[B] (4.2) | 1.27[A] (1.7) | 1.77[A] (2.2) |
| Panova | 0.00 | 0.00 | <0.01 | <0.01 | 0.06 | <0.01 |
| Correlation matrix | | | | | | |
| Model | Y=517.01-0.515*X | Y=1418.67-1.302*X | Y=644.95-0.566*X | Y=2358.72-1.191*X | NS [f] | Y=1.68+0.001*X |
| R | -0.57 | -0.58 | -0.85 | -0.78 | | 0.55 |
| P | 0.00 | 0.00 | 0.00 | <0.01 | 0.21 | 0.02 |

**Table 3**: Performance of male broiler chickens fed fumonisin B1 contaminated feed during 28 days.

A-C Averages with different superscripts within the same column differ under Bonferroni's test (P≤0.05). a FB = Fumonisin B1 contamination in feed (mg/kg); b Mean body weight (g); c Coefficient of variation (%); d Mean feed intake (g/bird); e Mean feed conversion rate (g/g); f Not significant on simple regression analysis (P>0.10). The reduction on BW can be partially explained by the reduced FI, but it can also be due to changes in intestinal morphology (reducing nutrients digestibility) and to the effect of FB on liver metabolism. The relative weight of liver (RWL) was significantly increased in broilers receiving FB contaminated feed in both evaluations (14 and 28 days). Histopathological lesions were found only in liver and kidney (no significant lesions were found in heart, lungs, thymus, bursa of fabricius, spleen and pancreas) in both evaluations (14 and 28 days). In the liver, main alterations observed were hyperplasia of biliary ducts, hepatocellular degeneration, lymphoid hyperplasia and proliferation of biliary ducts Figure 12.

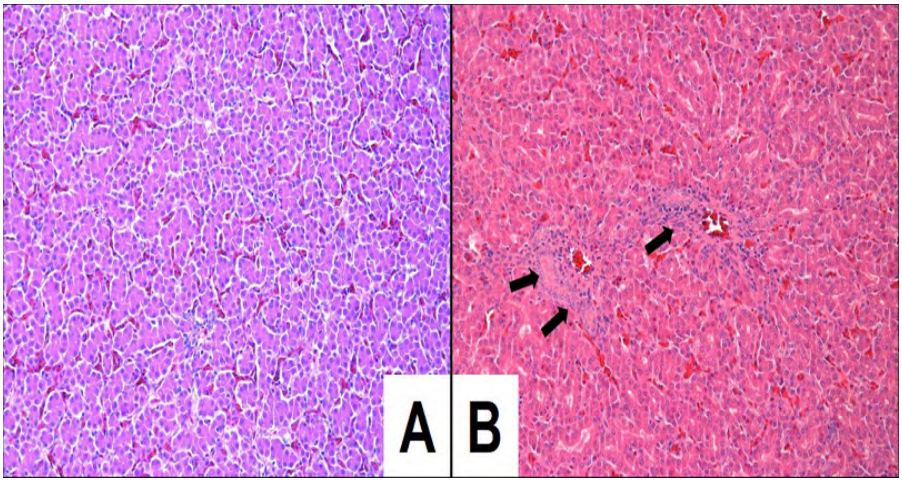



**Figure 12:** A. Histological section of liver from 28 days old broilers from control group, B. Receiving 200mg/kg of Fumonisin B1. Black arrows in B indicate discrete multifocal proliferation of biliary ducts.

## Impact of Fumonisin on Fishery

Maize is major component of fish feed typically contains 300-350 g maize/kg in USA. Consumption of fumonisin contaminated feed results in general symptoms ofdecrease in body weight, carp erythrodermatitis (reddening of skin along with shedding of skin), neurotoxicity, and brain odema [10].

## Oesophageal Cancer in Humans

Fumonisin B1 has been classified as a group 2B carcinogen by the International Agency for Research on Cancer. Group 2Bagents are those that may be carcinogenic to humans but

have limited evidence in humans and less than sufficient evidence in experimental animals. In humans, fumonisin exposure has been most notably associated with oesophageal cancer, which includes clinical signs such as coughing, difficulty in swallowing and chest pain [10].

### Neural Tube Defect (NTD)

These are the embryonic defects of brain and spinal cord resulting from failure of neural tube to close. In the third week of pregnancy called gastrulation, specialized cells on the dorsal side of the embryo begin to change the shape and form the neural tube. There are two types of NTDs that is anencephaly and spina bifida. Anencephaly occurs due to the failure of anterior tube closure, which results in baby borned with underdeveloped brain and incomplete skull, whereas spina bifida occurs due to failure of neural tube closure in the spinal cord which results in protruding spinal cord tissue along with tuff of hairs on it. Missmer, et al. [16] conducted a population based study along the Texas-Mexico border to examine whether or not maternal exposure to fumonisin increases the risk of neural tube defects (NTD) in off-springs. They estimated sphinganine: sphingosine (sa:so) ratio from fumonisin exposureand from maternal recall of preconceptional corn tortilla intake, revealed that, increased exposure to fumonisins, has increased the NTD Table 4.

| Fumonisin (ng/day/kg body weight) | Cases | Control | Crude OR (95% CI) | Adjusted OR (95% CI) |
|---|---|---|---|---|
| ≤30.0 | 13 | 28 | 1.0 (referent) | 1.0(referent) |
| 30.1-150 | 47 | 63 | 1.6 (0.8, 3.4) | 1.9 (0.9, 4.3) |
| 150.1-650 | 58 | 66 | 1.9 (0.9, 4.0) | 2.3 (1.1, 5.1) |
| >650 | 19 | 28 | 1.5 (0.6, 3.5) | 1.1 (0.4, 3.0) |

**Table 4:** Maternal fumonisin exposure imputed from corn tortilla samples and odd's ratio (OR) of NTDs.

## Conclusion

The contamination of food and feed by fumonisin is a serious threat for disease outbreaks worldwide. Fumonisins are neurotoxic, nephrotoxic, hepatotoxic and carcinogenic agents. The high incidence of mycotoxigenic F. verticillioides is of primary concern for policy makers and food experts in order to reduce the economic losses caused by these fungi and also to minimize the exposure of human and animal life to the potential risks of mycotoxins. Various techniques ranging from physical to biochemical, biological as well as genetic engineering can be utilized in an efficient manner to mitigate the contamination of fumonisin in foods. Contamination of fumonisin in the foods to the levels recommended by the U.S. Food and Drug Administration (USFDA) will reduce the risk to the human and animal health.

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