MYCOTOXINS IN FOODS AND FEEDS
4-FUMONISINS

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REVIEW ARTICLE

ABSTRACT:

Mycotoxins are toxic metabolites produced by naturally occurring fungi under certain ecological conditions. Mycotoxins contaminated food and feed supplies could increase the economic and health risks to humans and animals. Fumonisins are a group of recently discovered secondary metabolites produced by Fusarium spp. especially F. moniliforme and occasionally F. proliferatum that commonly contaminate corn and corn screenings.

Human consumption of fumonisins- contaminated corn has been associated with increased incidence of esophageal cancer in South Africa, India and China. Fumonisins have been shown to be associated with some major toxicological effects in animals including equine leukoencepalomalacia (ELEM) in horses and porcine pulmonary oedema (PPE) in pigs. Experimentally high doses of fumonisins caused also adverse effects in cattle, sheep, goats, rabbits, poultry and catfish.

Although many domestic animals are susceptible, natural outbreaks of clinical toxicosis from fumonisins have only been reported in horses and swine. Clinical signs of ELEM may include depression, convulsion, ataxia, sweating, apparent blindness, head pressing, recumbency, convulsions and death. The pathognomic lesions are liquefactive necrosis of white matter of brain leaving fluid- filled cavities. Actually affected horses may have centriflobular hepatic necrosis which may be present with or without brain lesions.

Signs of fumonisin toxicosis in swine (PPE) include poor weight gain, weakness, dyspnoea, cyanosis and death. Lesions include pulmonary edema and hydeothorax, hepatic and pancreatic necrosis.

INTRODUCTION:

Natural occurrence:

Fumonisins are a group of recently discovered secondary metabolites mainly produced by Fusarium moniliforme (Giberella fujikuroi) and F. proliferatum (Gelderblom et al., 1988; Edrington et al., 1995).

Fumonisin B1 (FB1) was isolated in 1988 by Gelderblom et al., and it was chemically characterized by Bezuidenhout et al. (1988) and Laurent et al. (1989), from cultures of F. verticillioides and F. moniliforme.
Fumonisin B₁ is produced by other species of Fusarium including, *F. anthophilum*, *F. beomiforme*, *F. diamini*, *F. globosum*, *F. hapiforme*, *F. nygamai*, *F. oxysporum*, *F. polyphialidicum*, *F. subglutinans* and *F. thapsinum* (WHO, 2000).

The mold is usually found in maize such as screening, that has been damaged by insects or adverse weather conditions (Plumlee, 1997). *F. moniliforme* has also been isolated from pellet feeds (Plumlee, 1997).

A part from maize and maize products, fumonisins have seldom been found in other products, such as rice (Abbas et al., 1998), asparagus (Logrieco et al., 1998) and sorghum (Shetty and Bhat, 1997). Surveys on other cereals, such as wheat, rye, barley and oats did not show the occurrence of the toxin (Meister et al., 1996).

Maize contaminated naturally by FB₁ can be simultaneously contaminated with other *F. verticillioides* or *F. proliferatum* toxins or with other agriculturally important toxins including deoxynivalenol, zearalenone, aflatoxin and ochratoxin.

Many factors including environmental conditions and host susceptibility, determine the incidence and severity of grain mold and subsequent mycotoxin contamination (Stack, 2003). High levels of fumonisins are associated with hot and dry weather, followed by periods of high humidity (Shelby et al., 1994).

Fumonisin levels in raw corn are also influenced by storage conditions and the optimal growth of fumonisin-producing mold that leads to increased levels of fumonisin in the raw corn can occur when the moisture content of harvested raw corn during storage is 18-23% (Bacon and Neslon, 1994). High levels of fumonisins may also occur in raw corn that has been damaged by insects (Bacon and Neslon, 1994; Miller, 1999). The best temperature for the production of FB₁ on corn was 20°C (Weidenborner, 2001).

### Types and chemical structure:

The main fumonisins are currently recognized and are designated as fumonisin B₁ (FB₁), fumonisin B₂ (FB₂) and fumonisin B₃ (FB₃), based on the hydroxylation of the hydrocarbon chain (Edrington et al., 1995). FB₁ is the predominating fumonisins in naturally contaminated maize kernels with a ratio of 3:1 (FB₁: FB₂) and 12:1 (FB₁:FB₃) which corresponds to about 70% of the total fumonisins concentration detected. However, in vitro there is some isolates of *F. moniliforme* producing more FB₂ than FB₁ (Weidenborner, 2001).

At least 15 different fumonisins have so far been reported and other minometabolites have been identified, although most of them have not been shown to occur naturally (WHO, 2000). They have been grouped into four main categories FA₁, FA₂, FA₃ and FAK₁; FB₁, FB₂, FB₃ and FB₄; FC₁, FC₂, FC₃ and FC₄; FP₁, FP₂ and FP₃ (Plattner, 1995; Abbas and Shier, 1997; Musser and Plattner, 1997).

Fumonisins are water soluble, heat stable, alkaline-resistant, aliphatic hydrocarbons with a terminal amine group and two tricarboxylic acid side chains (Osweiler, 1999). The number of position of hydroxy groups on the aliphatic hydrocarbon determines the structure as FB₁, FB₂ or FB₃ (Bezuidenhoudt et al., 1988; Steyn, 1995).

The FB₁ form is hydroxylated at the 3, 5 and 10 positions, whereas FB₂ or FB₃ are reduced at the 10 and 5 positions, respectively (Osweiler et al., 1993).
Fumonisin B₁ has the empirical formula C₃₄H₅₉NO₁₅ and is diester of propane-1,2,3-tricarboxylic acid and 2-amino-12,16-dimethyl-3, 5, 10, 14, 15-pentahydroxyeicosane (relative molecular mass: 721). The pure structure is a white hygroscopic powder, which is soluble in water, acetonitrile-water or methanol, is stable in acetonitrile-water (1:1), and at food processing temperature and to light (WHO, 2000).

FA₁, FA₂ or FA₃ are the N-acetyl derivatives of FB₁, FB₂ and FB₃, respectively. Within each series different hydroxyl substitution result in different fumonisins FC₁, FC₃ and FC₄ lacking the C-1 terminal methyl group which is characteristic for other fumonisins. In comparison to FC₁, the hydroxylated FC₁(OH-FC₁) has one more hydroxyl group at the C-3 position (Weidenborner, 2001).

**Occurrence in foods and feeds:**

Maize based human foodstuffs from retail outlet in 5 countries were analysed for FB₁ and FB₂ (Syndenham et al., 1991). The highest man concentration occurred in 2 Egyptian samples 2.38 mg/kg FB₁ and 0.595 mg/kg FB₂. Only of 4 Peruvian samples contained 0.66 mg/kg FB₁ and 0.135 mg/kg FB₂, while only 1 of 2 Canadian samples contained a level of FB₁ (0.05 mg/kg). The corn meal and 10 corn grits products from the USA contained mean concentration of 1.048 mg/kg FB₁ and 0.298 mg/kg FB₂ and 0.601 mg/kg FB₂ and 0.375 mg/kg FB₂, respectively. The mean concentration in 52 corn meal and 15 corn grits samples from South Africa were 0.138 mg/kg FB₁ and 0.083 mg/kg FB₂ and 0.125 mg/kg FB₁ and 0.85 mg/kg FB₂, respectively. Only 1 of 10 corn flakes/lime treated samples contained a low level of FB₁.

Dry milling of maize results in the distribution of fumonisin into the bran, germ and flour (WHO, 2000). In dry milled maize fractions, the fumonisin concentration was approximately 3 times higher in germ and bran than in whole maize, 13 times higher in "C" flour and 29 times higher than in corn meal and corn grits (Broggi et al., 2002). In experimental wet milling, fumonisin was detect in steep water, gluten fiber and germ, but not in the starch (WHO, 2000).

Fumonisin B₁ levels in animal feedstuffs can be exceptionally high, and reached maximum concentration of 330, 70, 38, 9 and 2 mg/kg in North America, Italy, Brazil, South Africa and Thailand, respectively (WHO, 2000). FB₁ has been recorded to occur in maize and screening servings at levels as high as 195 and 330 mg/kg, respectively (Ross et al., 1991).

The center of veterinary medicine conducted as survey on fumonisin in maize and maize screenings in 1991, in response to an equine leukoencephalomalacia (ELEM) outbreak occurring in late 1990 in the united states. Fumonisin was detected in 13% of the shelled maize samples (1.2 to 3.2 mg/kg), and in 100% of corn screening samples (2.6 to 32 mg/kg) (Price et al., 1993). Another survey found 85% of 158 maize samples (0.6 to 96 mg/kg) (Russel et al., 1993).

In Uruguay all samples of maize-based animal feeds were positive for FB₁. However, highest FB₁ were observed in South Africa for compound feed (11 mg/kg), and Thailand and China for maize (18.8 and 25.97 mg/kg, respectively). In a study of Argentina maize, FB₁ was the major fumonisin at values of up to 11.30 mg/kg (Placinta et al., 1999).

In 1998, random samples of maize and poultry feeds were collected from poultry farms, feed manufactures and markets in Haryana, India and analyzed for FB₁. 91% of maize samples and 42% of poultry feed samples were
found to contain \(\text{FB}_1\), \(\text{FB}_1\) concentrations in the maize samples ranged from 0.1 to 87 ppm, whereas the poultry feed samples contained \(\text{FB}_1\) in the range of 0.2 to 28 ppm (Jindal et al., 1999).

Concentrations of fumonisin in foods and feeds associated with human and animal health problems:

Of several samples obtained from a high oesophageal cancer risk area in the USA 7 of 7 contained \(\text{FB}_1\) at levels of 0.105 to 1.915 mg/kg and 6 of 7 \(\text{FB}_2\) at levels of 0.07 to 0.46 mg/kg (Sydenham et al., 1991).

The fumonisin \(\text{B}_1\) contamination of maize samples collected from two areas of Iran during 1999 was determined (Shephard et al., 2002). The \(\text{FB}_1\) levels in Mazandaran province, an area of high esophageal cancer were 0.68-7.66 mg/kg, a mean level of 3.18 mg/kg, while the \(\text{FB}_1\) levels found in maize samples form Isfahan, an area of low esophageal cancer were 0.01 to 0.88 mg/kg, a mean level of 0.22 mg/kg.

The fumonisin levels associated with episodes of ELEM and PPE have been found to be higher (Ross et al., 1991). A total of 98 samples of feeds associated with 44 cases of ELEM and 83 samples of feed associated with 44 cases of PPE in USA were analysed for \(\text{FB}_1\). Feeds associate with ELEM contained \(\text{FB}_1\) ranging form < 1 to 126 mg/kg, with 75 of cases have at least 1 sample > 10 mg/kg. While, feeds associated with PPE ranged from < 1 to 330 mg/kg, with 71% of the cases having at least 1 sample > 10 mg/kg (Ross et al., 1991).

Fourteen feed samples form the USA that were fed to horses prior to the development of LEM were analysed for \(\text{FB}_1\) and \(\text{FB}_2\) (Thiel et al., 1991 b). All samples contained both \(\text{FB}_1\) (1.3-27.0 mg/kg) and \(\text{FB}_2\) (0.1-12.6 mg/kg). \(\text{FB}_1\) was found to be the major fumonisin in feed samples (53-93%).

A total of 21 \textit{F. moniliforme} contaminated feed sample associated with outbreaks of confirmed and suspected cases of mycotoxicosis in various animal species (mainly horse and pigs) were collected from farms in the state of Parana, Brazil and analysed for \(\text{FB}_1\) and \(\text{FB}_2\) (Syndenham et al., 1992). \(\text{FB}_1\) and \(\text{FB}_2\) were detected in 20 and 18 of the 21 samples, respectively at concentration of 0.2 to 38.5 mg/kg \(\text{FB}_1\) and 0.1 to 12.0 mg/kg \(\text{FB}_2\).

Absorption, distribution and excretion:

As described by WHO (2000), there is no reports available for fumonisin absorption through inhalation or dermal exposure. However, because fumonisins are present in \textit{F. verticilloides} cells (mycelia, spores and conidiophores) (Tejada- Simon et al., 1995), there is a potential for absorption through inhalation or buccal exposure. The risk from absorption due to animal exposure would seem slight, since fumonisins are very water soluble and, typically polar compounds do not easily penetrate the undamaged skin (Flynn, 1985).

Fumonisins have been reported to be poorly absorbed, rapidly excreted and persistent in small amounts in liver and kidney (Norrd et al., 1996). Fumonosine when dosed orally to vervet monkeys, dairy cows and pigs are poorly absorbed (2 to < 6% of dose) (Prelusky et al., 1994, 1995, 1996 a, b; Shephard et al., 1994a, b).

In ruminants, rumen metabolism may reduce the bioavailability of \(\text{FB}_1\) as the hydrolyzed form of \(\text{FB}_1\), comprised 60-90% of the total amount of \(\text{FB}_1\) found in feces. In non-ruminants the parent compound was the dominant species present (Rice and Ross, 1994). In orally dosed laying hens and dairy cows, the quantity of \(\text{FB}_1\) detected in plasma and tissues is very low (< 1% of dose) (Scott et al., 1994;
Vudathala et al., 1994 and Prelusky et al., 1996a).

No FB₁ was detected in the milk of lactating sows fed diets containing non-lethal levels of FB₁ and there was no evidence of toxicosis in their suckling pigs (Becker et al., 1995). However, in a study with lactating cows administered FB₁ intravenously, the carry over rate of FB₁ into the milk reached a maximum of 0.11% (Hammer, et al., 1996). In other studies no fumonisins were detected in cows milk (Scott et al., 1994; Richard et al., 1996). FB₁ was found in only one of 165 samples of milk from Wisconsin, USA at a level close to 5 ng/ml (Maragos and Richard, 1994).

There are also no data demonstrating that fumonisin consumption results in transfer to chicken eggs (Vudathala et al., 1994; Prelusky et al., 1996a). Also, FB₁ was not found in milk, meat or eggs from animals fed grains containing FB₁ levels that would not affect the health of the animals (WHO, 2000).

Mode of action:

Experiments by Wang et al. (1991) indicated that fumonisins are inhibitors of sphingolipids biosynthesis through inhibition of ceramide synthetase and by blocking protein synthesis. Sphingolipids are found in large quantities in brain and nerve tissues. Sphingosin is synthesized in the endoplasmic reticulum. Ceramide is form by a combination of either a free fatty acid or an acyl-coenzyme A and sphingosine (Mayes, 1988).

The site of inhibition occurs where sphingosine and fatty acyl-coenzyme A combine to form dihydroceramide, which would result in accumulation of free sphingosine in tissues and serum (Norred et al., 1992; Merrill et al., 1993b). It has been postulated that the similarities between fumonisins and long-chain (sphingoid) basis allow them to be recognized as substrate (transition state/or product analogs) of sphingosine or sphinganine-N-acetyl transfearse. Disruption of this pathway could explain at least some of the pathological effects of fumonisins (Leeson et al., 1995).

The degeneration of neuronal cells seen in ELEM may be due to inhibition of sphingolipid biosynthesis because of their high concentration in the brain. On the other hand accumulation of sphinganine in cells exposed to fumonisins may lead to cell death (since long-chain bases are highly cytotoxic), or to cell proliferation, these compounds are mitogenic for some cell types (Wang et al., 1991).

The alteration in sphingolipid metabolism caused by fumonisins can be monitored by measuring serum lipids of sphingosine (So), sphinganine (Sa) and complex sphingolipids (Leeson et al., 1995). Analysis of sphingosine and sphinganine levels in livers and serum revealed an increase in the level of sphinganine, with no change in the level of sphingosine, that result in an increase in the sphinganine: sphingosine ratio (Henery et al., 2000).

Studies in horses (Wang et al., 1991, 1992), pigs (Riley, 1993), sheep (Gurung et al., 1998), broiler chicks (Weibking et al., 1993a), turkeys (Weibking et al., 1993b) and catfish (Goel et al., 1994) have demonstrated a significant increase in the serum Sa to So ratio in animals fed a ration containing FB₁.

Toxicity:

Species difference: FB₁ is extremely toxic to horses, moderately toxic to swine, weakly toxic to cattle and has been associated with oesophageal cancer in humans. Poultry are even more resistant to adverse health effects from fumonisin (Stack, 2003). Pregnant New Zealand rabbits are found to be very sensitive to the toxic effects of FB₁ (LaBord et al., 1997). The
species, age and health of the animal as well as the level and duration of exposure to the mycotoxin will determine the magnitude of the effect of exposure (Stack, 2003).

The feeding of fumonisins contaminated corn produced leukoencephalomalacia (LEM) in horses (Wilson et al., 1990; Ross et al., 1991) and pulmonary edema (PE) and hydrothorax in swine (Harrison et al., 1990; Osweiler et al., 1992). Experimental high doses of fumonisine caused adverse effects in cattle (Osweiler et al., 1993) and poultry (Weibking et al., 1993a). Human consumption of corn has been correlated with increased incidence of oesophageal cancer in certain parts of the world (Sydenham et al., 1991; Chu and Li, 1994). In addition to their adverse effects on the brain, liver and lungs, fumonisins also affect the kidneys, pancreas, tests, thymus, gastrointestinal tract and blood cells (Vencelli and Parker, 1999).

Fumonisine have produced liver damage and changes in the levels of certain classes of lipids especially sphingolipids, in all animal studies (Merill et al., 1997), kidney lesions were also found in many animals (Norred et al., 1998; Merrill et al., 1997).

Chronic feeding of purified FB$_1$ at levels of 50 ppm or more produced liver cancer and decreased life span in female mice and kidney cancer in male rats without decrease life spans (NTP, 1999).

Disturbances of thermoregulation has been observed in some animals exposed to the mycotoxin (Becker et al., 1995). In horses, FB$_1$ causes profuse sweating, the major cooling mechanism for this species, even though body temperature remain normal (McCue, 1989). Cattle with fumonisin toxicosis has hyperthermia, with heat intolerance developing at a lower body temperature than normal for cattle (Schmidt and Osborn, 1993; Thompson and stuedermann, 1993). Although, hyperthermia has not been reported in swine with FB$_1$ toxicosis, the reduced lung function associated with edema would reduce the ability to pant. In swine panting is a major mechanism for coping with high temperature, thus high environmental temperature may exacerbate FB$_1$ toxicosis attributable to reduced pulmonary function associated with FB$_1$ induced pulmonary edema (Becker et al., 1995).

Human health effects:

Currently, there is no direct evidence that fumonisins cause adverse health effects in humans. Studies currently available demonstrate only inconclusive association between fumonisins and human cancer (FDA, 2001b).

A very high incidence of oesophageal cancer among the black population of the Transkei, South Africa has been reported in several surveys (Jaskiewics et al., 1987; Makaula et al., 1996). Investigation in South Africa suggested an association between high levels of fumonisin producing molds on corn used to make alcoholic beverages and oesophageal cancer in humans (Rheeder et al., 1992). This corn has been found to contain up to 118 mg/kg fumonisins.

Based on experiments conducted on beer made from worth containing FB$_1$, such beers could contain fumonisin concentration of 30 mg/liter beer (Scott et al., 1995). However, these studies were limited by the lack of controlled conditions, particularly for established confounding risk factors (e.g. alcohol consumption) and therefore do not allow any definite conclusions to made about cancer causation in humans (FDA, 2001 b).

An outbreak of poisoning, characterized by abdominal pain and diarrhea caused by
fumonisin-contaminated maize and sorghum in India during 1995, was reported (Bhat et al., 1997). An epidemiological survey was conducted in the affected villages and a detailed house to house in selected villages. People in 27 out of 50 villages surveyed in Karnatake state were affected and disease was seen only in households and subjects consuming rain damaged moldy sorghum or maize.

All 20 sorghum and 12 maize samples collected from household had fusarium sp. as the dominant microflora and contained FB\textsubscript{1} in the range of 0.14 to 7.8 and 0.25 to 64.7 mg/kg, respectively. In contrast, samples collected from unaffected households had FB\textsubscript{1} in low levels ranging from 0.07 to 0.36 and 0.05 to 0.24 mg/kg, respectively.

However, this study lacked control of established risk factors. In addition, contaminants other than mycotoxins cannot be eliminated as causative factors, and a similar dissociation was not detected in studies conducted in other countries (FDA, 2001 b).

Other studies associated with high levels of fumonisin producing molds on corn with oesophageal cancer in China reported that corn samples from areas with high incidence of oesophageal cancer, contained FB\textsubscript{1} at levels ranging from 18 to 155 mg/kg. These results established that home-grown maize in high incidence areas of oesophageal cancer in China may be contaminated with very high levels of FB\textsubscript{1}. These studies were correlation studies where there was no clear picture on the association of either fumonisins or \textit{F.verticillioides} contamination with oesophageal cancer (WHO, 2000).

Further in an area of China with high incidence of gastric cancer, Groves et al. (1999) observed a lack of association between consumption of fumonisin- contaminated corn with gastric or any other human cancer.

Animal health effects: Ruminants:

Cattle and sheep are mildly affected by dietary concentrations of fumonisin greater than 100 ppm, but fatalities do not occur (Osweiler et al., 1993). Very few studies have focused on the effects of fumonisins in ruminants. (Kriek et al., 1981) demonstrated that \textit{F.moniliforme} cultures capable of inducing ELEM and PPE were also toxic to sheep. Beasley and Buck (1982) reported feed refusal in cattle given corn contaminated with \textit{F.moniliforme}, but existence of fumonisins was not known at that time.

Dietary fumonisins concentration greater than 148 mg/kg of diet to calves may adversely affect liver and immune functions (Osweiler et al., 1993). Livers from treated calves had mild hydropic degeneration and cloudy swelling in a periacinar pattern throughout the liver. These changes were consistent with the mild to moderate elevation of liver enzymes. Cattle fed 530 mg of total fumonisins /kg diet, supplied by fumonisin- containing- culture material for 30 days, showed no signs of toxicosis (Smith and Thakur, 1996), although liver function tests revealed some hepatobiliary compromise.

Fumonisin B\textsubscript{1}- contaminated feed (95 mg/kg), fed for 112 days caused no treatment-related effects on feed intake, nutrient digestibility, or weight gain in weanling angora goats (Gurung et al., 1998). However, sphingolipid disruption and mild liver and kidney damage were observed in weanling goats.
In contrast, (Edrington et al., 1995) observed clinical signs such as marked decrease in feed intake diarrhea, lethargy and ultimately death in lambs dosed intraruminally with 11.1, 22.2 and 45.5 mg of total fumonisins/ kg of b.wt. for only 4 days. The actual amounts of total fumonisin intake were determined to be 355.2, 710.4 and 1456 mg/ lamb/ day. Such as concentrations have not been reported to occur under normal feeding conditions (Gurung et al., 1998).

Monogastric animals:

Equidae:

Horse are the most sensitive of the domestic animals and dietary concentration as low as 10 ppm for more than 50 days may cause leukoencephalomalacin (LEM) (Wilson et al., 1990; Ross et al., 1992). The ELEM has been recognized since 19th century as a sporadically occurring condition (WHO, 2000), and was experimentally produced by feeding moldy maize obtained from a field case in Kansas by Butler in 1902. The disease was known as "moldy corn poisoning" but attempts to identify the responsible fungus failed. History has referred to this disease by many names including: moldy corn poisoning, corn stalk disease, forage poisoning, leukoencephalomyelitis, blind staggers, epizootic cerebritis and non virus encephalomyelitis (Wilson et al., 1985; Asquith, 1991; Masri, 1992).

As described by WHO (2000), Wilson and Maronport (1971) succeeded in establishing the causative agent when they isolated F. verticillioides as the predominant contaminant of moldy maize that has caused cases of ELEM in Egypt, and reproduced the disease by feeding culture material of the fungus on maize to 2 donkeys. Subsequently investigators in South Africa confirmed the ability of F. verticillioides (MRC826) culture material to induce the characteristic clinical signs and pathological changes of ELEM as well as hepatosis in horses and donkeys (Kellerman et al., 1972; Marasas et al., 1976, 1988 and Kriek et al., 1981).

ELEM has also produced in horse by intravenous administration of pure FB$_1$ (Bezuidenhout et al., 1988; Gelderblam et al., 1988) and in horses given pure FB$_1$ by stomach tube (Kellerman et al., 1990). Moreover the disease has been observed naturally in horses and ponies fed feeds contaminated with fumonisins (Wilson et al., 1992; Ross et al., 1993).

The lowest FB$_1$ dose that has resulted in ELEM in a controlled experiment is 22 mg/kg in diets formulated with naturally contaminated maize screenings (Wilson et al., 1992). Ross et al. (1992) suggested that concentrations > 10 mg/kg FB$_1$ in horse feeds were likely to be involved in LEM. In 40 to 45 confirmed cases of ELEM, FB$_1$ levels in feeds were > 10 mg/kg, while non-problem feeds contained < 10 mg/kg FB$_1$.

Clinical signs:

The clinical signs of ELEM appear at a variable length of time after feeding of the mycotoxin is begun (Kibluk et al., 1995). In experimental cases, clinical signs have appeared as early as day 7 and as late as day 75 (Ross et al., 1993). Clinical signs of the disease usually appear abruptly and the clinical course is relatively short, with most affected horses dying within 2 to 3 days (Wilson et al., 1985; Marsi et al., 1987; Kobuk et al., 1995).

The first sign may be inappetence, followed quickly by neurologic abnormalities. Behavioral signs vary from depression and a pathy to apprehension, hyperecitability or frenzy (Kellerman et al., 1990; Masri et al., 1992; Ross
et al., 1993; Kobluk et al., 1995). Other neurologic signs may include head pressing, aimless circling, unilateral or bilateral blindness, ataxia, tremors, cranial nerve deficits (such as lip and tongue paresis and dysphagia), and weakness. Progression of the condition leads to recumbency, convulsions, coma and death (Wilson et al., 1985, 1990; Masri et al., 1987; Marasas et al., 1988; Kellerman et al., 1990; Thiel et al., 1991b; Ross et al., 1993 and Konluk et al., 1995).

In a horse injected intravenously 7 times over 10 days with 0.125 mg of FB$_1$/kg b.wt./day, clinical signs of neurotoxicosis included nervousness followed by a pathy, a wide-based stance, trembling, atoxin, reluctance to move, paresis of the lower limb and tongue and an inability to eat or drink were recorded (Marasas et al., 1988). The principal lesions were severe oedema of the brain and early bilaterally symmetrical focal necrosis in the medulla oblongata.

Death frequently occurs within 5 days of the onset of clinical signs (Smith, 2000): sudden death, without prior clinical signs, has been reported. Animals that survive often have persistent neurologic deficit (Plumlee, 1997). The hepatic form of the disease may be accompanied by icterus, oedema, hemorrhage and hepatomegalapathy (Plumlee, 1997).

Gross and histopathological findings: ELEM syndrome is characterized macroscopically by the presence of liquefactive necrotic lesions in the white matter of the cerebrum (WHO, 2000). Other lesions include encephalomalacia of both white and grey matter in the cerebrum, cerebellum, midbrain or brain stem (Masri et al., 1987; Kobluk et al., 1995). Acutely affected horses may have centrilobular hepatic necrosis, which may be present with or without the brain lesions (Marasas et al., 1988; Wilson et al., 1990).

Microscopic lesions included: liquefactive necrosis of white matter, with complete loss in some areas perivascular edema, hemorrhage and perivascular cuffing in the white matter adjacent to malacic foci. Eosinophils and plasma cells predominated in perivascular cuffs. Foci of myelin degeneration were seen in non-necrotic areas of white matter. Lesions in grey matter included satellitosis and neuronophagia. Leptomeningeal edema was present in some cases (Marasas et al., 1976; Rooney and Robertson, 1996).

In conjunction with ELEM, muscular melting and cardiac failure have been reported (Vencilli and Parker, 1999). In addition to brain lesions, histopathological abnormalities in liver and kidney have been reported in horses orally dosed with pure fumonisins, maize screening, naturally contaminated with fumonisins, or culture material containing known amounts of fumonisins (Kellerman et al., 1990; Wilson et al., 1992; Caramalli et al., 1993 and Ross et al., 1993). Lesions of hepatic form include centrilobular necrosis, periportal fibrosis, periportal vacuolation and bile duct proliferation; lipofuscin deposition in macrophages and kupffer cells, and infiltration with a mixture of inflammatory cells (Marasas et al., 1976; Plumlee, 1997). Perirenal edema and congestion may be present (Marasas et al., 1976).

Elevated serum enzyme level indication of liver damage (Wilson et al., 1992) are produced by elevation of the serum Sa/So ratio (Wang et al., 1992). The protein concentration and white cell count in the cerebrospinal fluid are elevated (Plumlee, 1997).

Natural occurrence of ELEM:

Outbreak of ELEM has been described throughout the world in Argentina, China,
Egypt, New Caledonia, South Africa, Greece and other parts of Europe and the United States (Jubb and Kennedy, 1985 and Marasas et al., 1988).

The disease occurs most commonly in the United states from September to May, Certain growing and harvest conditions (dry summers and/or drought, followed by rainy Autumns) increase the amount of *Fusarium moniliforme* on feed corn (Rooney and Robertson, 1996). Epizootics have occurred in years in which corn was harvested during periods of high humidity (Badiali et al., 1968; Masri et al., 1987). In 1934 to 1935, an episode of ELEM was recorded in Illinois (Graham, 1936), where 5000 horses died following a summer drought and early fall rains, when horse were allowed to forage in the stalk fields, and others were fed moldy corn after harvesting. Sporadic occurrences of the disease were reported in Egypt by Badiali et al. (1968), following the flooding of the Nile, resulting in mold growth on the autumn crop which was fed to donkeys.

An outbreak of ELEM was reported in a riding club in new Caledonia in 1981, where horses were being fed a ration containing high levels of locally grown corn. The development of the disease coincided with the feeding of a new batch of feed containing the corn. Out of the 45 affected horses, 5 died 10 to 28 days after the onset of clinical signs. *F. moniliforme* was recovered from all samples of corn that were examined. A second episode occurred in 1983 involving a 15-year-old stallion that had been fed locally produced corn. In this case, the major gross pathology was a focus of liquefaction of the white matter in the right cerebral hemisphere (Domench et al., 1985; Asquith, 1991).

A survey conducted in 1984 to 1985, evaluated 22 farms with confirmed cases of ELEM in North Carolina. Gross lesions of necropsied animals revealed liquefaction necrosis in the white matter of one or both cerebral hemispheres preliminary data suggested that some of the oats used in the feed preparation may have been infected. This was the first report of the disease occurring from the ingestion of commercial pelleted and non-pelleted horse rations and indicated that *F. moniliforme* may be capable of remaining viable even after the pelleting process (Wilson et al., 1985; Asquith, 1991).

During the autumn of 1989, in an ELEM involving 18 of 66 purebred Arabian horses at breeding, training stable in Arizona, USA, the condition was fatal in 14 horses (Wilson et al., 1990). These horses had been fed a diet containing 37 to 122 ppm of FB$_1$. Gross pathological findings included, liquefactive necrosis in parts of the cerebral white matter and hemorrhagic foci of various sizes in the brain stem. Histopathological findings included reafied white matter with pyknotic nuclei and eosinophilic cytoplasm. This was the first definite report on ELEM and associated FB$_1$ concentration.

An outbreak of ELEM affecting 6 of 10 pleasure horses in adjacent paddocks at a boarding facility in Pennsylvania, USA is reported (Wilkins et al., 1994). The horses showed depression, lethargy, ataxia, blindness, seizures and recumbency after eating whole ear maize. Four horses died or were euthanized. *F. moniliforme* (*Gibberella fujikuroi*) was cultured from the ear maize and fumonisins B$_1$, B$_2$ and B$_3$ at concentrations of 370, 105 and 41 ppm, respectively, were detected.

The first report of ELEM in Italy was observed by Caramelli et al. (1993) on a farm in Piedmont, where 3 of 40 horses showed sudden anorexia, hyperexcitability, incoordination,
flacid lips, blindness and recumbency followed by death in 72 hours. These horses had been fed for some days on maize screenings containing 60 mg/kg FB$_1$ and 14.6 mg/kg FB$_2$.

ELEM was first diagnosed in Hungary in September 1995, in a 13- years-old castrated male, a 6-ears-old stallion and a 2-years-old foal (Fazekas and Bajmicy, 1996). The disease started with lack of appetite followed by difficulties in swallowing and chewing indicating the paralysis of cephalic and pharyngeal muscles. Paralysis of the cephalic and cervical muscles spread to the muscles of the extremities and trunk and ataxia developed. Signs of blindness appeared in an animal. At the final stages of the disease, the affected animals became recumbent and died. Post-mortem examination of one horse showed oedema of the lungs and white matter of the brain. The affected animals were fed green maize containing FB$_1$ at 18.5 mg/kg of the whole plant.

Swine consuming more than approximately 120 ppm dietary fumonisins for 4 to 10 days develop acute porcine pulmonary oedema (PPE) (Coloin and Harrison, 1992; Colvin et al., 1993), more than 50 ppm of fumonisins causes mild liver lesions within 7 to 10 days, but concentrations of 25 ppm or less cause no apparent clinical effects. Mild microscopic hepatic lesions can be produced from diets as low as 23 ppm (Mortelin et al., 1994; Osweller, 1999). The sphinganine- sphingosine ratio may be altered in the serum by feed concentrations as low as 5 ppm and in the lung, liver and kidney by feed concentrations of 10 ppm, although the clinical significance of this is not established (Mortelin et al., 1994; Riley et al., 1993 and Rotter et al., 1996).

PPE represents the acute effects of FB$_1$ (Becker et al., 1995), while, the chronic effects of FB$_1$ in weaned pigs showed hyperplastic plaques in the oesophageal mucosa (Casteel et al., 1993). Swine fed a ration containing 100-190 ppm FB$_1$ for up to 83 days developed nodular hyperplasia of the liver and hyperplasia of the esophageal mucosa (Casteel et al., 1993). Swine fed 150-170 ppm FB$_1$ for up to 210 days developed medial hyperplasia of the pulmonary arteries and changes in gravimetric measurements of the heart (Casteel et al., 1994). In experimental trials, culture material of F. moniliforme (NRC826) was fed to horses, pigs, sheep, rats and baboons (Krick et al., 1981) lung oedema occurred only in pigs.

Acute PPE might be induced by increases in pulmonary interstitial macrophages resulting in release of vasoactive mediators (Huschek et al., 1992), pulmonary hypertension caused by vasoconstriction (Smith et al., 1996) and acute left-sided heart failure (Smith et al., 1999). There responses have been hypothesized to lead to pulmonary oedema either by increased pulmonary hydrostatic pressure or by pulmonary capillary endothelial cell damage (Cumpecht et al., 1998; Osweller, 1999).

Clinical signs of PPE typically occur soon (2-7 days) after pigs consume diets containing large concentrations of fumonisins over a short period of time (WHO, 2000). These signs include labored or difficult breathing (dyspnoea), weakness, cyanosis and death (Osweller et al., 1992; Mortelin et al., 1994 and Stack, 2003). Once signs appear, death may occur in less than 4 hours (Colvin and Harrison, 1992; Riley et al., 1993). Pregnant sows may abort from 1 to 4 days after the onset of signs (Osweller, 1992), probably as a sequela to fetal anoxia from severe pulmonary oedema (Osweller, 1999).
At necropsy, the diseased animals exhibit varying degrees of interstitial or interlobular oedema, with pulmonary oedema and hydrothorax. Varying amounts of clear cell-free yellow fluid accumulate in the pleural cavity (Colvin and Harrison, 1992; Colvin et al., 1993). Early histologic changes in the lung consisted of perivascular oedema followed by interlobular and peribronchial oedema. Ultrastructurally, alveolar endothelial cells contained unique accumulations of membranous material in the cytocavitory network (Cumpecht et al., 1998). Acidophilic fibriller material in alveoli and interlobular lymphatics, hyalinized alveolar capillary thrombi and increased numbers of pulmonary intravascular macrophages filled with osmophilic material (Colvin et al., 1992; Riley et al., 1993 and Osweller, 1999).

Dietary fumonisins concentrations of 75 to 120 ppm for 1 to 4 weeks cause icterus, reduced feed intake weight loss and occasionally diarrhoea (Osweller et al., 1993; Osweller, 1999). Toxic hepatosis occurs concurrently with PPE (Osweller et al., 1992; Colvin et al., 1993) and in also observed in animals that consume high levels of fumonisins but do not develop PPE (Hascek et al., 1996). Typically the liver contains multiple foci of coagulative necrosis with disrupted hepatic architecture, increased mitotic figures in heptocytes and single hepatic necrosis (Osweller et al., 1992; Colvin and Harrison, 1992; Colvin et al., 1993 and Riley et al., 1993).

Rabbits and Poultry:

Rabbits:

Rabbits given multiple doses of FB (0.15, 0.3, 0.5 or 1.0 mg/kg b.wt. for 4 or 5 days) intravenously, were lethargic and anorectic and had decreased urine production (Gumprecht et al., 1995). Renal lesions consisted of severe proximal tubular necrosis. Liver lesions were variable and consisted of mild hepatic vacuolation and bile stasis. A single dose of FB1 at 1.0 mg/kg b.wt induced renal but not hepatic injury.

Bucci et al. (1996) studied LEM and hemorrhage in the brain of rabbits gavaged with FB1 (1.75 mg/kg b.wt. daily) and observed that of 5 gavaged pregnant rabbits, 2 died after receiving 9 and 13 doses, respectively. Microscopic examination revealed focal small hemorrhages in cerebral white matter in both animals, with malacia and hemorrhage also present in the hippocampus of one. Both animals also had marked degeneration of renal tubules epithelium and of hepatocytes. Apoptosis was the dominant degenerative change in kidney and liver.

Pregnant New Zealand white rabbits are very sensitive to the toxic effects of FB1 (LaBorde et al., 1997). Maternal toxicity was observed at daily gavage dosage 0.25 mg/kg b.wt from gestational day 3 to gestational day 19. The maternal kidney, serum and urine Sa/So ratios were increased, but there was no increases in these ratios in fetal liver, brain or kidney. The lowest observed effect level for maternal toxicity was 0.1 mg FB1/kg b.wt., which is equivalent to a calculated dietary FB1 level of 2.3 mg/kg diet (LaBorde et al., 1997; WHO, 2000). This level is very close to the 2.24 mg/kg of fumonisin in the diet of young colts that could be theoretically be hazardous. Consequently, rabbits were grouped with horses (FDA, 2001a).

Poultry:

Turkey poultcs are more sensitive to the toxic effect of FB1 than broiler chicks (Weibking et al., 1993b) but chickens, turkeys and ducklings are relatively resistant to FB1 in comparison to
horses and swine, where significant toxicity and mortality occur at levels greater than 10 and 20 mg FB₁/ kg diet, respectively (Ross et al., 1991; Osweiler et al., 1992). On the other hand, one day-old chicks are more sensitive to the adverse effects of FB₁ than 7 or 21 days-old chicken (Javed et al., 1993).

**Broilers:**

A day-old chicks fed diets containing 200 or 300 mg FB₁/kg diet for 3 weeks had thymic cortical atrophy, multifocal hepatic necrosis, biliary hyperplasia and widening of the proliferating cartilage zone in proximal tibiotarsal physes (Ledoux et al., 1992). Acute randomly oriented hepatic necrosis with moderate biliary hyperplasia and hypertrophy of kupffer cells, mild-villus atrophy and goblet cells hyperplasia in the lower small intestines, small foci of acute myocardial and skeletal muscle necrosis and widening of both proliferating and hypertrophic zones in proximal tibiotarsal physes were found in a day-old chicks fed 300mg FB₁/kg diet for 2 weeks (Brown et al., 1992).

A day-old chicks fed diets containing 89, 190, 283, 481, 592 and 681 mg of total fumonisins/ kg diet for 3 weeks, had increased sphinganine: sphingosine ratios. Isolated foci of hepatic necrosis with a mild heterophil and macrophage infiltration, moderate diffuse hepatocellular hyperplasia, mild biliary hyperplasia and moderate to severe periportal granulocytic cell proliferation were noted only in broiler fed levels equal to or greater than 289 mg/kg (Weibking et al., 1993a; FDA, 2001a).

Dose response clinical signs, reduced body weight and mortality were observed in chicken fed diets containing 125 or 274 mg purified FB₁/kg diet (Javed et al., 1993).

Immunosuppression in chickens was produced in broilers fed diets containing 10 mg pure FB₁/kg diet or diets formulated from F.verticilloides (MRC826) culture material containing 30 to 80 mg FB₁/kg diet. Birds had reduced spleen and/ or bursa weights and altered haematological parameters (Espada et al., 1994, 1997).

Decreased prothrombin time and increased fibrinogen concentration and the activity of antithrombin III were observed in blood from broiler chicks that had been fed dietary FB₁ at a concentration of 10 mg/kg for only 6 days (Henry et al., 2000). Dietary FB₁ at concentration of 80 mg/kg or less did not adversely affect body weight, feed efficiency or water consumption in broiler chicks. Liver sphinganine concentration and the sphinganine: sphingosine ratio were increased significantly in all treated groups that had received 20, 40 and 80 mg FB₁/kg diet (Henry et al., 2000).

**Ducks:**

A day-old white Pekiny ducklings fed diets containing 120.5, 240.9 and 481.8 mg of total fumonisins/kg diet for 21 days had statistical increase in the mean kidney weights, liver sphinganie: sphingosine ratio and serum gamma glutamyl transferase activity as well as, mild to moderate hepatocellular hyperplasia (Bermudez et al., 1995; FDA, 2001a).

**Turkeys:**

Turkey poult have been shown to be susceptible to the adverse effects of FB₁. Biliary hyperplasia, hypertrophy of kupffer cells, thymic cortical atrophy and moderate widening of the proliferating and degenerating hypertrophied zones of tibial physes were observed in turkey pouls fed diets containing 100-200 mg FB₁/ kg diets (Weibking et al.,
Poor performance, increased organ weight, diarrhea, biliary hyperplasia, hepatocellular hyperplasia and rickets are caused in poults by dietary levels of FB₁ (>75 mg/kg) (Weibking et al., 1993a, 1995).

A day-old turkey poults fed diets containing graded levels of total fumonisins (33, 66, 99, 132, 231, 330, 429, 528 and 627 mg/kg) for 21 days showed liver lesions at levels equal to or greater than 99 mg/kg. Hepatocellular hyperplasia was mild at 99 and 132 mg/kg, moderate to severe at 330 mg/kg and severe at 429, 528 and 627 mg/kg (Leudoux et al., 1996; FDA, 2001a).

Turkey poults fed FB₁-contaminated diet for 21 days showed mild hepatic lesions at 75 mg/kg, cardiac lesions at 475 mg/kg, decreased performance at 325 mg/kg and increased liver weights at 25 mg/kg (Ledoux et al., 1996). Increased liver weight with moderate diffuse hepatocellular hyperplasia and elevated enzymes were observed in poults fed 200 mg FB₁/Kg of diet (Bermudez et al., 1997).

Gross lesions induced by fumonisin toxicity in poultry comprise consistent enlargement of the liver, and variable enlargement of kidney, pancrease, proventriculus and gizzard, atrophy of lymphoid organs and rickets (Calnek et al., 1997).

Histologically, the liver has multifocal necrosis of hepatocytes, hyperplasia of hepatocytes and bile ductules and hypertrophy of Kupffer cells. The intestine has villus atrophy and goblet cell hyperplasia. Growth plates are widened in both the zones of proliferating and hypertrophic cartilage. Myocardium and skeletal muscles have mild lesions and lymphoid tissues are depleted (Gureshi and Hagler, 1992; Calnek et al., 1997).

From the results of experimental studies conducted on fumonisins in poultry, it appears that: the turkey poult study (Ledoux et al., 1996) showed toxic effects at 99 ppm, the broiler study (Weibking et al., 1993a) at 190 to 280 ppm and the duckling study (Bermudez et al., 1995) at 120 ppm of total fumonisins in the diet. These toxic effects center around liver lesions. Although chicken may be slightly more resistant to fumonisins than turkeys and duckling, it appears that these 3 species should be considered fairly resistant to the toxic effects of fumonisins and should be grouped into one category (poultry fed for slaughter) (FDA, 2001a).

Catfish:

In channel catfish dosed with F. moniliforme culture, the lowest dietary concentrations of fumonisin associated with significantly elevated ratios of sphinganine to sphingosine in kidney, serum, liver and muscle were 10, 20, 40 and 80 mg of FB₁/kg of diet, respectively (Goel et al., 1994). Catfish fed diets containing FB₁ levels equal to or higher than 40 mg/kg of diet for 12 weeks showed decreased feed consumption, feed efficiency and weight gain (Li et al., 1994; Li and Robinson, 1995). The minimum level of FB₁ that depressed growth was 20-40 mg/kg (Li et al., 1994).

Catfish fed diets containing 40 mg FB₁/kg diet for 12 weeks had increased liver glycogen, increased vacuolation in nerve fibers and perivascular lymphohistiocytic investment in the brain compared with fish fed diets containing lower levels of fumonisins (0.7 to 20 mg/kg) (Li et al., 1994). Small white foci (2 to 4 mm diameter) of subcapsular adipocyte hyperplasia were observed in the livers of channel catfish fed 20 mg of FB₁/kg of diet for 10 and 14 weeks. Livers had also swollen hepatocytes with lipido containing vacuoles, lymphocyte infiltration and scattered necrotic hepatocytes (Lumlertdacha et al., 1995).
Regulatory control:

Based on the wealth of available information on the adverse animal health effects associated with fumonisins, human health risks associated with exposure to fumonisins are possible. Therefore, human exposure to such natural toxins should not exceed levels achievable with the use of good agricultural and good manufacturing practices (FDA, 2001b).

The recommended maximum levels for fumonisins in human foods and animal feeds (Tables, 1 and 2) that FDA considers achievable with the use of good agricultural and good manufacturing practices are presented below (FDA, 2000; FDA, 2001 b, c).

Table (1): Recommended maximum levels of fumonisins in human food products, U.S.

<table>
<thead>
<tr>
<th>Product</th>
<th>Total fumonisins (FB₁ + FB₂ + FB₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degermed dry milled corn products (e.g., flaking grits, corn grits, corn meal, corn flour with fat content of &lt; 2.25%, dry weight basis)</td>
<td>2</td>
</tr>
<tr>
<td>Whole or partially degermed dry milled corn products (e.g. flaking grits, corn grits, corn meal, corn flour with content of &lt; 2.25%, dry weight basis)</td>
<td>4</td>
</tr>
<tr>
<td>Dry milled corn bran</td>
<td>4</td>
</tr>
<tr>
<td>Cleaned corn intended for masa production</td>
<td>4</td>
</tr>
<tr>
<td>Cleaned corn intended for popcorn</td>
<td>3</td>
</tr>
</tbody>
</table>

1. Total fumonisins FB₁ + FB₂ + FB₃.

Table (2) Recommended maximum levels for fumonisins in corn, corn by products and the total ration for various animals species

<table>
<thead>
<tr>
<th>Animal or class</th>
<th>Maximum level of total fumonisins in corn and corn products (ppm)</th>
<th>Feed factor²</th>
<th>Maximum levels of total fumonisins in total ration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horses¹</td>
<td>5</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Rabbit</td>
<td>5</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Catfish</td>
<td>20</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>Swine</td>
<td>20</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>Ruminants¹</td>
<td>60</td>
<td>0.5</td>
<td>30</td>
</tr>
<tr>
<td>Milk²</td>
<td>60</td>
<td>0.5</td>
<td>30</td>
</tr>
<tr>
<td>Poultry³</td>
<td>100</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>Ruminant, poultry and mink breeding sock</td>
<td>30</td>
<td>0.5</td>
<td>15</td>
</tr>
<tr>
<td>All others⁴</td>
<td>10</td>
<td>0.5</td>
<td>5</td>
</tr>
</tbody>
</table>

1. Total fumonisins FB₁ + FB₂ + FB₃.
2. Fraction of corn or corn by-products mixed into the total ration
3. Includes asses, zebra and onagers.
4. Cattle, sheep, goats and other ruminants that are ≥ 3 months old and fed for slaughter.
5. Fed for pelt production.
6. Turkeys, chickens, ducklings and other poultry fed for slaughter.
7. Includes laying hens, roosters, lactating dairy cows and bulls.
8. Includes dogs and cats.

In six instances, the U.S. FDA (2000) grouped species together because the animals seemed to have a similar sensitivity to fumonisins. This is an attempt to avoid a multitude of guidance levels and does not necessarily imply that the species are biologically similar.

1-Horses and rabbits were grouped together as the most sensitive species. Corn and corn-by products used in rations of horses and rabbits should contain less than 5 ppm of total fumonisins and comprise no more than 20% the dry weight of the total ration (Table 2). The total ration should contain less than 1 ppm of total fumonisins.
2-Catfish and swine were grouped together as intermediate in sensitivity to fumonisins. Corn and by products used in rations of catfish and swine should contain less than 20 ppm of total fumonisins, and comprise no more than 50% of the dry weight of the total ration. The total ration should contain less than 10 ppm of total fumonisins.

3-Ruminants, mink and poultry were considered more resistant than horses, rabbits, catfish and swine to fumonisins. Corn and corn by products used in rations of ruminants that are at least 3 months old fed for slaughter and in rations of mink fed for pelt production should contain less than 60 ppm of total fumonisins, and comprise no more than 50% of the dry weight of the total ration. The total ration should contain less than 30 ppm of total fumonisins.

4-Corn and corn by products used in the rations of poultry fed for slaughter should contain less than 100 ppm of total fumonisins, and comprise no more than 50% of the dry weight of the total ration. The total ration should contain less than 50 ppm of total fumonisins.

5-Corn and corn by products used in the rations of mink, ruminants and poultry breeding stock should contain less than 30 ppm of total fumonisins, and comprise no more than 50% of the weight of the total ration. The total ration should contain less than 15 ppm of total fumonisins.

6-Corn and corn by products used in rations of dogs and cats should contain less than 10 ppm of total fumonisins, and comprise no more than 50% of the dry weight of the total ration. The total ration should contain less than 5 ppm of total fumonisins.

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السموم الفطرية في الأغذية والأعلاف

4- الفيومونيزنس

بدير إبراهيم عجاج

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