Nutritional and Health Implications of Mycotoxins in Animal Feeds: A Review

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Abstract: Mycotoxins are harmful substances produced by fungi in various foods and are estimated to affect as much as 25% of the world’s crop each year. Most of these mycotoxins belong to the three genera of fungi: Aspergillus, Penicillium and Fusarium. Although over 300 mycotoxins are known, those of most concern based on their toxicity and occurrence, are aflatoxin, vomitoxin, ochratoxin, zearalenone, fumonisin and T-2 toxin. They are produced in cereal grains as well as forages before, during and after harvest in various environmental conditions. The presence of mycotoxins in feeds may decrease feed intake and affect animal performance. In addition, the possible presence of toxic residues in edible animal product such as milk, meat and eggs may have some detrimental effects on human health. Fungal contamination affects both the organoleptic characteristics and the alimentary value of feeds and entails a risk of toxicosis. The biological effects of mycotoxins depend on the ingested amounts, number of occurring toxins, duration of exposure to mycotoxin and animal sensitivity. Mycotoxins display a diversity of chemical structures, accounting for their different biological effects. Depending on their precise nature, these toxins may be carcinogenic, teratogenic, mutagenic, immunosuppressive, tremor genic, hemorrhagic, hepatotoxic, nephrotoxic and neurotoxic. Controlling mould growth and mycotoxin production is very important to the feed manufacturer and livestock producer. Control of mould growth in feeds can be accomplished by keeping moisture low, feed fresh, equipment clean and using mould inhibitors. In addition, control of mycotoxins in animal diets would reduce the likelihood that mycotoxin residues would appear in animal products destined for human consumption.

Key words: Nutritional, health, mycotoxins, moulds, animal feeds

Introduction
Mycotoxins are diverse range of molecules that are harmful to animals and humans. They are secondary metabolites secreted by moulds, mostly Penicillium and Fusarium. They are produced in cereal grains as well as forages before, during and after harvest, in various environmental conditions. Due to the diversity of their toxic effects and their synergetic properties, mycotoxins are considered as risky to the consumers of contaminated foods and feeds (Yiannikouris and Jonany, 2002).

Mycotoxins are metabolized in the liver and the kidneys and also by microorganisms in the digestive tract. Therefore, often the chemical structure and associated toxicity of mycotoxin residues excreted by animals or found in their tissues are different from the parent molecule (Ratcliff, 2002).

No region of the world escapes the problem of mycotoxins and according to Lawlor and Lynch (2005) mycotoxins are estimated to affect as much as 25 percent of the world’s crops each year. Whether grain is produced in temperate, sub-tropical or tropical climates, if rainfall and humidity are experienced in the harvest season, infection of the grain by fungi is likely. Fungi are extremely adaptable organisms being able to metabolize a large variety of substrates over a wide range of environmental conditions mycotoxins are produced only under aerobic condition (Ratcliff, 2002).

In farm animals, mycotoxins have negative effects on feed intake, animal performance, reproductive rate, growth efficiency, immunological defense as well as been carcinogenic, mutagenic, teratogenic, tremor genic-cause tremor or damage the central nervous system, haemorrhagic, as well as causing damage to the liver and kidneys. Ruminant animals are generally more tolerant of feed contaminated by mycotoxins than non-ruminant species due to the detoxifying capabilities of rumen micro organisms. Swine are generally the most sensitive with poultry intermediate (Ratcliff, 2002).

Mycotoxins occur sporadically both seasonally and geographically. The formation of mycotoxins in nature is considered a global problem, however, in certain geographical areas of the world, some mycotoxins are produced more readily than others (Devegowda et al., 1998; Ratcliff, 2002; Lawlor and Lynch, 2005). Table 1, shows the mycotoxin that may be found in feeds that come from different global locations. They occur naturally in a wide variety of feedstuffs used in animal feeds. In most European countries aflatoxins are not considered to be a major problem. In contrast, vomitoxin, ochratoxin, zearalenone are found more frequently. Aflatoxins are common in humid climatic conditions like those existing in Asian and African countries and certain parts of Australia. Mycotoxins are regularly found in feed
ingredients such as maize, sorghum, barely, wheat, rice meal, cotton seed meal, groundnuts and other legumes. The problem of mycotoxins does not just end in animal feed or reduce animal performance, many become concentrated in meat, egg and milk of animal and can pose a threat to human health. Some examples of foods of animal origin which may be naturally contaminated with mycotoxins are shown in Table 2. There is increasing concern about levels of mycotoxin in human foods, both from vegetable origin and animal origin. In milk, aflatoxin appears as aflatoxin M₁, which is one of its metabolites.

Common mycotoxins in feedstuffs: The most commonly encountered mycotoxins in feedstuffs and foods are aflatoxins, zearalenone, ochratoxins, fumonisins, T2-toxin and deoxynivalenol (vomitoxin).

Aflatoxins: Aflatoxins are fluorescent compound, they are chemically classified as difurocoumarolactones and their biosynthesis by the producing fungi is via the polyketide pathway (Smith and Moss, 1985). Four major aflatoxins produced in feedstuffs and foods are aflatoxins B₁, B₂, G₁ and G₂. The most potent and the most frequently occurring of the four compounds is aflatoxin B₁. Aflatoxin is a metabolite of aflatoxin B that occurs in various tissues and fluids from animals (Richard et al., 1993).

Two major species of Aspergillus are responsible for the production of aflatoxins in feedstuffs and foods, Aspergillus flavus and Aspergillus parasiticus. Infection and production of aflatoxins in field crops by these species is often associated with drought stress and insect damage (Richard et al., 1993).

While young animals are most susceptible to the effects of aflatoxin, all ages are affected; and clinical signs include gastrointestinal dysfunction, reduced productivity, decreased feed utilization and efficiency. Nursing animals may be affected by exposure to aflatoxin metabolites secreted in the milk.

Aflatoxin causes a variety of symptoms depending on the animal species. However, in all animals, aflatoxin can cause liver damage, decreased reproductive performance, reduced milk or egg production, embryonic death, teratogenicity (birth defects), tumors and suppressed immune system function, even when low levels are consumed (Jones et al., 1994). Aflatoxin contaminated feed is detrimental to the swine industry (CAST, 1989). Reduced feed intake, lowered gains and in some cases reduced feed efficiency has been observed for swine fed contaminated feed (Harvey et al., 1988). The physiological effects of aflatoxin consumption include liver damage characterized by enlargement, release of enzymes into the blood (for example, asparatase aminotransferase and alkaline phosphatase) and impaired protein synthesis (CAST, 1989). Aflatoxins M₁ appears in milk of sows consuming aflatoxin contaminated feeds and may affect piglets nursing those sows (Jones et al., 1994). Aflatoxin affects all poultry species. Although it generally takes relatively high levels to cause mortality, low levels can be detrimental if continually fed. Young poultry, especially ducks and turkeys are very susceptible. As a general rule, growing poultry should not receive more than 20ppb aflatoxin in their diet. However, feeding levels lower than 20ppb may still reduce their resistance to disease, decrease their ability to withstand stress and bruising and generally make them unthrifty (Jones et al., 1994).

Zearalenone: Zearalenone, a non-steroidal estrogenic mycotoxin and it major metabolic products (α-zearalenol and β-zearalenol). Zearalenone is insoluble in water and heat-stable and it persists in both animal feeds and human food prepared from contaminated grains (Shipchandler, 1975).

Fusarium graminearum (Gibberella zeae and Fusarium culmorum are the major zearalenone producing species and are distributed worldwide (Marasas et al., 1984). Zearalenone mimics the effect of the female hormone estrogen and at low doses, increases the size or early maturity of mammary glands and reproductive organs. At higher doses zearalenone interferes with conception, ovulation, implantation, fetal development and the viability of newborn animals (Jones et al., 1994). Zearalenone causes estrogenic responses in dairy cattle, and large doses of this toxin are associated with abortions. Other responses of dairy animals to zearalenone may include reduced feed intake, decreased milk production, vaginitis, vaginal secretions,
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Table 2: Some Food of Animal Origin which may be Naturally Contaminated with Mycotoxins

<table>
<thead>
<tr>
<th>Mycotoxins</th>
<th>Potential Effects on Humans</th>
<th>Occurrence</th>
<th>Maximum Level Reported (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aflatoxin B₁</td>
<td>Hepatic cancer</td>
<td>Eggs</td>
<td>0.4</td>
</tr>
<tr>
<td>Pig liver</td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Pig muscle</td>
<td></td>
<td></td>
<td>1.04</td>
</tr>
<tr>
<td>Pig kidney</td>
<td></td>
<td></td>
<td>1.02</td>
</tr>
<tr>
<td>Aflatoxin M₁</td>
<td>Carcinogenic</td>
<td>Cow milk</td>
<td>0.33</td>
</tr>
<tr>
<td>Ochratoxin A</td>
<td>Renal damage</td>
<td>Pig liver</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kidney</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sausages</td>
<td>3.4</td>
</tr>
<tr>
<td>Zearalenone</td>
<td>Oestrogenic</td>
<td>Pig liver</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pig muscle</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: (FAO, 2002)

Poor reproductive performance and mammary gland enlargement in heifers. It is recommended that zearalenone should not exceed 250 ppb in the total diet (Jones et al., 1994).

Ochratoxins: The ochratoxins are metabolites produced by certain species of the genera Aspergillus and Penicillium (Wood, 1992). Ochratoxin A, discovered in 1985 by South African Scientists as a toxic secondary metabolite of Aspergillus ochraceus (Van der Merwe et al., 1965). Other species of Aspergillus ochraceus group and several Penicillium species, including Penicillium viridicatum, have been shown to form ochratoxin A (Harwig et al., 1974).

Ochratoxin A is the major metabolite of toxicological significance and it is mainly a contaminant of cereal grains (corn, barley, wheat and oats). It has also been found in beans (soybeans, coffee, cocoa) and peanuts and meat in some countries (Krogh, 1987). Ochratoxin A is teratogenic in rat, hamster and chick embryo and is an inhibitor of hepatic mitochondrial transport systems. Ochratoxin A has also been reported to cause damage to the liver, gut, lymphoid tissue and renal tubular damage (Harwig et al., 1974).

Fumonisins: The fumonisins are a group of compounds originally isolated from Fusarium moniliforme (Gelderblom et al., 1988). Six different fumonisins (F₁, FA₁, FB₁, FB₂, FB₃ and FB₄) have been reported, the A series are amides and the B series have a free amine (Gelderblom et al., 1992).

In most animals fumonisin impairs immune function, causes liver and kidney damage, decreases weight gains, and increases mortality rates. It also causes respiratory difficulties in swine (Jones et al., 1994). The fumonisins (FB₁ and FB₂) were recently isolated from Fusarium moniliforme cultures and found to promote cancer in rats (Gelderblom et al., 1988). These toxins occur naturally in corn and have been associated with equine leukoencephalomalacia (Ross et al., 1990).

T-2 Toxin: The T-2 toxin, produced mainly by Fusarium tricinctum, was the first trichothecene to be found as a naturally occurring grain contaminant in the United States (Hsu et al., 1972). It was associated with a lethal toxicosis in dairy cattle that had consumed moldy corn in Wisconsin. This mycotoxin rarely associated with disorders in animals or humans in other countries (Mirocha, 1984).

Yoshizawa et al., 1981, stated that the chance of finding T-2 toxin as a residue in edible tissue is remote because it is rapidly metabolized in vivo.

In dairy cattle T-2 toxin has been associated with feed refusal, production losses, gastroenteritis, intestinal haemorrhages and death. T-2 has also been associated with reduced immune response in calves. In poultry, T-2 toxin has been implicated to cause mouth and intestinal lesion as well as impair the bird’s immune response, causing egg production declines, decreased feed consumption, weight loss and altered feather patterns (Jones et al., 1994).

Vomitoxin: Vomitoxin also called deoxynivalenol is stable, survives processing, milling and does occur in food products and feeds prepared from contaminated corn and wheat. The most common producer of vomitoxin is Fusarium graminearum (Marasas et al., 1984). Vomitoxin is perhaps, the most commonly detected Fusarium mycotoxin. Vomitoxin has been associated with reduced milk production in dairy cattle, vomiting by swine consuming contaminated feed or their refusal to eat feed containing the toxin, and inhibiting reproductive performance and immune function in several animal species (Jones et al., 1994).

Effects of mycotoxins on animal nutrition and health: Mycotoxins have significant economic and commercial impact, in that both the productivity and nutritive value of the infected cereal and forage is affected (Ratcliff, 2002). The effect of mould contamination on nutritional value of stored maize is presented in Table 3. The nutritive value drops after contamination by mould.

Contamination by moulds affects both the alimentary value and organoleptic characteristic of feed and entails a risk of toxicosis. The biological effects of mycotoxins
depend on the ingested amounts, number of occurring toxins, duration of exposure to mycotoxins and animal sensitivity. Also mycotoxins can induce health problems that are specific to each toxin as shown in Table 4, or affect the immune status of animals, favouring infections. This is the major reason for the difficulty of diagnosing mycotoxicoses (Yiannikouris and Jonany, 2002).

Mycotoxins produce a wide range of harmful effects in animals. The economic impact of reduced animal productivity, increased incidence of disease due to immunosuppression, damage to vital organs and interference with reproductive capacity is many times greater than the impact caused by death due to mycotoxic poisoning. Mycotoxins in combination appear to exert greater negative impact on the health and productivity of livestock in comparison to their individual effects (Smith and Seddon, 1998).

Control of Moulds and Mycotoxins in Animal Feeds: Controlling mould growth and mycotoxin production is very important to the feed manufacturer and livestock producer. Control of mould growth in feeds can be accomplished by keeping moisture low, feed fresh, equipment clean and using mould binders and inhibitors. Grains and other dry feedstuffs should be stored at a moisture level of less than 14 percent to prevent mould growth. Aeration of grain bins is important to reduce moisture migration and keep the feedstuff dry (Jones et al., 1994). The use of chemical mould inhibitors is a well-established practice in the feed industry. However, mould inhibitors are only one of several tools useful in the complex process of controlling the growth of moulds, and they should not be relied upon exclusively. The main types of mould inhibitors are:

1. Individual or combinations of organic acids (for example, propionic, sorbic, benzoic and acetic acids).
2. Salts of organic acids (for example, calcium propionate and potassium sorbate), and
3. Copper sulphate, solid or liquid forms work equally well if the inhibitor is evenly dispersed through the feed.

Generally, the acid form of a mould inhibitor is more active than its corresponding salt (Jones et al., 1994).

Binding agents such as bentonite, aluminosilicates, spent canola oil, bleaching clays and alfalfa fibre have been used in feeds containing mycotoxins to prevent intestinal absorption of the toxins (Smith and Seddon, 1998). Mineral clay products such as bentonites, zeolites and aluminosilicates have been found to be effective in binding/adsorbing mycotoxins (Ramos et al., 1996). Among these, aluminosilicates have been found to be more effective. The molecular surfaces of these additives, when saturated with water, attract the polar functional atomic structure of the mycotoxin and trap it against its surface. This isolates the mycotoxin from the digestive process and thereby prevents it from entering into circulation. Hydrated sodium calcium aluminosilicate (HSCAS) at 1.0% of the feed (10kg per tonne) can significantly diminish the adverse effects of aflatoxin in chickens, pigs and cows (Scheidler, 1993). However, these clays have a number of disadvantages, the high inclusion levels and narrow range of binding efficacy. They appear to have little or no beneficial effect against vomitoxin, T-2 toxin and Ochratoxin (Huff et al., 1992). In addition, they reduce mineral utilization at a higher level of inclusion (Chestnut et al., 1992).

Modified yeast cell wall mannanoligosaccharide (MOS) has been reported to effectively bind aflatoxin and to bind ochratoxins. This product has advantage over other binding agents in that it does not bind vitamins or minerals (Lawlor and Lynch, 2005).

Some foods may contain compounds that are inhibitory to fungal growth and mycotoxin production (Bullerman et al., 1984). Certain herbs, spices and essential oils contain naturally occurring antifungal substances that may exert a protective effect at normal usage levels. Hitokoto et al. (1978) reported that mustard, green garlic, cinnamon bark and hops inhibit mould growth, whereas peppers, cloves, thyme and green tea inhibited toxin production only. Llewellyn et al. (1981), also found that cinnamon, cloves and mustard had antymycotic properties and thyme and oregano were anti aflatoxigenic. Cinnamon, cinnamon oil, clove and clove oil have been demonstrated to have strong antymycotic properties (Bullerman, 1974; Bullerman et al., 1977). All four substances inhibited growth and aflatoxin production. The essential oils of lemon and orange have been shown to be inhibitory to Aspergillus niger and Aspergillus flavus and to suppress aflatoxin formation (Subba, 1967; Alderman and Marth, 1976). Welford et al., 1978 reported that honey had an antifungal effect against Aspergillus flavus and Aspergillus parasiticus and an even stronger anti aflatoxigenic effect. Other substances such as the antifungal antibiotic natamycin (pimaricin) has strong antymycotic properties but are only permitted for limited use in the United States. Azzouz and Bullerman (1982) reported that 0.0035% (5ppm) natamycin delayed the growth of seven mycotoxigenic species for 5 to 21 days.

At the farm level a number of management strategies...
Table 4: Mycotoxins and their effects on different species of livestock

<table>
<thead>
<tr>
<th>Mycotoxins</th>
<th>Species susceptibility</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aflatoxin</td>
<td>All domestic animals and poultry</td>
<td>Hepatotoxic, carcinogenic, immunosuppressive</td>
</tr>
<tr>
<td>Zearalenone</td>
<td>Mainly pigs and dairy animals</td>
<td>Estrogenic and reproductive disorder</td>
</tr>
<tr>
<td>Vomitoxin</td>
<td>Mainly pigs and dairy animals</td>
<td>Dermatotoxic, feed refusal</td>
</tr>
<tr>
<td>Ochratoxin</td>
<td>Mainly pigs and poultry</td>
<td>Nephrototoxic, gout</td>
</tr>
<tr>
<td>T-2 toxin</td>
<td>Mainly pigs and poultry</td>
<td>Mouth lesions, loss of appetite</td>
</tr>
<tr>
<td>Fumonisins</td>
<td>Mainly pigs and horses</td>
<td>Neurological disorders, liver damage</td>
</tr>
</tbody>
</table>

Source: Ratcliff (2002)

can be employed to minimize the development of mycotoxins in feeds. One of the key factors is the time feed is stored on the farm. More frequent delivery of feed with shorter residence time reduces the build up of mycotoxins (Good and Hamilton, 1981).

Various techniques on dietary manipulation have been reported to reduce the adverse effects of mycotoxins. Increasing the levels of selenium, methionine, carotenoids and vitamin supplementation have been found to be beneficial although not necessarily cost effective (Ratcliff, 2002). Jones et al., 1994 also reported that increasing nutrient such as protein, energy (fats and carbohydrates) and vitamins in the diet may also be advisable. The addition of antioxidants to animal diets may assist in dealing with the effects of mycotoxins.

**Conclusion:** It is clear that mycotoxins will be of increasing importance for all those involved in feed manufacturing, farming and food production. Quality of raw materials, prevention of the occurrence of mycotoxins, control and testing systems are all essential to reducing the exposure of humans and animals to mycotoxins.

**References**


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