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Review

Mycotoxins in animals: Occurrence, effects, prevention and management

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Globalization of the trade in agricultural commodities has contributed significantly to the discussion about potential hazards involved and has increased in particular the awareness of mycotoxins. Safety awareness in food and feed production has also risen due to the simple fact that methods for testing residues and undesirable substances have become noticeably more sophisticated and more available at all points of the supply chain. Mycotoxins comprise of a family of fungal toxins, many of which have been implicated as chemical progenitors of toxicity in man and animals. There are four classes of mycotoxins of major concern namely aflatoxins, zearalenone, ochratoxins, and fumonisins. Formation of mycotoxins varied between species as well as within a given species. A variety of physical, chemical, and biological methods to counteract the mycotoxin problem have been reported, but large-scale, practical, and cost-effective methods for detoxifying mycotoxin-containing feedstuffs are currently not available. Detoxification strategies for the contaminated foods and feeds should be done to reduce or eliminate the adverse actions of mycotoxin to improve food safety and prevent economic losses. The most recent approach to the problem has been the addition to the animal's diet of nonnutritive sorbents that sequester mycotoxins, reduce their gastrointestinal absorption and avoiding their toxic effects on livestock and toxin carryover into animal products. This review comments on the potential hazards of several mycotoxins together with prevention strategy for fungal and mycotoxin contamination.

Key words: Mycotoxins, detoxification, aflatoxins, zearalenone, ochratoxins, prevention.

INTRODUCTION

Toxic substances are almost ubiquitous in the environment. Thus, they are also present in ingredients for animal feed. Adequate risk management depends on knowledge of absorption, metabolism, carry-over and toxicological profile of these substances and on practical measures to reduce them. Generally, toxic substances are metabolized before or after absorption through the intestinal tract (Kan and Meijer, 2007). Depending on their physico-chemical characteristics, some substances are metabolized into naturally occurring and generally harmless constituents. Most veterinary drugs and feed additives fall into this group (Kan and Meijer, 2007). Some mycotoxins were heat stable up to as much as 400°C. As a result, they may also be of relevance in processing operations (Mayer et al., 2008).

Molds (fungi) develop from spores that are found ubiquitously in the environment. Mold growth on grain under field conditions or during storage can occur at moisture levels above 16% and at temperatures above freezing. The growth of molds on grain can affect the nutritional quality of grain in several ways (Marguardt, 1996). First, they decrease the nutritional value of the commodity as they consume fats, protein and carbohydrates

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Table 1. Examples of fungal species and mycotoxins of economical significance in animal agriculture (D'Mello and Macdonald, 1997).

Fungal species	Mycotoxins
Aspergillus flavus and *A. parasiticus*	Aflatoxins
A. Ochraceus, Penicillium viridicatum, and *P. cyclopium*	Ochratoxin A
Fusarium culmorum, F .graminearum, and *F. sportrichoides*	Deoxynivalenol
F. sporotrichoides and F. poae	T-2 toxin
F. sporotrichoides, F. graminearum, and *F. poae*	Diacetoxyscirpenol
F. culmorum, F. graminearum, and *F. sporotrichoides*	Zearalenone
F. proliferatum, F. verticillioides	Fumonisins
Acremonium coenophialum	Ergopeptine
Alkaloids	
A. *lolii*	Lolitrem alkaloids

that are present in the grain. Thus these nutrients are no longer available to the animal. Secondly, some species of mold are able to produce highly toxic compounds called mycotoxins.

These toxins can adversely affect animal health and production and can cause harmful effects to humans if transmitted into foods. The combined presence of mold and mycotoxins may cause decreased feed intake, decreased feed efficiency, decreased rate of gain, and increased risk of infection as well as reproductive problems (Marguardt, 1996).

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 excreated 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 Lowlor and Lynch (2005) mycotoxins are estimated to affect as much as 25% of the world's crop each year.

Moulds and associated mycotoxins are important factors adversely affecting foods produced using contaminated plant products or animal products derived from animals fed on contaminated feeds (Robens and Cardwell, 2003). Mycotoxins are toxic to humans and animals, which explains the major concern of food and feed industries in preventing them from entering the food chain (Pierre, 2007). Toxin-producing moulds may invade plant material in the field before harvest, during post-harvest handling and storage and during processing into food and feed products. Thus, toxigenic fungi have been roughly classified into two groups (i) field fungi; (ii) storage fungi (Pierre, 2007).

Mycotoxins are secondary metabolites produced by filamentous fungi that cause a toxic response (mycotoxicosis) when ingested by higher animals. Cereal plants may be contaminated by mycotoxins in two ways: fungi growing as pathogens on plants or growing saprophytically on stored plants (Glenn, 2007). However, not all fungal growth results in mycotoxin formation and detection of fungi do not imply necessarily the presence of mycotoxins. Consumption of a mycotoxin-contaminated diet may induce acute and long-term chronic effects resulting in teratogenic, carcinogenic, and oestrogenic or immune-suppressive effects. Direct consequences of consumption of mycotoxin-contaminated animal feed include: reduced feed intake, feed refusal, poor feed conversion, diminished body weight gain, increased disease incidence (due to immune-suppression), and reduced reproductive capacities (Fink-Gremmels and Malekinejad, 2007; Morgavi and Riley, 2007; Pestka, 2007; Voss and Haschek, 2007) which leads to economic losses (Huwig et al., 2001; Wu, 2004, 2006).

Due to modern laboratory methods and a growing interest in this field of research, more than 300 different mycotoxins have been differentiated thus far. However, for a practical consideration in the feed-manufacturing process only a small number of toxins are of relevance, with aflatoxins, trichothecenes, zearalenone, ochratoxins and fumonisins (Table 1) being of particular interest, although it has to be mentioned that the extent of each toxin impairment is highly species-dependant (Erber and Binder, 2004). The Fusarium genus, e.g. *Fusarium verticillioides* (formerly *Fusarium moniliforme*), *Fusarium roseus*, *Fusarium tricinctum* and *Fusarium nivale*, are ubiquitous soil organisms, which may infect cereals directly in the field thereby, increasing fumonisins, trichothecene, and zearalenone levels (depending on the species) during growth, ripening of grain and at harvesting.

Although the scientific literature offers a broad variety of information on the effects of individual mycotoxins in various animal species, concurrent exposure to multiple mycotoxins is more likely in the livestock industry (Table 2). For example, aflatoxin and fumonisin B1, as well as deoxynivalenol (DON) or other trichothecenes (one or even more of them) and zearalenone frequently occur

Table 2. Geographic occurrence of mycotoxins**.**

Location	Mycotoxins
Western Europe	Ochratoxin, Vomitoxin, Zearalenone
Eastern Europe	Zearalenone, Vomitoxin.
North America	Ochratoxin, Vomitoxin, Zearalenone, Aflatoxins
South America	Aflatoxins, fumonisins, Ochratoxin, Vomitoxin, T-2 toxin.
Africa	Aflatoxins, fumonisins, Zearalenone.
Asia	Aflatoxins
Australia	Aflatoxins, fumonisins

Source: Devegowda et al. (1998).

together in the same grain. Additionally, in the feed manufacturing process, various batches of different raw materials are mixed together thus producing a totally new matrix with a new risk profile. Poor livestock performance and/or disease symptoms observed in commercial operations may be due to the synergistic interactions between multiple mycotoxins. Scientific reports on synergistic effects of mycotoxins at acute toxicity levels describe combinations of aflatoxins with various trichothecenes, as well as with ochratoxins and fumonisins, but also combinations of fumonisins plus DON. Nevertheless it has to be pointed out that far more work has to be done in this particular field of research, especially in the sub-acute contamination range as well as with combinations of more than two toxins (CAST, 2003; Erber and Binder, 2004).

Several of the major mycotoxins exert their effects through different organ systems and different biological pathways. Aflatoxin, ochratoxin, and T-2 toxin all interfere with protein formation, but each does so in a different manner; aflatoxin binds to both RNA and DNA and blocks transcription (Kan and Meijer, 2007). T-2 toxin blocks initiation of translation, and ochratoxin blocks phenylalanine-t RNA synthetase, and thus blocks translation. Some scientists assume complete absorption of these noxious substances, as a worst-case scenario to predict residues in animal products from those in feed (Kan and Meijer, 2007). By doing so, they ignore the physiological processes occurring during transit through the intestine and after absorption into the general circulation as well as intermediary metabolism. Furthermore this approach does not take advantage of existing knowledge to identify or implement possible control points for reduction of levels of residues in animal products (Kan and Meijer, 2007).

Multi-toxin occurrence may be one important explanation for divergences in effect levels described in the scientific literature, where defined, mostly purified mycotoxins are used in most studies. In field outbreaks, naturally contaminated feeds may contain multiple mycotoxins and thus apparently lower contamination levels of a single specific mycotoxin can be associated with more severe effects.

Analytical methods for separation of mycotoxins included thin-layer chromatography (TLC), gas chromatography (GC), and High-performance liquid chromatography (HPLC). The few TLC methods had been used for screening and not for quantification (Abbas et al., 2004; Benedetti et al., 2006). GC with high-resolution MS had also been used for analysis of some mycotoxins (Fernandez et al., 2007; Ikonomou et al., 2008). However, a labour-intensive derivatization step was often indispensable prior to GC analysis. Therefore, HPLC–MS–MS had increasingly become the method of choice for mycotoxin analysis (Abbas et al., 2004; Benedetti et al., 2006; Fernandez et al., 2007).

Mycotoxin losses and costs of mycotoxin management are overlapping areas of concern. Costs of mycotoxin management include research production practices, testing and research necessary to try to prevent the toxins from appearing in food and feed products of affected commodities (Robens and Cardwell, 2003). Mycotoxin losses result from lowered animal production (Robens and Cardwell, 2003) and any human toxicity attributable to the presence of the toxin (Council for Agricultural Science and Technology (CAST, 1989) in the affected commodity which lowers its market value, as well as secondary effects on agriculture production and agricultural communities (CAST, 1989).

Due to the multiple possible origins of fungal infection, any prevention strategy for fungal and mycotoxin contamination must be carried out at an integrative level all along the food production chain (Robens and Cardwell, 2003). Three steps of intervention have been identified. The first step in prevention should occur before any fungal infestation; the second step is during the period of fungal invasion of plant material and mycotoxin production; the third step is initiated when the agricultural products have been identified as heavily contaminated. Such hazard analysis has some similarity with the HACCP management system of food safety (Degirmencioglu et al., 2005), mainly with the principles 2 (Determination of critical control points) and 3 (Establish critical limits). Most of the efforts must be concentrated on the two first steps since, once mycotoxins are present, it is difficult to eliminate them in a practical way.

Approaches to prevent mycotoxicoses include pre- and post-harvest strategies; the latter are often categorized into physical, chemical and biological methods (Jouany, 2007). The best way would be the prevention of mycotoxin formation in the field of its first place, which is supported by proper crop rotation and fungicide administration at the right time. In case of toxin manifestation, measures are required that act specifically against certain types and groups of toxins. The most prevalent approach counteracting mycotoxins in the feed industry is to include sorbent materials into the feed, for more or less selective removal of toxins by means of adsorption within the route of the gastrointestinal tract, or to add enzymes or microbes capable of detoxifying certain mycotoxins or toxin groups (Leibetseder, 2005).

FACTORS THAT PROMOTE FUNGAL GROWTH AND MYCOTOXIN PRODUCTION

Besides the presence of nutrients, the most important factors for growth and mycotoxin production are temperature, water activity (aw) and oxygen. Often contamination of food by fungi may vary due to different origins of contamination, especially storage buildings, bins or underground pits (Christensen and Sauer, 1982). Often, fungi invade only a minor fraction of feed particles with appropriate condition for a growth such as enough water content, aeration, etc.

Substrates differ in their ability to support fungal growth due to differences in their physical and chemical characteristics, which include water activity, oxygen availability and surface area, while chemical characteristic include carbohydrates, fat, protein, trace elements and amino acid composition (Russell et al*.,* 1991). While some substrates are susceptible to colonization, other environmental conditions increase the vulnerability of the fungi to the substrate. The conditions include temperature, water activity, pH and atmospheric air (oxygen) (Moss, 1991).

Temperature

It has been shown that *Penicillium* species have a lower minimum temperature range than *Aspergillus* species. The optimal temperature for *Penicillium* and *Aspergillus* is 25 to 30°C and 30 to 40°C, respectively. The maximal temperature is 28 to 30°C for *Penicillia* and 37 to 47°C for most *Aspergilli*. Various *Fusarium* species can also be regarded as psychrophilic, because of their low optimal temperature of 8 to 15°C (Moss, 1991).

Water activity

Water activity (aw) is a measure of unbound water in the food available for the growth of the mould. Values for water activity appreciation vary between 0.61 and 0.91. Most storage fungi grow at aw<0.75 (Moss, 1991). It is important to note that ambient conditions (temperature and humidity) do not only influence the rate at which chemical changes may take place, but also the growth of fungi and insect pests (Francis and Wood, 1982). This is because high temperatures and relative humidity provide ideal conditions for growth and development of moulds with possible production of mycotoxins (Pitt and Hocking, 1997).

Smith and moss (1985) reported that moisture determines whether microbes can colonize a substrate or not. These factors enable moulds to break down complex macromolecular compounds and utilize them for growth and metabolism. In the process, they produce and secrete toxic secondary metabolite, which are "mycotoxins" (Moss, 1996). Excessive moisture in the field and in storage, temperature extremes, humidity, drought, variations in harvesting practices and insect infestations are major environmental factors that determine the severity of mycotoxin contamination (Hussein and Brassel, 2001).

pH

At high water activities, fungi compete with bacteria as food spoilers (Wheeler et al*.,* 1991). Most fungi are little affected by pH over a broad range, commonly 3 to 8 (Wheeler et al*.,* 1991), however, the pH of a medium may exercise important control over a given morphogenic event without remarkably influencing the overall growth of a fungus (Pitt and Hocking, 1997).

Oxygen

Oxygen is essential for the growth of fungi, but certain species can also grow under anaerobic conditions with the formation of ethanol and organic acids. Oxygen also influences production of mycotoxins. The production of patulin and penicillic acid decrease sharply at low oxygen concentrations, while fungal growth is not noticeably influenced (Northolt, 1979). *Aspergillus* growth is restricted at an oxygen concentration of less than 1% (Pitt and Hocking, 1997) (Tables 1 and 2).

Aflatoxins

Aflatoxins, a family of closely related, biologically active mycotoxins, have been known as a prominent cause of animal disease for many years. The toxins occur naturally on several key animal feeds, including corn, cottonseed, and peanuts. Occurrence of aflatoxins on some field crops tends to spike in years when drought and insect

damage facilitate invasion by the causative organisms, *Aspergillus flavus* and *Aspergillus parasiticus,* which abound in the crop's environment. Aflatoxins B1 was present in contaminated peanut containing feed that caused a mass death of turkeys in England in 1960; an incidence that triggered much subsequent mycotoxin research.

Acute aflatoxicosis causes a distinct overt clinical disease marked by hepatitis, icterus, hemorrhage, and death. More chronic aflatoxins poisoning produces very variable signs that may not be clinically obvious; reduced rate of gain in young animals is a sensitive clinical register of chronic aflatoxicosis. The immune system is also sensitive to aflatoxins, and suppression of cell-mediated immune responsiveness, reduced phagocytosis, and depressed complement and interferon production are produced. Acquired immunity from vaccination programs may be substantially suppressed in some disease models. In such cases the signs of disease observed are those of the infectious process rather than those of the aflatoxins that predisposed the animal to infection. Of considerable potential economic consequence is the fact that aflatoxins can suppress the immune system of young animals by in utero-transfer across the placenta of the pregnant dam (Pier et al., 1985). In these cases the affected newborn animals lack resistance to infection and cannot respond well to vaccines. These are reactions of considerable consequence in colonized animals in which we rely on elective vaccination procedures in disease prevention.

Aflatoxins in feedstuffs

Aflatoxins, primarily aflatoxin B1, occur in a number of important animal feeds. Growth of toxigenic strains of *A. flavus* and *A. parasiticus* on corn, cottonseed, and peanuts often results in injurious levels of aflatoxin B1, the most biologically active member of the aflatoxin family (Cheeke and Shull, 1985). These three feedstuffs are the most important sources of aflatoxin in animal feeds (Cheeke and Shull, 1985). The causative molds may occasionally colonize small cereal grains (barley, oats, and wheat) and produce low to moderate levels of aflatoxin. Soybeans do not support appreciable levels of aflatoxin B1 production (Lillehoj et al., 1991).

The moisture content promotes the growth of the toxigenic molds and grinding of the kernel destroys the natural barrier to infestation. Moisture content of the feed must be ≥ 15% to support growth of the molds. The fungus must gain access to susceptible parts of the plant (e.g., the corn kernel, cotton seed, etc.) before it grows and elaborates aflatoxins. Seasonal peaks in aflatoxin content are seen in key years when drought-damaged plants or insect-damaged crops are rendered more susceptible to fungal invasion. Wet harvest seasons also may contribute to high levels of aflatoxin in certain crops.

Aflatoxin sometimes develops in crops stored at levels of moisture content > 15% or properly dried crops stored in leaky bins. Development of aflatoxin can be prevented in stored grains by good management practices (Christensen and Meronuck, 1986); the occurrence of aflatoxin in field crops, however, is largely a matter of uncontrollable natural events. In these events careful use of blending with clean crops or detoxification through ammonization, with close attention to existing rules and regulations, may be possible to reduce the toxin content in animal feeds to safe levels (Park et al., 1988; FDA, 1989). Recent information suggests that binding agents fed with aflatoxins may reduce the availability of the toxins and thereby reduce their effects in some animal species (Harvey et al., 1989). In the absence of one of these control procedures the feed should be withheld from animal use.

Zearalenone

Zearalenone (previously known as F-2 toxin) was produced by some Fusarium species *Fusarium graminearum* (Gibberella zeae), *Fusarium culmorum, Fusarium cerealis, Fusarium equiseti, Fusarium crookwellense* and *Fusarium semitectum*. These fungi infected contaminants of cereal crops worldwide (Bennett and Klich, 2003). The concentration of accumulated Zearalenone (ZEA) in cereals depended on several factors such as the substrate, temperature, duration of Fusarium growth and strain of fungal species. Moreover, the humid tropical climate promoted microbial proliferation on food and feedstuffs and finally mycotoxin biosynthesis (Nuryono et al., 2005).

Toxicity of ZEA and its metabolites was related to the chemical structure of the mycotoxins, similar to naturally occurring estrogens (Gromadzka et al., 2009). ZEA was heat-stable, which made it difficult to remove and/or decomposed from food (Kuiper-Goodman et al., 1987). Additionally, it was observed that during food and feed processing (e.g. milling, extrusion, storage and heating) ZEA was not decomposed (Yumbe-Guevara et al., 2003).

Zearalenone imitates the effect of female hormone oestrogen 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 new born animals (Zinedine et al., 2007). Zearalenone causes estrogenic responses in dairy cattle and large doses of this toxin are associated with abortions. Other responses of dairy animals to zearalenone are reduced in feed intake, decreased milk production, vaginitis, increase vaginal secretions, poor reproductive performance and mammary gland enlargement in heifers. It is recommended that zearalenone should not exceed 250 ppb in the total diet (Zinedine et al., 2007).

Ochratoxins

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

Ochratoxin A is the major metabolite of toxicological significance and it is mainly a contaminant of cereal grains (corn, barely, wheat and oats). It has also been found beans (soyabeans, 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 to cause damage to the liver, gut, lymphoid tissue and renal tubular damage (Krogh, 1987).

Fumonisins

The fumonisins are a group of compounds originally isolated from *Fusarium moniliforme* (Gelderblom et al., 1988). Six different fumonisins (FA_1, FA_2, FB_1, FB_2, FB_3 and FB_4) have been reported, the A series are amides and the B series have a free amine (Gelderblom et al., 1991).

In most animals tumonisin impairs immune function, causes liver and kidney damage, decreases weight gains, and increases mortality rates. The fumonosins (FB_1 and FB_2) were recently isolated from *F. 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).

Fumonisins are stable during food processing: they are not degraded during corn fermentation (Scott and Lawrence, 1995); they are heat stable (Marasas, 1997) and resistant to canning and baking processes (Castelo et al., 1998), although in corn the nixtamalization process reduces fumonisin B1 levels, a five-fold more toxic product with respect to the original level (Bullerman and Bianchini, 2007; Hendrich et al., 1993; Voss et al., 1996).

The use of natural bioactive substances for control of postharvest fungal infections has gained attention due to problems associated with chemical agents. These include the development of fungal species resistant to chemical treatments, which increases food-borne pathogenic microorganisms, in addition to increasing the number of pesticides under observation or regulation (Rabea et al., *2003).* Also, essential oils of cinnamon (Cinnamomum zeylanicum Blume) and oregano have shown fungicidal activity *in vitro* against *A. flavus* Link: Fr. *(*García-Camarillo et al., 2006).

In addition, Sánchez et al. (2005) reported the inhibition of both growth and mycotoxin production by *A. flavus* and *A. parasiticus* Speare when exposed to ethanolic, methanolic, and aqueous extracts of Agave species. For that reason, it is possible that native plants such as *Larrea tridentata*, *Baccharis glutinosa, Ambrosia confertiflora* DC, and *Azadirachta indica* A. Juss. can be used as source of natural preservative compounds for the control of filamentous fungi like *Fusarium verticillioides*.

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 toxicosos in dairy cattle that had consumed moldy corn in Wisconsin. This mycotoxin rarely associated with disorders in animals or humans in other countries (Mroch et al., 1983). 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 feed refusal, production losses, gastroenteritis, intestinal hemorrhages 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 impair the bird's immune response, causing decreased in egg production, decreased feed consumption, weight loss and altered feather patterns (Mroch et al., 1983).

Vomitoxin

Vomitoxin also called deoxynivalenol is stable, survive processing, milling and does occur in food products and feeds prepared from contaminated corn and wheat. The most common producer of vomitoxin is *F. graminearum* (Marasas et al., 1984). Corn contaminated with *F. graminearum* was shown to contain the trichothecene vomitoxin (3, 7, 15-trihydroxy- 12, 13-epoxytrichothec-9-en-8-one). Vomitoxin is perhaps, the most commonly detected *Fusarium* mycotoxin. Vomitoxin has been associated with reduced milk production in dairy cattle, vomiting by swine contaminated feed or their refusal to eat feed containing the toxin, and inhibiting reproductive performance and immune function in several animal species (Marasas et al., 1984).

Toxicology and syndromes

In common with other physiologically active compounds, the Fusarium mycotoxins are capable of inducing both acute and chronic effects. The effects observed are often related to dose levels and duration of exposure. Although

Table 3. Mycotoxins and their effects on different species of livestock.

Mycotoxins	Species susceptability	Effects
Aflatoxins	All domestic animals and poultry	Hepatoxic, carcinogenic, immnosuppressive
Zearalenone	Mainly pigs and dairy animals	Estrogenic and reproductive disorder
Vomitoxin	Mainly pigs and dairy animals	Dermatotoxic, feed refusal
Ochratoxin	Mainly pigs and poultry	Nephrotoxic, gout
T-2 Toxin	Mainly pigs and poultry	Mouth lesions, loss of appetite
Fumonisins	Mainly pigs and horses	Neurological disorders, liver damage.

Source: Ratcliff, 2002.

acute and chronic effects in farm livestock are readily demonstrated under experimental conditions, similar manifestations have been reported in natural outbreaks of Fusarium mycotoxicoses in Europe, Asia, New Zealand and South America (Fazekas and Bajmocy, 1996; Prathapkumar et al., 1997; Kramer et al., 1997; Galhardo et al., 1997).

Chronic exposure of farm animals to DON is a continuing hazard in Canada, the USA and continental Europe. In Japan, several cases of mycotoxicoses in animals have been attributed to consumption o f cereals contaminated with DON and NIV (Yoshizawa, 1991). A number of specific syndromes in farm livestock have now been positively linked with exposure to certain trichothecenes, ZEN, and fumonisins. These include feed refusal, emesis and anorexia; oral and gastro-intestinal lesions; ill-thrift; reproductive dysfunction; equine leukoencephalomalacia; and porcine pulmonary edema. In addition, Duodenitis/ proximal jejunitis and acute mortality syndrome have tentatively been linked with particular Fusarium mycotoxins.

Effect of mycotoxins on animals

Acute primary mycotoxicoses are produced if high to moderate amounts of mycotoxins are consumed. Specific, overt, acute episodes of disease ensue, which include hepatitis, hemorrhage, nephritis, necrosis of oral and enteric epithelium, and death. These effects belonged to the target organs usually affected by specific mycotoxins. Chronic primary mycotoxicoses, resulting from moderate to low levels of mycotoxin intake, often cause reduced productivity in the form of slower rate of growth, reduced production and inferior market quality. These effects often occur without the production of an overt, primary mycotoxicosis syndrome (Table 3).

Consumption of low levels of mycotoxins through the feeds do not cause overt mycotoxicoses, but often predisposes to various infectious diseases and especially to secondary bacterial infections or to a heavy progression of some often encountered parasitic diseases (Stoev et al., 2000; Koynarski et al., 2007), because of the suppression in both humoral and cell-mediated immune response in such animals (Stoev et al., 2000). Suppression of the cellular immune system is a known result after ingestion of several mycotoxins. Cheeke (1998) confirmed that in monogastrics, variable immune responses have been observed after ingestion of these mycotoxins. Various degrees of mycotoxicoses from natural sources occur in different animal species because of the wide range of feed ingredients used and the differences among and within species (Hussein and Brassel, 2001).

Mycotoxins have several effects in poultry (Figure 1). Early investigations concerning the sudden death of 100, 000 turkey poults consuming groundnuts in England linked *A. flavus* to acute hepatic necrosis and hyperplasia of the bile ducts of intoxicated birds (Newberne and Butler, 1969). High levels of aflatoxins (from 0.2 to 1 mg/kg) in combination with other mycotoxins (OTA and / or trichothecenes) in poultry feed may cause diseases such as hepatitis and can lead to the development of salmonelosis, coccidiosis, and infectious bursal disease (Ratcliff, 2002). Chickens have been shown to bruise and haemorrhage from AF (Table 4 and Figures 2 to 4b).

De-contamination and amelioration

A number of de-contamination procedures have been investigated, broadly divisible into physical and chemical principles (Placinta et al., 1999). Physical methods include milling which has been shown to be highly effective for DON, and density segregation which has resulted in reduced levels of trichothecenes and ZEN. Super activated charcoalis partially effective at reducing the incidence of oral lesions in broilers fed T-2 toxin, but mortality remains unaffected (Edrington et al., 1997). Furthermore, amelioration of oral lesions was not consistent between experiments. Chemical methods tested include calcium hydroxide monomethylamine, sodium bisulphite and ammonia.

The commercial potential of these de-contamination procedures, however, has yet to be determined. Anti-oxidants such as vitamin E have been considered as dietary supplements to counteract the effect of T-2 toxin.

A partial beneficial effect, in terms of reduced *in vivo*

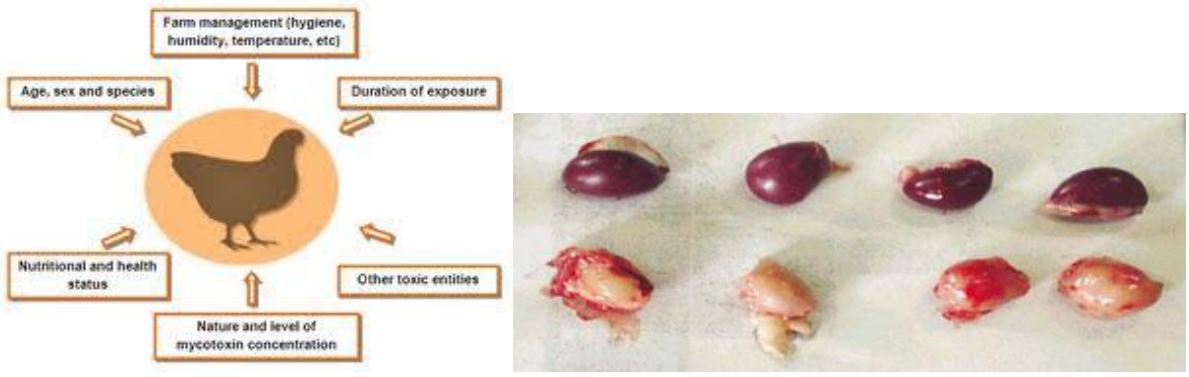

Figure 1. Mycotoxins effects on poultry (The poultrysite.com, mycotoxin.com).

Table 4. Mycotoxins and their effects on different species of livestock.

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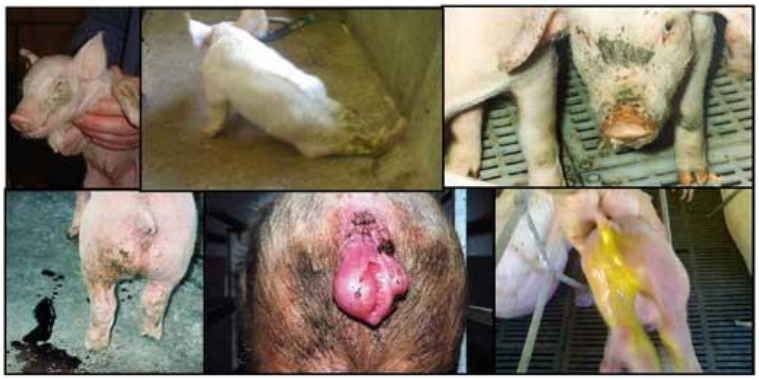

Figure 2. Mycotoxins effects on pigs (en.engormix.com).

lipid peroxidation, has been reported in one study with chickens (Hoehler and Marquardt, 1996). Vitamin C was ineffective in this respect.

The general harmony now prevailing is that preventive measures offer greater potential than remedial procedures (Figure 5). With ZEN, a feeding strategy for breeding ewes has been suggested, based on the use of chicory pastures containing inherently low levels of the mycotoxin (Kramer et al., 1997). However, selection of cultivars of cereal and forage plants that are resistant to infection by toxigenic species of Fusarium pathogens is likely to be the long-term objective of any effort to control contamination with the associated mycotoxins.

ALawadi and AL-Jedabi (2000) proved an inhibitory and antibiotic activity of camel urine against the growth of *Candida albicans* (yeast), *Aspergillus niger*, *Fusarium oxysporum* even after it is boil to 100°C. The effect of camel urine and milk on the growth properties of such fungi or on the efficiency of aflatoxins as inhibitors to *Bacillus subtilus* growth is seen as a primary step fined

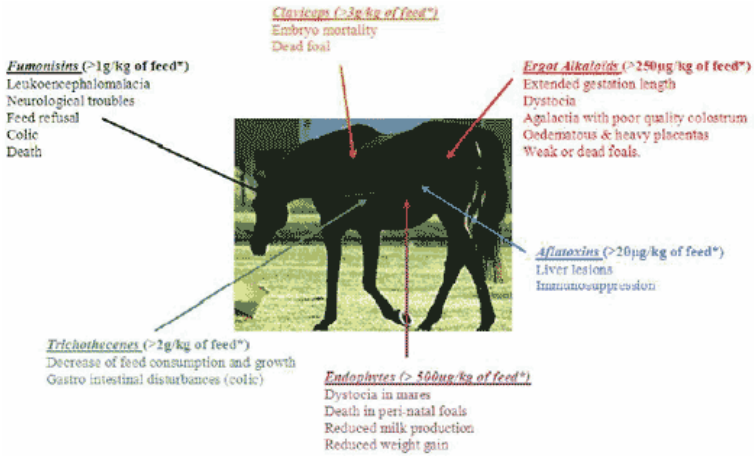

Figure 3. Mycotoxin effects in Equine (en.engormix.com).

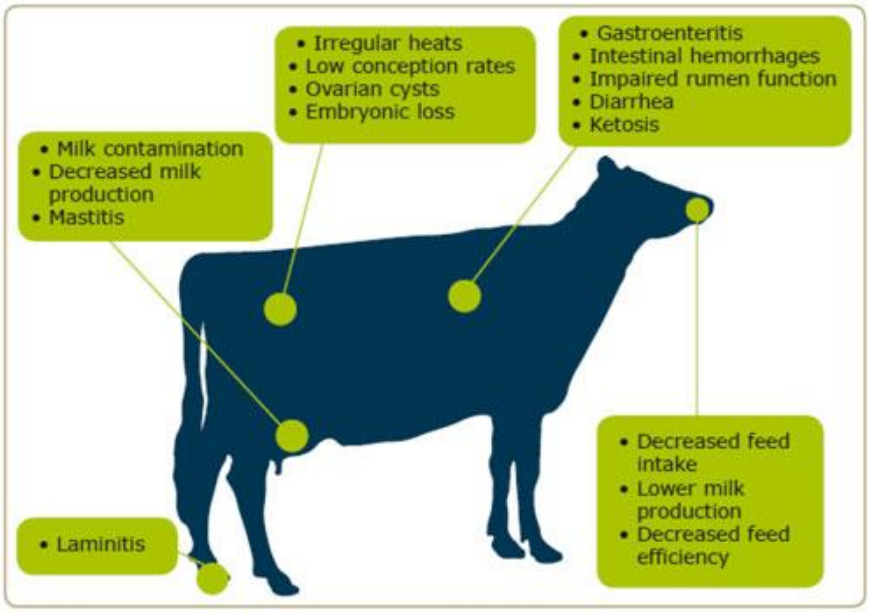

Figure 4a. Mycotoxins effects on ruminants (en.engormix.com).

away to get rid of fungal toxins. The chemical and organic constituents of urine proved to have inhibitory properties against fungal and bacterial growth (Ghosal et al., 1974; Varley et al., 1980; Mura et al., 1987; Amer and Hendi, 1996).

When Amer and Al-hendi (1996) analyzed urine of mature camels of between 5 to 10 years old, they found that its relative density ranged from 1.022 to 1.07, while pH values varied to be either acidic or alkaline. Urea level ranged from 18 to 36 g/dl. Keratin recorded 0.2 to 0.5 g/L. Microscopical analysis proved the presence of phosphorus and calcium oxalate and ammonium urate; some epithelial and granular cells appeared. Al-Attas (2008), using neutron activation analysis, estimated some essential elements within milk and urine of camels, and discovered that it contains large amount of Na and K substituting the loss of such elements in the case of diarrhea. Also it contains large amount of Zn which assists in the cure of the infection due to diarrhea.

Prevention and management of mycotoxins in food and feed

When contamination cannot be prevented at pre-harvest or during the post-harvest stage, decontamination/

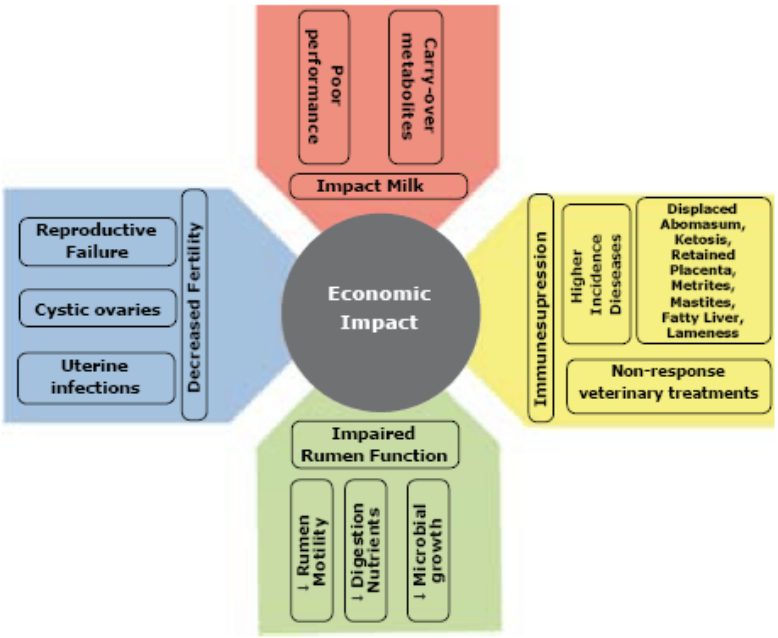

Figure 4b. Mycotoxins effects on ruminants (en.engormix.com).

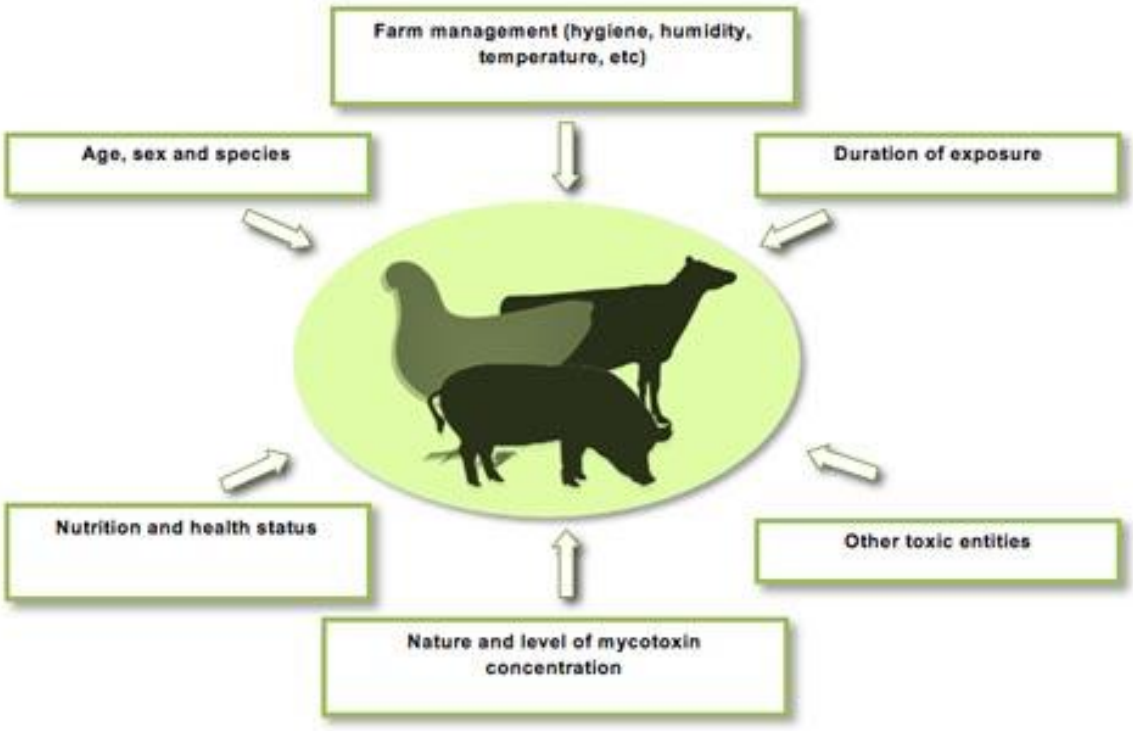

Figure 5. Farm management for prevention and control of mycotoxin (en.engormix.com).

detoxification procedures played an important role in helping prevent exposure to the toxic and carcinogenic effect of mycotoxins through the physical separation and physical, chemical and biological inactivation and/or

removal of the toxin (Kabak et al., 2006). Any detoxification procedure to reduce the toxic
and economic impact of mycotoxins needs the following basic criteria (Jemmali, 1979):

1) It must destroy, inactivate or remove the mycotoxins in foods and feeds.
2) It must not produce or leave toxic and/or carcinogenic residues in the final products.
3) It should not alter significantly the nutritional and technological properties of the product.
4) It must be capable of destroying fungal spores and mycelia in order to avoiding new toxin forming under favourable conditions.
5) It had to be technically and economically feasible.

REMOVAL OF MYCOTOXINS FROM CONTAMINATED COMMODITIES

Several methods were reported for the removal of mycotoxins from contaminated commodities, including physical separation, extraction with solvents and adsorption.

Physical separation

Since detoxification of mycotoxins by chemical applications was not an acceptable practice in some regions, physical separation of contaminated crops was a very important option for the producer (Kabak et al., 2006). Cleaning grains removed kernels with extensive mold growth, broken kernels and fine materials, which reduced mycotoxin concentration (Bullerman and Bianchini, 2007). Cleaning of the maize removed 26.6 to 69.4% of the fumonisins (Sydenham et al., 2004), while a 40 to 80% reduction in aflatoxin levels were reported after physical cleaning and separation of mould-damaged kernels and seeds (Park, 2002). However, cleaning was not effective in removing DON; only 6 to 19% reduction was achieved in wheat by cleaning (Abbas et al., 1985).

Washing procedures, using distilled water, resulted in 65 to 69% reductions of DON and 2 to 61% reductions of ZEA in barley and maize, whereas using 1 M sodium carbonate solution for the first wash reduced DON by 72 to 74% and ZEA by 80 to 87% (Trenholm et al., 1992). This process might be a useful treatment before wet milling and brewing; otherwise, the cost of seed drying would be prohibitive. Such approaches are also capable of reducing patulin levels in the final juiced products (Acar et al., 1998).

Extraction with solvents

Extraction with a variety of solvents including ethanol, aqueous isopropanol, methanol–water, and acetonitril–water removed aflatoxins from contaminated commodities such as cottonseed and peanuts. On the other hand, high cost and problems related to disposal of the toxic extracts restrict its use for large scale application (Rustom, 1997).

Adsorption

Two of the most potent adsorbents for removal of mycotoxins were activated carbon (AC) and bentonite. When phosphate-buffered saline (PBS) and wine samples contaminated with 5 ng/ ml OTA were treated with 1 mg/ ml AC, 100 and 87% of the available toxin were absorbed by the sorbent respectively (Var et al., 2008). In relation to other mycotoxins, AC was shown to considerably decrease patulin levels in apple juice (Artuk et al., 1995). Bentonite, which had a negative charged surface, for its part showed a very poor affinity for OTA (Var et al. ,2008), DON and NIV (Avantaggiato et al. ,2004), while Diaz et al. (2002) observed that bentonite was effective in removing AFB1 in the range 95 to 98.1%. Yeasts were focused on the removal of mycotoxins in liquids in recent years.

Cecchini et al. (2006) demonstrated that the percentage of OTA removal during fermentation was between 46.83 and 52.16% in white wine and between 53.21 and 70.13% in red wine, depending on the yeast strain used. Similarly, Caridi et al. (2006) reported that the removal of OTA in wines by 20 different *Saccharomyces sensu stricto* strains, using a naturally and spiked OTA-containing grape must (1.58 and 7.63 ng/ ml respectively), after 90 days of fermentation was between 39.9 and 92.1% and between 67.9 and 83.4% respectively.

INACTIVATION OF MYCOTOXINS IN CONTAMINATED COMMODITIES

Physical methods

Physical strategies including thermal processing (cooking, boiling, baking, frying, roasting, microwave heating, extrusion) and irradiation were applied for inactivation of the toxin or to reduce its content in foods and feeds.

Thermal treatment

Most mycotoxins were heat-resistant within the range of conventional food processing temperatures (80 to 121°C), so little or no reduction in overall toxin levels occurred as a result of normal cooking conditions such as boiling and frying, or even following pasteurization. The initial level of contamination, type of mycotoxin and its

concentration, heating temperature and time, and the degree of heat penetration, as well as the moisture content, pH and ionic strength of food, among other factors, played a significant role in the achievement of toxin degradation (Samarajeewa et al., 1990; Rustom, 1997).

Chemical methods

A variety of chemicals, including acids, bases, oxidizing reagents, reducing agents, chlorinating agents, and miscellaneous reagents were tested to detoxify mycotoxins. The success of detoxification process by chemical treatments highly depends on the type of food and/or feed. The use of chemicals in combination with physical treatments such as thermal processing for the detoxification of food products contaminated with mycotoxins increased the efficacy of mycotoxins degradation.

Acid treatment

It was clear from the accumulated evidence that treatment of aflatoxins with strong acids destroyed the biological activity of AFB1 and AFG1 by converting them to the hemiacetal forms AFB2a and AFG2a respectively, due to acid-catalysed addition of water across the double bond in the furan ring (Heathcote and Hibbert, 1978). Treatment with HCl (pH 2) reduced AFB1 levels by 19.3% within 24 h (Doyle et al., 1982).

Treatment with bases

Among bases and other chemicals, ammoniation was proved to be an effective method for detoxifying aflatoxin-contaminated agricultural products and animal feeds. The ammoniation process, using either ammonium hydrochloride or gaseous ammonia (NH_3), was equally effective in the detoxification of aflatoxins in maize, and was shown in some cases to decrease aflatoxin levels by more than 75% (Burgos-Herna´ndez et al., 2002). Ammoniation caused a 79% reduction of FB1 in contaminated maize (Park et al., 1992). It was reported that ammoniation almost completely decomposed OTA in maize, wheat and barley (Scott, 1996).

The ammoniation process did not leave toxic metabolites of mycotoxins in feed (Scott, 1998), but the relatively long period of aeration and its cost, which increased the price of the product by 5 to 20%, restricted its use in animal feeds (Peraica et al., 2002). In addition, some undesirable effects in the sensory and nutritional quality of the feed, such as brown colour of the treated feed, a decrease in lysine and sulphur-containing amino acids, cannot be overlooked (Piva et al., 1995; Scott, 1998).

Oxidizing agents

It was well-known that aflatoxins such as AFB1, AFG1 and AFM1 which had a terminal double bond in the dihydrofuran ring were more susceptible to attack by Ozone (O_3) and other oxidizing agents than AFB2, AFG2 and AFM2, which lack this double bond (McKenzie et al., 1997). Ozone was reported to reduce AFB1 and AFG1 levels by 77 and 80% respectively in peanuts after treatment at 75°C for 10 min, while the maximum degradation was 51%, occurring for AFB2 and AFG2 in peanuts, regardless of the exposure times (Proctor et al. , 2004). In another study, the reductions of AFB1 in paprika were 80 and 93% after exposures to 33 mg/L O_3 and 66 mg/L O_3 for 60 min respectively (Inan et al., 2007).

However, limited experiments with other mycotoxins showed that patulin, CPA, OA, FB1 and ZEA were effect-tively degraded after treatment with O_3 at 10% for 15 s (McKenzie et al., 1997). H_2O_2, one of the oxidizing agents, was used on a commercial scale to detoxify aflatoxin. Treatment of figs with H_2O_2 at 0.2% caused a 65.5% reduction in AFB1 levels following 72 h storage (Altug˘ et al., 1990). Additionally, citrinin can be completely detoxified by H_2O_2 at 0.05% for 30 min at room temperature, whereas OTA was not detoxified by treatment with 0.05 to 0.1% H_2O_2 (Fouler et al., 1994). Abd Alla (1997) revealed that ZEA was degraded by 83.9% when using 10% H_2O_2 at 80°C for 16 h.

Reducing agents

Sodium bisulfite ($NaHSO_3$) was shown to destroy mycotoxins, primarily AFB1 in maize (Doyle et al., 1982) and dried figs (Altug˘ et al., 1990). Additionally, $NaHSO_3$ solutions reduced DON level (85%) in contaminated maize (4.4 mg/ kg) and form a DON-sulfonate conjugate when the treatment was performed at 80°C for 18 h (Young et al., 1987). Also, sodium metabisulfite at 10 g/ kg was reported to be an effective tool for overcoming the depressing effects of DON on feed-intake in piglets (Da¨nicke et al., 2005). Alternatively, the reaction of FB1 with reducing sugars such as D-glucose, D-fructose at 65°C for 48 h blocked the primary amino group of FB1, and prevented FB1-induced toxicity on cell tissue cultures on rats and swine (Fernandez-Surumay et al., 2005).

Biological methods

An alternative approach to remove the toxic and carcinogenic potential of mycotoxins was the biological detoxification, intended as enzymatic degradation or

modifying of toxins that led to less toxic products. Studies in this area were dramatically increased with the recent advances in molecular biology, genetic engineering and microbial genomics, coupled with the discovery of the catabolic capabilities of microbial populations. Detoxification of mycotoxins by microorganisms was reviewed extensively by Bata and La´sztity (1999) and Karlovsky (1999).

Many species of bacteria were reported to degrade mycotoxins. Earlier work by Ciegler et al. (1966) identified *Flavobacterium aurantiacum* NRRL B-184, which could irreversibly remove AFB1 from a variety of food products including milk, oil, peanut butter, peanuts and maize without leaving toxic by-products. On the other hand, the bright orange pigmentation associated with *F. aurantiacum* restricted its use in food and feed fermentations (Line et al., 1994). Apart from *F. aurantiacum*, a variety of lactic acid bacteria originating from fermented products were reported to inhibit mutagenic activity of AFB1 (Park and Rhee, 2001). Earlier work demonstrated that more than 99% of patulin (50 mg/L) removed during alcoholic fermentation of apple juice, while only 10% decrease was observed in the control sample (Stinson et al., 1978). Later, three commercial cider strains of *S. cerevisiae* degraded patulin during active fermentative growth (Moss and Long, 2002).

With respect to other mycotoxins, fermentation by *S. cerevisiae* of wort containing ZEA resulted in conversion of 69% of the toxin to b-zearalenol and 8.1% to a-zearalenol (Scott et al., 1992). Similarly, cultures of *Candida tropicalis*, *Torulaspora delbrucki, Zygosaccharomyces rouxii*, and seven *Saccharomyces* strains were able to convert ZEA to a- and b-zearalenol (Boswald et al., 1995). In another study, OTA, FB1 and FB2 at the levels of 0.19, 0.95 and 0.95 mg/ ml respectively were degraded in the range of 87 to 91% by three strains of *S. cerevisiae* during fermentation of worth at 25°C for 8 days (Scott et al., 1995). Additionally, some losses (<40%) of OTA occurred during fermentation (Baxter et al. 2001), while alcoholic fermentation of malt by *S. cerevisiae* resulted in an average of 53% decrease in the initial contamination level of DON and T-2 toxin (Garda et al., 2005).

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REFERENCES

Abbas HK, Mirocha CJ, Pawlosky RJ, Pusch DJ (1985): Effect of cleaning, milling, and baking on deoxynivalenol in wheat. Appl. Environ. Microbiol., 50: 482-486.

Abbas HK, Zablotowicz RM, Weaver MA, Horn BW, Xie W, Shier WT (2004). Can J. Microbiol., 50: 193-199.

Abd Alla ES (1997): Zearalenone: incidence, toxigenic fungi and chemical decontamination in Egyptian cereals. Nahrung, 41: 362–365.

Acar J, Gokmen V, Taydas EE (1998): The effects of processing technology on the patulin content of juice during commercial apple juice concentrate production. Z Lebensm Unters Forsch A, 207: 328–331.

Al-Attas AS (2008). Determination of Essential Elements in Milk and Urine of Camel and in Nigella sativa Seeds. Arabian J. Chem., 1(2): 123-129.

Alawadi A, AL-Jedabi A (2000). Antimicrobial agents in cemel's Urine (9B) Microbiol. Viruses, 8(11): 265-281.

Altug T, Yousef AE, Marth EH (1990). Degradation of aflatoxin B1 in dried figs by sodium bisulfite with or without heat, ultraviolet energy or hydrogen peroxide. J. Food Prot., 53: 581–582.

Amer HA, Al-Hendi AB (1996). Physical, biochemical and microscopically analysis of camel urine. J. Camel Practice Res., 3(1): 17-21.

Artuk N, Cemeroglu B, Aydar G, Saglam N (1995): Elma suyu konsantresinde aktif ko¨mu¨r kullanm u¨zerinde aras¸trmalar. Tr. J. Agric. For., 19: 259–265.

Avantaggiato G, Havenaar R, Visconti A (2004). Evaluation of the intestinal absorption of deoxynivalenol and nivalenol by an *in vitro* gastrointestinal model, and the binding efficacy of activated carbon and other adsorbent materials. Food Chem. Toxicol., 42: 817–824.

Bata A, La´sztity R (1999): Detoxification of mycotoxin-contaminated food and feed by microorganisms. Trends Food Sci. Technol., 10: 223–228.

Baxter ED, Slaiding IR, Kelly B (2001): Behavior of ochratoxin A in brewing. J. Am. Soc. Brew Chem., 59: 98–100.

Benedetti R, Nazzi F, Locci R, Firrao G (2006): Biodegradation, 17: 31–38.

Bennett JW, Klich M (2003). Mycotoxins. Clin. Microbiol. Rev., 16: 497–516.

Boswald C, Engelhardt G, Vogel H, Walnofer PR (1995) Metabolism of the Fusarium Mycotoxins zearalenone and deoxynivalenol by yeast strains of technological relevance. Nat Toxins, 3: 138–144.

Bullerman LB, Bianchini A (2007): Stability of mycotoxins during food processing. Int. J. Food Microbiol., 119: 140–146.

Burgos-Hernandez A, Price RL, Jorgensen-Kornman K, Lopez-Garcia R, Njapau H, Park DL (2002). Decontamination of aflatoxin B1-contaminated corn by ammonium persulphate during fermentation. J. Sci. Food Agric., 82: 546–552.

Caridi A, Galvano F, Tafuri A, Ritieni A (2006). Ochratoxin A removal during winemaking. Enzyme Microb Technol., 40: 122–126.

Castelo MM, Sumner SS, Bullerman LB (1998). Occurrence of fumonisins in corn-based food products. J. Food Protection, 61: 704-707.

CAST Report (2003). Mycotoxins: risks in plant, animal, and human systems. In: J.L. Richard, G.A. Payne (Eds.), Council for Agricultural Science and Technology Task Force Report No. 139, Ames, Iowa, USA. ISBN 1-887383-22-0

Council for Agricultural Science and Technology (CAST), 1989) Mycotoxins.Economic and health risks. Task Force Rep. No. 116. November 1989. Council for Agric. Sci. Technol., Ames, IA.

Cecchini F, Morassut M, Moruno EG, Di Stefano R (2006): Influence of yeast strain on ochratoxin A content during fermentation of white and red must. Food Microbiol., 23: 411–417.

Cheeke PR (1998). Natural Toxicants in Feeds and Poisonous Plants, 2nd ed Interstate Publishers, Danville, United States, pp. 116–122.

Cheeke PR, LR Shull (1985). Natural Toxicants in Feeds and Poisonous Plants. AVI Publishing Com- pany, Westport, CT, pp. 393-476.

Christensen CM, Sauer DB (1982). Microflora. In: Storage of cereal grains and their products (Christensen CM ed), American Association

of Cereal Chemists, St. Paul, pp. 219- 240.
Christensen CM, RA Meronuck (1986). Quality maintenance in stored grains and seeds. University of Minnesota Press, Minneapolis.
Ciegler A, Lillehoj EB, Peterson RE, Hall HH (1966): Microbial detoxification of aflatoxin. Appl. Microbiol., 14: 934–939.
Danicke S, Valenta H, Gareis M, Lucht HW, Reichenbach H (2005). On the effects of a hydrothermal treatment of deoxynivalenol (DON)-contaminated wheat in the presence of sodium metabisulfite (Na2S2O5) on DON reduction and on piglet performance. Animal Feed Sci. Technol., 118: 93–108.
Degirmencioglu N, Esecali H, Cokal Y, Bilgic M (2005). From safety feed to safety food: the application of HACCP in mycotoxin control Arch. Zootech., 8: 19-32.
Devegowda G, MVLN Raju, and HVLN Swamy (1998). Mycotoxins: Novel solutions for their counteraction. Feedstuffs, pp. 12-15.
Diaz DE, Hagler WM Jr, Hopkins BA, Whitlow LW (2002). Aflatoxin binders I: *In vitro* binding assay for aflatoxin B1 by several potential sequestering agents. Mycopathologia, 156: 223–226.
D'Mello JPF, Porter JK, Macdonald AMC, Placinta CM (1997) Fusarium mycotoxins. In: Handbook of Plant and Fungal Toxicants. Edited by JPF D'Mello, CRC Press, Boca Raton, FL, USA, p. 287.
Doyle MP, Applebaum RS, Brackett RE, Marth EM (1982). Physical, chemical and biological degradation mycotoxins in foods and agricultural commodities. J. Food Prot., 45: 964–971.
Edrington TS, Kubena LF, Harvey RB, Rottinghaus RE (1997). Influence of superactivated charcoal on the toxic effects of aflatoxin or T-2 toxin in growing broilers. Poult. Sci., 76: 1205–1211.
Erber E, Binder EM (2004). Managing the risk of mycotoxins in modern feed production. In: The 5th Korea Feed Ingredient Association International Symposium, Korea Feed Ingredient Association, Seoul, Korea, July 16, pp. 21–45.
Fazekas B, Bajmocy E (1996). Occurrence of equine leukoencephalomalacia caused by fumonisin-B1mycotoxin in Hungary.Magy.Allatorv. Lap., 51: 484-487.
Fernandez MP, Ikonomou, MG, Buchanan I (2007). Sci Total Environ., 373: 250–269
Fernandez-Surumay G, Osweiler GD, Yaeger MJ, Rottinghaus GE, Hendrich S, Buckley LK, and Murphy PA (2005): Fumonisin B-glucose reaction products are less toxic when fed to swine. J. Agric. Food Chem., 53: 4264–4271.
Fink-Gremmels J, Malekinejad H (2007). Biochemical mechanisms and clinical effects associated with exposure to the mycoestrogen zearalenone. In: Morgavi, D.P., Riley, R.T. (Eds.), Fusarium and their toxins: Mycology, occurrence, toxicity, control and economic impact. Anim. Feed Sci. Technol., pp. 283-298.
Food and Drug Administration (1989). Corn shipped in interstate commerce for use in animal feeds; action levels for aflatoxin in animal feeds. Fed. Reg., 54: 100- 22622.
Fouler SG, Triverdi AB, Kitabatake N (1994): Detoxification of citrinin and ochratoxin A by hydrogen peroxide. J AOAC Int., 77: 631–636.
Francis BJ, JF Wood (1982). Changes in The Nutritive Content and Value of Feed Concentrate During Storage. In: M. Rechigl (Ed). Handbook of Nutritive Value of Processed Food, CRC Press, Florida.
Galhardo M, Birgel EH, Soares LMV, Furlani RPZ (1997). Poisoning by diacetoxyscirpenol in cattle fed citrus pulp in the state of Sao Paulo, Brazil. Braz. J. Vet. Res. Anim. Sci., 34: 90-91.
García-Camarillo EA, Y Quezada-Viay, R Mexicana (2006). Actividad Antifúngica de Aceites Esenciales de Canela (Cinnamomum zeylanicum Blume) y Orégano (*Origanum vulgare* L.) y su Efecto sobre la Producción deAflatoxinas en nuez pecancra {Carya illinoensis(F.A. Wangenh) K.Koch }. Revista Mexicana de Fitopatologia, 24: 8 – 12.
Garda J, Macedo RM, Faria R, Bernd L, Dors GC, Badiale-Furlong E (2005): Alcoholic fermentation effects on malt spiked with trichothecenes. Food Control, 16: 423–428.
Gelderblom WCA, Jaskiewicz K, Marasas WFO, Thiel PG, Horak RM, Vleggaar R, Kriek NPJ (1988). Cancer promoting potential of different strains of Fusarium moniliforme in a short-term cancer initiation/promotion assay. Carcinogenesis (Eynsham), 9: 1405-1409.
Gelderblom WCA, Kriek NPJ, Marasas WFO, Thiel PG (1991). Toxicity and carcinogenicity of the Fusarium moniliforme metabolite, fumonisin Bj, in rats. Carcinogenesis (Eynsham), 12: 1247-1251.
Ghosal AK, Appanna TC, Dwaraknath PK (1974). Seasonal variations in water compartment of the Indian camel. Brit. Vet. J., 130: 132.
Glenn AE (2007). Mycotoxigenic Fusarium species in animal feed. In: Morgavi DP, Riley RT (Eds.), Fusarium and their toxins: Mycology, occurrence, toxicity, control and economic impact. Anim. Feed Sci. Technol., pp. 213-240.
Gromadzka K, Waskiewicz A, Golinski P, Swietlik J(2009). Occurrence of estrogenic mycotoxin - Zearalenone in aqueous environmental samples with various NOM content. Water Res. (Oxford), 43(4): 1051-1059.
Harvey RB, LF Kubena, TD Phillips (1989). Prevention of aflatoxicosis by addition of hydrated sodium, calcium, aluminosilicate to the diets of growing barrows. Am. J. Vet. Res., 50: 416.
Heathcote JG, Hibbert JR (1978). Aflatoxin chemical and biological aspects. Elsevier Scientific, Amsterdam, p. 212.
Hendrich S, Miller KA, Wilson TM, Murphy PA (1993). Toxicity of Fusarium proliferatum -fermented nixtamalized corn-based diets fed to rats: Effect of nutritional status. J. Agric. Food Chem., 41: 1649-1654.
Hoehler D, RR Marquardt (1996). Influence of vitamins E and C on the toxic effects of ochratoxin A and T-2 toxin in chicks. Poult. Sci., 75: 1508-1515.
Hsu lC, Smalley EB, Strong FM, Rlbelln WE (1972) Idcntific:lliun ofT•2 toxin in moldy corn associated with a lethal toxicosis in dairy cattle. Appl. Microbiol., 24: 682-690.
Hussein S, Brasel J (2001).Toxicity, metabolism, and impact of mycotoxinx on humans and animals. Toxicol., 167: 101–134.
Huwig A, Freimund S, Kappeli O, Dutler, H. (2001). Mycotoxin detoxification of animals feed by different adsorbents. Toxicol Lett., 122: 179–188.
Ikonomou MG, Cai SS, Fernandez MP, Blair JD, Fischer M (2008): Environ. Toxicol. Chem., 27: 243–251.
Inan F, Pala M, Doymaz I (2007). Use of ozone in detoxification of aflatoxin B1 in red pepper. J. Stored Prod. Res., 43: 425–429.
Jemmali M (1979): Decontamination and detoxification of mycotoxins. Pure Appl. Chem., 52: 175–181.
Jouany JP (2007). Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. In: Morgavi, D.P., Riley, R.T. (Eds.), Fusarium and their toxins: Mycology, occurrence, toxicity, control and economic impact. Anim. Feed Sci. Technol., pp. 342-362.
Kabak B, Dobson ADW, Var I (2006): Strategies to prevent mycotoxin contamination of food and animal feed: a review. Crit Rev. Food Sci. Nutr., 46: 593–619.
Kan CA, GAL Meijer (2007). The risk of contamination of food with toxic substances present in animal feed. Animal Feed Sci. Technol., 133: 84–108.
Pierre JJ (2007). Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. Animal Feed Science and Technol., 137(3-4): 342-362.
Karlovsky P (1999): Biological detoxification of fungal toxins and its use in plant breeding, feet, and food production. Nat Toxins, 7: 1–23.
Koynarski V, Stoev S, Grozeva N, T Mirtcheva, H Daskalov, J Mitev, P Mantle (2007). Experimental coccidiosis provoked by *Eimeria acervulina* in chicks simultaneously fed on ochratoxin A contaminated diet. Res. in Veterinary Sci,, 82(2): 225-231.
Kramer R, Keogh RG, Sprosen JM, McDonald MF (1997). Free and conjugated levels of zearalenone in ewes mated on grass-dominant pasture or chicory. Proc. N. Z. Soc. Anim. Prod., pp. 57-90.
Krogh P (1987): Ochratoxins in food. In: Krogh P, editor. Mycotoxins in food. London: Academic Press, pp. 97–121.
Kuiper-Goodman T, Scott PM, Watanabe H (1987): Risk assessment of the mycotoxin zearalenone. Regul. Toxicol. Pharmacol., 7: 253–306.
Lawlor PG, Lynch PB (2005). Mycotoxin management. Afr. Farming Food Process, 46: 12-13.
Leibetseder J (2005). Decontamination and detoxification of mycotoxins. In: Mosenthin R, Zentek J, Zebrowska T (Eds.), Biology of Nutrition in Growing Animals. Biology of Growing Animals Series, 4. Elsevier, Amsterdam.
Lillehoj EB, TE Cleveland, D Bhatnagar (1991). Mycotoxins in feedstuffs: Production in novel substrates. In: J. E. Smith and R. S. Henderson (Ed.) Mycotoxins in Animal Foods, pp. 399-413. CRC

Press, Boca Raton, FL.
Line JE, Brackett RE, Wilkinson RE (1994): Evidence for degradation of aflatoxin B1 by *Flavobacterium aurantiacum*. J. Food Prot., 57: 788–791.
Marasas WFO (1997). Risk assessment of fumonisins produced by *Fusarium moniliforme* in corn. Cereal Res. Commun., 25: 399–406.
Marasas WFO, Kriek NPJ, Fincham JE, van Rensburg SJ (1984). Primary liver cancer and oesophageal basal cell hyperplasia in rats caused by *Fusarium moniliforme*. Int. J. Cancer, 34: 383–387.
Marguardt RR (1996). Effects of molds and their toxins on livestock performance: A western Canadian perspective. Animal Sci. Technol., 58: 77-89.
Mayer S, Engelhart S, Kolk A, Blome H (2008): The significance of mycotoxins in the framework of assessing workplace related risks. Mycotoxin Res., 24(3): 151-164.
McKenzie KS, Sarr AB, Mayura K, Bailey RH, Millar DR, Rogers TD, Corred WP, Voss KA, Plattner RD, Kubena LF, Phillips TD (1997): Oxidative degradation and detoxification of mycotoxins using a novel source of ozone. Food Chem. Toxicol., 35: 820-807.
Morgavi D, Riley RT (2007). An historical overview of field disease outbreaks known or suspected to be caused by consumption of feeds contaminated with Fusarium toxins. In: Morgavi, D.P., Riley, R.T. (Eds.), Fusarium and their toxins: Mycology, occurrence, toxicity, control and economic impact. Anim. Feed Sci. Technol., pp. 201–212.
Moss MO (1991). Influence of agricultural biocides on mycotoxin formation in cereals. Chełkowski, J. Cereal grain: Mycotoxins, fungi and quality in drying and storage, pp. 281-295.
Moss MO (1996). Centenary review. Mycotoxins. Mycol. Res., 100: 513 -523.
Moss MO, Long MT (2002). Fate of patulin in the presence of yeast Saccharomyces cerevisiae. Food Addit Contam., 19: 387–399.
Mroch CJT, Pawlosky RA, Chatterjee K, Watson S, Hayes W (1983). Analysis for Fusarium toxins in various samples implicated in biological warfare in Southeast Asia. J. Ass. off. analytic. Chem., 66: 14-85.
Mura U, Osman AM, Mohamed AS, Di-Martino D, Ipata PL (1987). Purine salvage as metabolite and energy saving mechanism in Camelus dromedarius: the recovery of guanine. Comparative Biochemistry and Physiology Part B: Biochem. Molecular Biol., 87: 157-160.
Newberne PM, Butler WH (1969). Acute and Chronic Effects of Aflatoxin on the Liver of Domestic and Laboratory Animals-a Review. Cancer Res., 29: 236.
Northolt MD (1979). The Effect of Water Activity and Temperature on the Production of Some Mycotoxins. (PhD Dissertation). Bilthoven, Holland, pp. 170-174.
Nuryono N, Noviandi CT, Bohm J, Razzazi-Fazeli E (2005): A limited survey of zearalenone in Indonesian maize-based food and feed by ELISA and high performance liquid chromatography. Food Contr., 16: 65–71.
Park DL (2002): Effect of processing on aflatoxin. Adv Exp Med Biol 504:173–179.
Park DL, Lee LS, Price RL,Pohland AE (1988). Review of the decontamination of aflatoxins by ammoniation: Current status and regulation. J. Assoc. Off. Anal. Chem., 71: 685.
Park DL, Rua SM, Mirocha CJ Jr, Abd-Alla E, Weng CJ (1992): Mutagenic potentials of fumonisin contaminated corn following ammonia decontamination procedure. Mycopathologia, 117: 105-108.
Park HD, Rhee CH (2001). Antimutagenic activity of *Lactobacillus plantarum* KLAB21 isolated from kimchi Korean fermented vegetables. Biotechnol. Lett., 23: 1583–1589.
Peraica M, Domijan AM, Jurjevic Z, Cvjetkovic B (2002). Prevention of exposure to Mycotoxins from food and feed. Arh Hig Rada Toxicol., 53: 229-237.
Pestka JJ (2007). Deoxynivalenol: toxicity, mechanisms and health risks. In: D.P. Morgavi, R.T. Riley (Eds), Fusarium and their toxins: Mycology, occurrence, toxicity, control and economic impact. Anim. Feed Sci. Technol., pp. 283-298.
Pier AC, McLoughlin ME, Richard JL, Baetz AL, Dahlgren RR (1985). In utero transfer of aflatoxin an n d selected effects on neonatal pigs. In: J. Lacey (Ed.) Trichothecenes and Other Mycotoxins. John Wiley and Sons, New York. pp. 495-506.
Pitt JI, Hocking AD (1997). Fungi and Food Spoilage, 2nd ed.Aspen Publishers, Gaithersburg, MD, USA, pp. 209–220.
Piva G, Galvano F, Pietri A, Piva A (1995): Detoxification methods of aflatoxins. A review. Nutr. Res., 15: 767–776.
Placinta CM, D'Mello JPF, Macdonald AMC (1999). A review of worldwide contamination of cereal grains and animal feed with Fusarium mycotoxins. Anim. Feed Sci. Technol., 78: 21-37.
Prathapkumar SH, Rao VS, Paramkishan RJ, Bhat RV (1997). Disease outbreak in laying hens arising from the consumption of fumonisin-contaminated food. Br. Poult. Sci., 38: 475-479.
Proctor AD, Ahmedna M, Kumar JV, Goktepe I (2004): Degradation of aflatoxins in peanut kernels/flour by gaseous ozonation and mild heat treatment. Food Addit Contam., 21: 786–793.
Rabea EI, Badawy ME, Stevens CV, Smagghe G, Steurbaut W (2003). Chitosan as antimicrobial agent:applications and mode of action. Biomacromolecules, 4(6): 1457–1465.
Ratcliff J (2002). The role of mycotoxins in food and feed safety. Presented at AFMA (Animal Feed Manufacturers Association) on 16th August, 2002.
Robens J, Cardwell K (2003). The Costs of Mycotoxin Management to the USA: Management of Aflatoxins in the United States. Toxin Reviews, 22(2-3): 139-152.
Ross FF, Nelson PE, Richard JL, Osweiler GD, Rice LG, Plattner RD, Wilson TM (1990). Production of fumonisins by Fusarium moniliforme and Fusarium proliferation isolates associated with equine leukoencephalomalacia and a pulmonary edema syndrome in swine. Appl. Environ. Microbiol., 56: 3225-226.
Russell L, Cox DF, G Larsen, Bodwell K, CE Nelson (1991). Incidence of molds and mycotoxins in commercial animal feed mills in seven midwestern states. J Anim. Sci., 69: 5-12.
Rustom IYS (1997). Aflatoxin in food and feed: occurrence, legislation and inactivation by physical methods. Food Chem., 59: 57–67.
Samarajeewa U, Sen AC, Cohen MD, Wei CI (1990). Detoxification of aflatoxins in foods and feeds by physical and chemical methods. J Food Prot., 53: 489–501.
Sánchez E, Heredia N, Garcia S (2005). Inhibition of growth and mycotoxin production of *Aspergillus flavus* and *Aspergillus parasiticus* by extracts of Agave species. Int. J. Food Microbiol., 98: 271–279.
Scott PM (1996). Effects of processing and detoxification treatments on ochratoxin A: Introduction. Food Addit. Contam., 13: 19–21.
Scott PM (1998). Industrial and farm detoxification processes for mycotoxins. In: Le Bars J, Galtier P (eds) Mycotox'98 international symposium, 2–4 July, Toulouse, France, pp. 543–548.
Scott PM, Kanhere SR, Dailey EF, Farber JM (1992). Fermentation of wort containing deoxynivalenol and zearalenone. Mycotoxin Res., 8: 58–60.
Scott PM, Kanhere SR, Lawrance GA, Daley EF, Farber JM (1995): Fermentation of wort containing added ochratoxin A and fumonisins B1 and B2. Food Addit. Contam., 12: 31-40.
Scott PM, Lawrence GA (1995). Mycotoxin methodology Food Additives & Contaminants: Part A: Chemistry, Analysis, Control. Exposure & Risk Assessment, 12(3): 395-403.
Smith JE, Moss MO (1985). Mycotoxins, Formation, Analysis. and Signifiance. Chichester, Wiley & Sons, p. 148.
Stinson EE, Osman SF, Huhtanen CN, Bills DD (1978). Disappearance of patulin during alcoholic fermentation of apple juice. Appl. Environ. Microbiol., 36: 620–622.
Stoev SD, Anguelov G, Ivanov I, Pavlov D (2000): Influence of ochratoxin A and extract of artichoke on the vicinal immunity and health in broiler chicks. Exp. Toxicol. Pathol., 52(1) :43-55.
Sydenham EW, Van Der Westhuizen L, Stockenstrom S, Shephard GS, Thiel PG (2004): Fumonisin-contaminated maize: physical treatment for the partial decontamination of bulk shipments. Food Addit Contam., 11: 25–32.
Trenholm HL, Charmley LL, Prelusky DB, Warner RM (1992). Washing procedures using water or sodium carbonate solutions for the decontamination of three cereals contaminated with deoxynivalenol and zearalenone. J. Agric. Food Chem., 40: 2147–2151.
Van der Merwe KJ, Steyn PS, Fourie L, Scott DB, Theron JJ (1965). Ochratoxin A, a toxic metabolite produced by *Aspergillus ochraceus* Wilh. Nat., 205: 1112–1113.

Var I, Kabak B, Erginkaya Z (2008). Reduction in ochratoxin A levels in white wine, following treatment with activated carbon and sodium bentonite. Food Control, 19: 592–598.

Varley H, Gowenlock AH, Bell M (1980). Practical Clinical Biochemistry.5th ed. Vol.1, William Heinemann Medical Books, Ltd., London.Wen K, Seguim P, St-Arnaud M, Jabaji-Hare S (2005). Real-time quantitative RT-PCR of defense- associated gene transcripts of Rhizoctonia solani infected bean seedlings in response to inoculation, pp. 741–742.

Voss KA, Bacon C, Norred W, Chapin R, Chamberlain W, Plattner R, Meredith F (1996).Studies on the reproductive effects of *Fusarium moniliforme* culture material in rats and the biodistribution of [14C] fumonisin B1 in pregnant rats. Nat. Toxins, 4: 24–33.

Voss KA, Smith GW, Haschek WM (2007). Fumonisins: toxicokinetics, mechanism of action and toxicity. In: Morgavi DP, Riley RT (Eds.), Fusarium and their toxins: Mycology, occurrence, toxicity, control andeconomic impact. Anim. Feed Sci. Technol., pp. 299–325.

Wheeler KA, Hurdman BF, Pitt JI (1991): Influence of pH on the growth of some toxigenic species of Aspergillus, Penicillium and Fusarium. Int. J. Food Microbiol. 12: 141-150.

Wood GE (1992). Mycotoxins in foods and feeds in the United States. J. Anim. Sci., 70: 3941–3949.

Wu F (2004). Mycotoxins risk assessment for the purpose of setting International Regulatory Standards. Environ. Sci. Technol., 38(15): 4049–4055.

Wu F (2006). Economic impact of fumonisin and aflatoxin regulations on global corn and peanut markets. In: Barug D, Bhatnager D, van Egmond HP, van der Kamp JW, van Osenbruggen WA, Visconti A (Eds.), The Mycotoxin Factbook. Food & Feed Topics. Wageningen Academic Publishers, The Netherlands, pp. 277–289.

Yoshizawa T (1991). Natural occurrence of mycotoxins in small grain cereals (wheat, barley, rye, oats, sorghum, millet, rice). In: Smith JE, Henderson RS. (Eds.), Mycotoxins and Animal Foods. CRC Press, Boca Raton, FL, pp. 301-324.

Yoshizawa T, Mlltoclla CJ, Behrens JC, Swanson SP (1981). t'oletabolic fate of T-2 toxin in a lactating cow. Fd Cosmet. Toxic., 19: 31.

Young JC, Trenholm HL, Friend DW, Prelusky DB (1987). Detoxification of deoxynivalenol with sodium bisulfite and evaluation of the effects when pure mycotoxin or contaminated corn was treated and given to pigs. J. Agric. Food Chem., 35: 259–226.

Yumbe-Guevara BE, Imoto T, Yoshizawa, T (2003): Effects of heating procedures on deoxynivalenol, nivalenol and zearalenone levels in naturally contaminated barley and wheat. Food Addit. Contam., 20: 1132–1140.

Zinedine A, Soriano JM, Moltó JC, Mañes J (2007). Review on the toxicity, occurrence, metabolism, detoxification, regulations and intake of zearalenone: An oestrogenic mycotoxin. Food Chem. Toxicol., 45(1): 1-18.