Food Control 36 (2014) 159–165

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Review

Mycotoxins and their effects on human and animal health

Maria Edite Bezerra da Rocha [a,*], Francisco da Chagas Oliveira Freire [b,1], Fábio Erlan Feitosa Maia [c,2], Maria Izabel Florindo Guedes [c,2], Davide Rondina [d,3]

[a] Faculdade de Educação Ciências e Letras do Sertão Central, Universidade Estadual do Ceará, Rua: José de Queiroz, 2554, CEP: 63900-000, Quixadá CE, Brazil
[b] Embrapa Agroindústria Tropical, Rua Dra. Sara Mesquita, 2270, CEP: 60.511-110, Fortaleza CE, Brazil
[c] Laboratório de Bioquímica Humana, Universidade Estadual do Ceará, Avenida: Paranjana, 1700, CEP: 60740-000, Fortaleza, Ceará, Brazil
[d] Faculdade de Ciências Veterinárias, Universidade Estadual do Ceará, Avenida: Paranjana, 1700, CEP: 60740-000, Fortaleza, Ceará, Brazil

A R T I C L E I N F O

Article history:
Received 27 September 2012
Received in revised form
25 July 2013
Accepted 20 August 2013

Keywords:
Fungi
Mycotoxins
Toxicity

A B S T R A C T

Mycotoxins are secondary metabolites produced naturally by filamentous fungi, which are considered toxic substances when present in food for humans and feed for animals. They are frequently found in products such as nuts, corn, rice, and several other cereals, which can be contaminated in the field during harvest or during storage. Studies have demonstrated their toxigenic, nephrotoxic, hepatotoxic, carcinogenic, immunosuppressive and mutagenic characteristics, and most mycotoxins represent a considerable risk to human and animal health. This review describes the main mycotoxins that have been isolated and chemically characterized and which are currently the subject of studies due to their proven potential toxicity.

Contents

1. Introduction 159
2. Principal mycotoxins 160
   2.1. Aflatoxins 160
   2.2. Fumonisins 160
   2.3. Trichothecenes 161
   2.4. Zearalenone 162
   2.5. Citrinin 162
   2.6. Patulin 162
   2.7. Ergot alkaloids 163
   2.8. Ochratoxin A 163
3. Final considerations 164
   References 164

1. Introduction

Toxins produced by filamentous fungi are called mycotoxins. This term, by general consensus, is used almost exclusively for fungi associated with food products and animal feed, excluding toxins produced by mushrooms. However, recently, agaric acid (hydroxylated tribasic acid, produced by *Fomes officinalis*, a macrofungus) has been included among the mycotoxins under regulation in some countries in Asia and Oceania (FAO, 2011). Mycotoxins are

* Corresponding author. Tel./fax: +55 8834451036.
E-mail addresses: mariaeditebr@hotmail.com (M. Edite Bezerra da Rocha), freire@cnpat.embrapa.br (F.daC.O. Freire), erlanmaia@yahoo.com.br (F. Erlan Feitosa Maia), florinfg@terra.com.br (M. Izabel Florindo Guedes), davide_81@hotmail.com (D. Rondina).
[1] Tel.: +55 8533917101; fax: +55 8533917109.
[2] Tel./fax: +55 8531019822.
[3] Tel./fax: +55 8531019858.

0956-7135/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.foodcont.2013.08.021

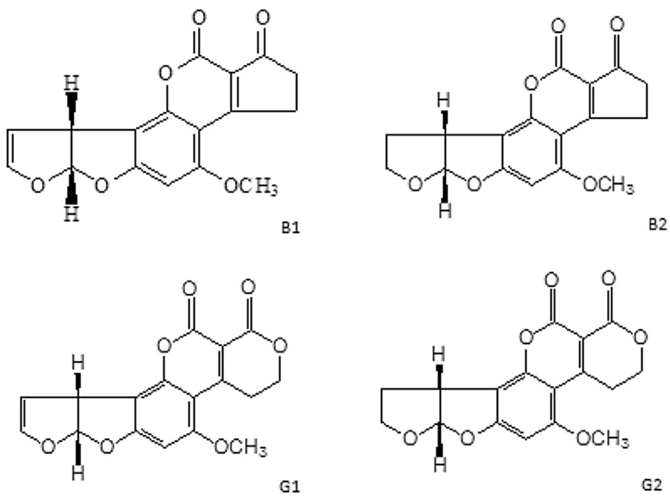


Fig. 1. Chemical structures of aflatoxins B_1, B_2, G_1 and G_2.

secondary metabolites, with no apparent function in the normal metabolism of fungi. They are produced mainly, although not exclusively, when the fungus reaches maturity. They are molecules with structures which vary from simple heterocyclic rings with molecular weights of up to 50 Da, to groups with 6–8 irregularly arranged heterocylic rings with a total molecular weight of >500 Da, and they do not show immunogenicity. Studies have revealed the existence of at least around 400 different mycotoxins (Betina, 1984, p. 528).

Mycotoxins commonly occur in human and animal food derivatives and can appear in the field before harvest, post-harvest or during processing, storage and feeding, adversely affecting the quality of the food (Sforza, Dall'asta, & Marchelli, 2006). In fact, the occurrence of mycotoxins in foods and derivatives is not only a problem in developing countries. Mycotoxins affect agribusiness in many countries, influencing or even impeding exportation, reducing livestock and crop farming production and, in some countries, affecting human health (Jelinek, Pohland, & Wood, 1989; Leung, Diaz-Llano, & Smith, 2006). Reliable calculations show that approximately 25%–50% of all of the commodities produced globally, especially basic foodstuffs, are contaminated in some way with mycotoxins (Bhat & Miller, 1991; Mannon & Johnson, 1985).

Mycotoxins can enter the human and animal food chains through direct or indirect contamination. The indirect contamination of foodstuffs and animal feed occurs when any ingredient has been previously contaminated by a toxigenic fungus, and even though the fungus has been eliminated during the processing the mycotoxins remain in the final product. Direct contamination, on the other hand, occurs when the product, food or feed becomes infected by a toxigenic fungus, with the subsequent formation of mycotoxins. It is known that the majority of food and feed products can allow the growth and development of toxigenic fungi during their production, processing, transport and storage (Frisvad & Samson, 1991). The ingestion of mycotoxins by humans occurs mainly through eating contaminated plant products, as well as through products derived from foods such as milk, cheese, meat and other animal products (Smith, Solomons, Lewis, & Anderson, 1995).

2. Principal mycotoxins

2.1. Aflatoxins

Since 1960, interest in *Aspergillus flavus* species was concentrated only on the use of some strains in food processing in Europe and the Far East, as well as the ability of some isolates to act as insect parasites (Beuchat, 1978). In fact, the term mycotoxin was created in 1962, following the famous death of turkeys poults, in England, after ingesting peanut meal originating from Brazil and Africa (Blout, 1961; Forgacs, 1962). After confirmation that a secondary metabolite produced by *A. flavus* was responsible for the bird deaths, a race for the study of these toxins ensued. The term aflatoxin was created based on the name of its main agent producer (*Aflavus*). The main known aflatoxins are called B_1, B_2, G_1 and $G_{2,}$ based on their fluorescence under ultraviolet light (B=Blue, G = Green) and their mobility during thin layer chromatography (Fig. 1). They are mainly produced by *A. flavus* and *Aspergillus parasiticus*. However, more recently, the species *Aspergillus nomius*, *Aspergillus bombycis*, *Aspergillus pseudotamari* and *Aspergillus ochraceoroseus* have also been shown to be aflatoxigenic (Kurtzman, Horn, & Hesseltine, 1987; Moss, 2002; Peterson, Ito, Horn, & Goto, 2001) but these species have low frequency in nature. In terms of mycology, there are enormous qualitative and quantitative differences in the aflatoxigenic capacity of isolates of *A. flavus*. It is known that only 50% of the strains of these species produce aflatoxins and that some of the aflatoxigenic isolates produce up to 106 μg/kg of aflatoxins (Cotty, Bayman, Egel, & Elias, 1994; Klich & Pitt, 1988).

Some substrates are extremely favorable for the growth of aflatoxigenic fungi and the formation of aflatoxins. The natural contamination of cereals, oleaginous seeds, nuts, spices and other commodities is a common occurrence in many countries. Both the genetic ability for the formation of aflatoxins and the capacity to contaminate foods with these toxins are highly variable among fungi. Some crops become contaminated in the field, before harvest, while others are contaminated post-harvest when stored under conditions of high humidity and temperature (Diener et al., 1987; Klich, 1987). In the case of cashew nuts, for instance, one of the most common routes of infection verified in Brazil is through invasion of the flowers (Freire & Kozakiewicz, 2005). The ability of fungi to invade flowers was brilliantly discussed in a publication by Ngugi and Scherm (2006).

Due to their capacity to bind with the DNA of cells, aflatoxins affect protein synthesis, besides contributing to the occurrence of thymic aplasia (congenital absence of thymus and the parathyroids, with a consequent deficiency in the cell immunity; also known as DiGeorge's syndrome) (Raisuddin, 1993).

Aflatoxins have oncogenic and immunosuppressive properties, inducing infections in people contaminated with these substances. They contribute to significantly to increasing the risk of liver cancer in people chronically infected with hepatitis B(VHB) (Groopman, Kensler, & Wild, 2008) and are considered a risk factor for the development of hepatocellular cancer in Africa and Asia (Scholl & Groopman, 2008).

In Brazil, aflatoxins have been found in peanuts and their derivatives (Caldas, Silva, & Oliveira, 2002; Oliveira, Germano, Bird, & Pinto, 1997; Santos, Lopes, & Kosseki, 2001), in cattle feed and in liquid milk (Pereira et al., 2005; Taveira & Midio, 1999), and in Brazil nuts and cashew nuts (Castrillon & Purchio, 1988; Freire, Kozakiewicz, & Paterson, 1999; 2000). Turkeys, chickens and pigs fed with feed contaminated with aflatoxins have a notably reduced immunity, leading to serious economic problems for the producers (Smith et al., 1995).

2.2. Fumonisins

Initially described and characterized in 1988 (Bezuidenhout et al., 1988; Gelderblom et al., 1988), these substances are produced by several species of the genus *Fusarium*, especially by *Fusarium verticillioides* (previously classified as *Fusarium moniliforme*), *Fusarium proliferatum* and *Fusarium nygamai*, besides

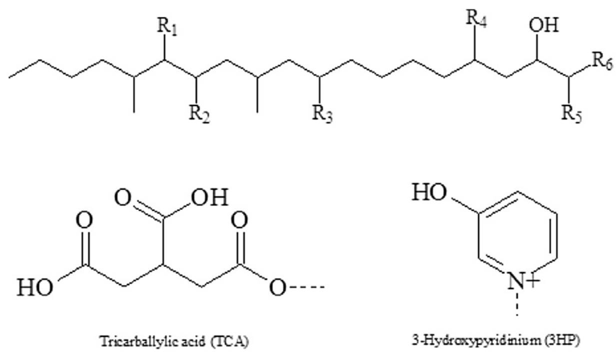


Fig. 2. Chemical structure of fumonisin.

Alternaria alternata f.sp. *lycopersici* (Bennet & Klich, 2003). Other species, such as *Fusarium anthophilum*, *Fusarium dlamini*, *Fusarium napiforme*, *Fusarium subglutinans*, *Fusarium polyphialidicum* and *Fusarium oxysporum* have also been included in the group of producers of these mycotoxins (Pozzi, Arcaro, Júnior, Fagundes, & Corrêa, 2002). Fumonisins constitute a group which include, to date, 16 substances referred to as B_1 (FB_1, FB_2, FB_3 and FB_4), A_1, A_2, A_3, AK_1, C_1, C_3, C4, P_1, P_2, P_3, PH_1a and PH_1b (Ah-Seo & Won Lee, 1999; Musser & Plattener, 1997).

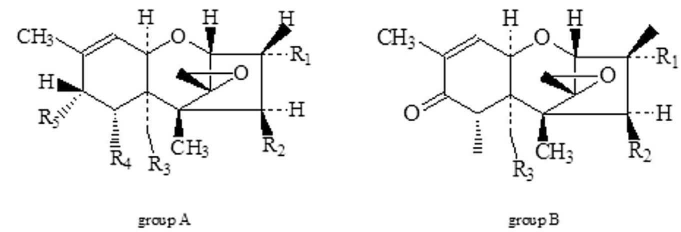
The presence of fumonisins in corn grains has been associated with cases of esophageal cancer in inhabitants of the region of Transkei in southern Africa, in China and in northeastern Italy (Peraica, Radic, Lucic, & Pavlovic, 1999). Fumonisins are also responsible for the leukoencephalomacia in equine species and rabbits (Bucci, Hansen, & Laborde, 1996; Fandohan, Hell, Marasas, & Winfgield, 2003; Marasas et al., 1988); pulmonary edema and hydrothorax in pigs (Harrison, Colvin, Greene, Newman, & Cole, 1990); and hepatotoxic, carcinogenic and apoptosis (programmed cell death) effects in the liver of rats (Gelderblom, Jaskiewickz, Marasas, & Thiel, 1991; Gelderblom et al., 1988; Gelderblom et al., 1996; Pozzi et al., 2000). Fumonisins have been isolated from corn sold in a supermarket in Charleston (South Carolina), the city with the highest incidence of the occurrence of esophageal cancer among Afro-Americans in the USA (Sydenham, Shephard, Thiel, Marasas, & Stockenstrom, 1991).

In contrast to the other mycotoxins, which are soluble in organic solvents, fumonisins are hydrosoluble, which hinders their study, and it is probable that many other mycotoxins remain undiscovered due to this hydrosolubility characteristic. The fumonisin B_1, the most extensively studied, is a diester of propane 1,2,3- tricarballylic acid and 2-amino-12, 16 dimethyl-3,5,10,14,15 – pentahydroxycosane (Bezuidenhout et al., 1988) (Fig. 2).

The carcinogenic character of fumonisins does not seem to involve interaction with DNA (Coulombe, 1993). On the other hand, its similarity with sphingosine suggests the probable intervention in the biosynthesis of sphingolipids (Shier, 1992). The inhibition of sphingolipid biosynthesis leads to serious problems related to cell activity, since these substances are essential for membrane composition, for cell–cell communication, for intracellular and cell–matrix interactions, and for growth factors (Merrill, Van Echten, Wang, & Sandhoff, 1993). In Brazil, these mycotoxins have been detected in various substrates, particularly in corn for animal feed (Hirooka et al., 1991; Hirooka, Yamaguchi, Aoyama, Sugiura, & Ueno, 1996).

2.3. Trichothecenes

Trichothecenes constitute a group of approximately 150 metabolites produced by fungi of the genera *Fusarium*, *Myrothecium*, *Phomopsis*, *Stachybotrys*, *Trichoderma*, *Trichotecium*, *Verticimonosporium* and possibly others (Scott, 1989; Ueno, 1983). The term trichothecene is derived from trichothecin, the first member of the family to be identified. All of the trichothecenes are characterized by the possession of a tetracyclic12,13-epoxy trichothene skeleton (Fig. 3). Despite the high number of molecules identified, few of them occur naturally. The most important trichothecenes are deoxynivalenol (DON), nivalenol (NIV), toxin T2, toxin HT2 and diacetoxyscirpenol (DAS). The trichothecenes are known for their strong capacity to inhibit eukaryotic protein synthesis, interfering in the initiation, the elongation and termination steps of protein synthesis. The trichothecenes were the first compounds proven to be involved in the inhibition of peptidyl transferase activity (Stafford & McLaughlin, 1973; Wei, Campbell, McLaughlin, & Vaughn, 1974).



	R1	R2	R3	R4	R5
Type A					
T-2	OH	OAc	OAc	H	O^{i}Pent
HT-2	OH	OH	OAc	H	O^{i}Pent
Diacetoxyscirpenol (DAS)	OH	OAc	OAc	H	H
Type B					
Nivalenol (NIV)	OH	OH	OH	OH	-
Deoxynivalenol (DON)	OH	H	OH	OH	-
Fusarenon X (FUSX)	OH	OAc	OH	OH	-
3-acetyl-deoxynivalenol (3-ADON)	OAc	H	OH	OH	-
15-acetyl-deoxynivalenol (15-ADON)	OH	H	OAc	OH	-

Ac = CH_3CO- ^{i}Pent = $(CH_3)_2CHCH_2CO$-

Fig. 3. Chemical structures of type A and B trichothecenes.

DON is the mycotoxin most commonly found in grains. When ingested in high doses by animals it causes nausea, vomiting and diarrhea. When ingested by pigs and other animals in small doses it can cause weight loss and the refusal to eat. Due to these symptoms induced by deoxynivalenol it is known as vomitoxin or food refusal factor. Although less toxic than other trichothecenes, DON is more common in the seeds of safflower, barley, rye, and wheat and in feed mixtures (Miller, Apsimon, Blackwell, Greenhalgh, & Taylor, 2001). It has been hypothesized that toxin T2 and DAS are associated with Alimentary Toxic Aleukia disease, which affected thousands of people in Orenburg, a region in the former Soviet Union, during the Second World War. Those affected had eaten grain infected with *Fusarium sporotrichioides* and *Fusarium poae* (Joffe, 1978; Lutsky, Mor, Yagen, & Joffe, 1978). The symptoms of the disease include inflammation of the skin, vomiting and hepatic tissue damage.

Other trichothecenes are widely produced by the fungi *Myrothecium*, *Stachybotrys* and *Trichothecium*. Notable among these are atranone, roridin, satratoxin and verrucarin (Hinkley & Jarvis, 2001). DON and toxin T2 have been detected, in Brazil, associated with corn grains, wheat bran and bakery products (Furlong, Valente, Lasca, & Kohara, 1995; Oliveira & Soares, 2001; Prado, Oliveira, Ferreira, Corrêa, & Ramos, 1997).

The fungus *Stachybotrys atra* (previously called *Stachybotrys chartarum*) has been associated with a rare form of mycotoxicosis. The macrocyclic trichothecenes produced by this fungus is located both in the spores (conidia) and in the mycelium fragments. The inhalation of fungal propagules has been responsible for an

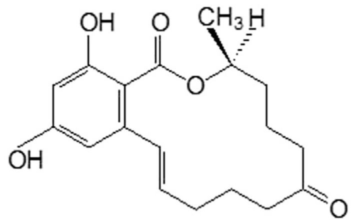


Fig. 4. Chemical structure of zearalenone.

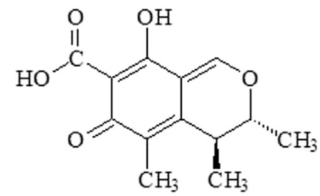


Fig. 5. Chemical structure of citrinin.

outbreak of hemorrhagic pneumonia in children in the city of Cleveland (USA). The disease is also known as pulmonary hemosiderosis. Stachybotryosis has been verified as an occupational disease of farmers involved in the handling of moldy hay. In this case the typical mycotoxicosis symptoms are nasal and tracheal bleeding. This fungus has also been associated with sick building syndrome. Since it is an efficient producer of cellulase the fungus degrades materials rich in cellulose and has an extraordinary capacity to survive in humid environments such as roofs, different types of roof lining and even air conditioning piping. The dispersion of propagules in the air is thus greatly facilitated. The trichothecenes produced by *S. atra* (atranones, roridin, stachylisin, satratoxins, trichoverroids, trichoverrins and verrucarins, among others) are inhibitors of protein synthesis in eukaryotic cells and can cause cephalea, irritation of the throat and eyes, dizziness and nose bleeds (Lourenço, 2011).

2.4. Zearalenone

This is a secondary metabolite produced mainly by *Fusarium graminearum* although other species, such as *Fusarium culmorum*, *Fusarium equisetii* and *Fusarium crookwellense* also produce this substances and other analogs. These fungal species are widely found as contaminants in many countries (Hagler, Towers, Mirocha, Eppley, & Bryden, 2001). The classification of zearalenone as a toxin is considered inappropriate since, although biologically potent, it is rarely toxic. Its structure, in fact, resembles 7β-estradiol, the main hormone produced in the human female ovary. Zearalenone would better fit the classification of a non-steroidal estrogen or a mycoestrogen (Bennet & Klich, 2003) (Fig. 4).

The association between the consumption of moldy grains and hyperestrogenism in pigs has been observed since 1920. High concentrations of zearalenone in pig feed may cause disturbances related to conception, abortion and other problems (Kurtz & Mirocha, 1978). Reproductive problems have also been observed in cows and ovine species (El-Nezami, Polychronaki, Salminen, & Mykkanen, 2002). Studies on experimental animals have not yet verified the carcinogenic capacity of zearalenone.

In Brazil this toxin has been found on cereals and oak flakes (Oliveira, Prado, Abrantes, Santos, & Veloso, 2002).

2.5. Citrinin

Citrinin was first isolated from secondary metabolites of *Penicillium citrinum*, well before the Second World War (Hetherington & Raistrick, 1931). Subsequently, other species of *Penicillium* (*Penicillium expansum* and *Penicillium viridicatum*) and even of *Aspergillus* (*Aspergillus niveus* and *Aspergillus terreus*) also showed the capacity to produce these substances. Certain isolates of *Penicillium camemberti*, used in cheese production, and *Aspergillus oryzae*, employed in the production of Asiatic foods, such as sake, miso and soy sauce, can also produce citrinin. More recently, citrinin was isolated from the metabolites of the fungi *Monoascus ruber* and *Monoascus purpureus*, species which are used industrially in the production of red pigments (Blane, Loret, & Goma, 1995; Manabe, 2001).

Citrinin was associated with ‘yellow rice’ syndrome in Japan in 1971, due to the constant presence of *P. citrinum* in this food product (Saito, Enomoto, & Tatsuno, 1971). It has also been considered responsible for nephropathy in pigs and other animals, although its acute toxicity varies depending on the animal species (Carlton & Tuite, 1977). Oat (moldy), rye, barley, corn and wheat grains are excellent substrates for the formation of citrinin (Abramson, Usleber, & Märtlbauer, 2000). This mycotoxin, which is present in the structure of polyketide, has also been found in products naturally colored with pigments of *Monoascus*, as well as sausages naturally fermented in Italy (Anderson, 1995; Chu, 1991) (Fig. 5).

Citrinin is considered to be nephrotoxic, and is generally found in association with another mycotoxin which is also nephrotoxic, ochratoxin (Flajs & Peraica, 2009). In Brazil, citrinin has been associated with pig nephropathy after ingestion of moldy barley grains (Rosa, Cruz, Chagas, & Veiga, 1985).

2.6. Patulin

This metabolite was first isolated as a substance with antimicrobial properties, in around 1940, from the fungus *Penicillium patulum*, later called *Penicillium urticae* and currently known as *Penicillium griseofulvum*. Patulin was later isolated from other fungal species and received different names, such as clavacin, claviformin, expansin, micoine C and penicidin (Ciegler, Detroy, & Lillejoj, 1971). It was used as a nose and throat spray in the treatment of the common cold and as an ointment for the treatment of skin infections (Ciegler, 1977; Ciegler et al., 1971). However, during the 1960s it became clear that although it did have antibacterial, antiviral and antiprotozoan activity it was also toxic to animals and plants. After these revelations it was reclassified as a true mycotoxin (Bennet & Klich, 2003). Chemically, patulin is known as 4-hydroxy-4H-furo[3, 2-c]pyran-2(6H)-one (Fig. 6).

The disease known as “blue mold”, which is common in apple, pear, cherry and other fruits, is caused by the fungus *Penicillium expansum*, currently considered the most efficient producer of patulin in nature. The species *Aspergillus clavatus*, *Aspergillus giganteus* and *Aspergillus terreus* are also producers of patulin (Pier & Richard, 1992). Patulin is commonly found in non-fermented apple juice, but it is not resistant to fermentation in products derived from cider, where it is efficiently metabolized by yeasts (Moss & Long, 2002). Studies on the toxicity toward human health, conducted in the laboratory, are not conclusive. Nevertheless, the

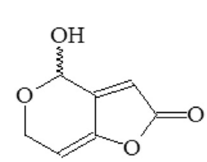


Fig. 6. Chemical structure of patulin.

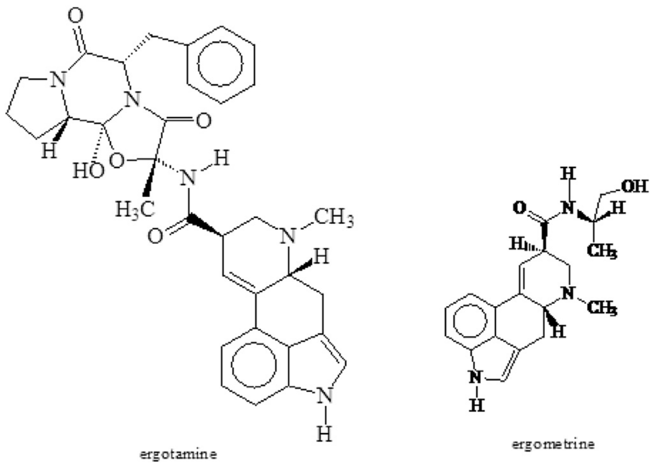


Fig. 7. Chemical structures of ergotamine and ergometrine.

World Health Organization has established a provisional daily dose of 0.4 mg/kg of body weight as the maximum limit of absorption for this mycotoxin (Trucksess & Tang, 2001).

2.7. Ergot alkaloids

These substances are among the most interesting secondary metabolites of fungi, and their production occurs in the scleroids of several species of the genus *Claviceps*. The effects of these alkaloids on humans have been known since the Middle Ages, a period in which some symptoms were called "Holy Fire" or "St Anthony's Fire". In the year 994, in the south of France, thousands of people died after eating cereal grains infected by *Claviceps purpurea* (Kruppa, 2004). Also known as ergotism, this intoxication occurs after the ingestion of bread or other products prepared with rye bread grains infected by fungus. Ergotism has two classic forms: gangrenous and convulsive. The gangrenous form affects the supply of blood to the extremities of the body, while the convulsive form acts directly on the central nervous system (Bennet & Bentley, 1999). In the small French town of Pont Saint Esprit, in 1951, there was an outbreak of ergotism, in which around 30 people were contaminated and the deaths of at least 5 of them were verified (Fuller, 1968, p. 301). The most recent outbreak of gangrenous ergotism occurred in Ethiopia between 1977 and 1978, when 140 people were affected, and the mortality rate reached 34%. In India, in 1975, an outbreak of convulsive ergotism was verified which affected 78 people but no deaths were confirmed. Cases of ergotism are currently rare since the majority of scleroids are eliminated during the processing in mills and only very low levels of ergot alkaloids can still be detected. In addition, these alkaloids are relatively thermolabile and are almost always destroyed in the bread making process (Peraica et al., 1999).

The scleroids of these fungi possess an array of alkoids of which the most important are derivatives of lysergic acid. Other alkoids which occur are ergometrine, ergotamine and ergotoxine (a mixture of ergocornine, ergocristine and ergocriptine, all cyclic tripeptides derived from lysergic acid) (Fig. 7). The species which produce these alkaloids, besides *C. purpurea* (rye and other cereals), including *Claviceps paspali* (forage grass), *Claviceps fusiformis* (in *Pennisetum typhoides*), *Claviceps gigantea* and *Sphacelia sorghi* (anamorphic form of *Claviceps*) (Hawksworth, Kirk, Sutton, & Pegler, 1995, p. 8, 616).

With the modern techniques of grain cleaning the problem of ergotism has been practically eliminated from the human food chain. However, it remains a threat from the veterinary perspective. The animals which are susceptible to intoxication include cattle, ovine species, pigs and birds. The clinical symptoms of ergotism in these animals manifest in the form of gangrene, abortion, convulsions, suppression of lactation, hypersensitivity and ataxia (loss of coordination of voluntary muscular movements) (Lorenz, 1979).

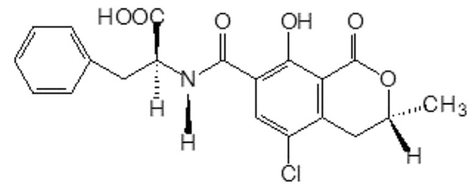


Fig. 8. Chemical structure of ochratoxin A.

2.8. Ochratoxin A

Ochratoxin A was discovered in 1965 as a metabolite of *Aspergillus ochraceus* during studies aimed at identifying new mycotoxin molecules (Van Der Merwe, Steyne, Fourie, Scott, & Theron, 1965). It has a chemical structure similar to that of aflatoxins, being represented by an isocoumarin substitute bound to an L-phenylalanine group (Fig. 8). Not all of the isolates of *A. ochraceus* are capable of producing ochratoxin A. Besides this species, *Aspergillus alliaceus*, *Aspergillus auricomus*, *Aspergillus carbonarius*, *Aspergillus glaucus*, *Aspergillus meleus* and *Aspergillus niger*, as well as *Penicillium nordicum* and *Penicillium verrucosum*, are producers of ochratoxin A (Abarca, Bragulat, Castellà, & Cabañes, 1994; Bayman, Baker, Doster, Michailides, & Mahoney, 2002; Chu, 1974; Ciegler, Cennell, Mintzlaff, & Leisthner, 1972; Larsen, Svendsen, & Smedsgaard, 2001; Pitt, 1987). Since *A. niger* is a species widely used in industry for the production of enzymes and citric acid for human consumption it is important to certify that industrial isolates are not producers of ochratoxin A (Heenan, Shaw, & Pitt, 1998; Teren, Varga, Hamari, Rinyu, & Kevei, 1996).

Ochratoxin A has been found in oats, barley, wheat, coffee grains and other products for human and animal consumption. There is also concern that this mycotoxin may be present in wines if the vine fruits are infected by *A. carbonarius* (Marquardt & Frohlich, 1992; Pitt, 2000; Van Egmond & Speijers, 1994).

Ochratoxin A is associated with nephropathy in all animals studied to date. In humans it is commonly found in serum (Reddy & Bhoola, 2010), since this substance has a long half-life in relation to its elimination (Creppy, 1999). Besides being recognized as nephrotoxic, ochratoxin A also shows hepatoxic, immunosuppressive, teratogenic and carcinogenic behavior (Beardall & Miller, 1994; Kuiper-Goodman & Scott, 1989; Pléstina, 1996; Schlatter, Studer-Rohr, & Rásonyi, 1996). It has been found in the blood and other tissues of animals and in milk, including human milk (Marquardt & Frohlich, 1992), as well as in pork meat intended for human consumption (Fink-Gremmels, 1999). Ochratoxin A has been found to be responsible for pig nephropathy, which has been widely studied in Scandinavian countries. The disease is endemic in pigs in Denmark, where it is also associated with bird deaths (Burns & Dwivedi, 1986; Hamilton, Huff, Harris, & Wyatt, 1982; Krogh, 1987). Studies have revealed that although small quantities of ochratoxin A can survive the processing and metabolism of pigs and birds, it is improbable that this could be detected in milk or bovine meat (Scudamore, 1996).

The International Cancer Research Agency has classified ochratoxin A as a possible human carcinogen (category 2B) (Beardall & Miller, 1994). Approximately 50% of the samples of rice, beans, corn and wheat analyzed in Brazil contained levels of ochratoxin A

(Caldas et al., 2002), and its presence has also been confirmed in roasted, ground and instance coffee (Prado et al., 2000).

3. Final considerations

The contamination of food and feed by mycotoxins represents a serious health problem for humans and animals as well as a considerable economic obstacle in African, Asian and Latin American countries, where the trade balance is based on the exportation of commodities. The recognition of problems caused by mycotoxins in foods destined for human and animal consumption is undoubtedly the first step toward the implementation of programs which enable the adoption of appropriate measures for the prevention and reduction of this problem.

References

Abarca, M. L., Bragulat, M. R., Castellà, G., & Cabañes, F. J. (1994). Ochratoxin A production by strains of *Aspergillus niger* var. niger. *Applied Environmental Microbiology, 60*, 2650–2652.

Abramson, D., Usleber, E., & Märtlbauer, E. (2000). Immunochemical method for citrinin. In M. W. Trucksess, & A. E. Pohland (Eds.), *Series: Methods in molecular biologyMycotoxin protocols* (pp. 195–204). USA: Humana Press Inc.

Ah-Seo, J., & Won Lee, Y. (1999). Natural occurrence of the C series of fumonisins in moldy corn. *Applied and Environmental Microbiology, 65*, 1331–1334.

Anderson, S. J. (1995). Compositional changes in surface mycoflora during ripening of naturally fermented sausages. *Journal of Food Protection, 58*, 426–429.

Bayman, P., Baker, J. L., Doster, M. A., Michailides, T. J., & Mahoney, N. E. (2002). Ochratoxin production by the *Aspergillus ochraceus* group and Aspergillus alliaceus. *Applied Environmental Microbiology, 68*, 2326–2329.

Beardall, J. M., & Miller, J. D. (1994). Disease in humans with mycotoxins as possible causes. In J. D. Miller, & H. L. Trenholm (Eds.), *Mycotoxins in grains: Compounds other than aflatoxin* (pp. 487–539). USA: St. Paul Eagen Press.

Bennet, J. W., & Bentley, R. (1999). Pride and prejudice: the story of ergot. *Perspectives in Biology and Medicine, 32*, 333–355.

Bennet, J. W., & Klich, M. (2003). Mycotoxins. *Clinical Microbiology Reviews, 16*, 497–516.

Betina, V. (1984). *Mycotoxins: production, isolation, separation, and purification*. Amsterdam: Elsevier.

Beuchat, L. R. (1978). Traditional fermented food products. In L. R. Beuchat (Ed.), *Food and beverage mycology* (pp. 224–253). Westport: AVI.

Bezuidenhout, S. C., Gelderblom, W. C. A., Gorst-Allman, C. P., Horak, R. M., Marasas, W. F. O., Spiteller, G., et al. (1988). Structure elucidation of the fumonisins, mycotoxins from *Fusarium moniliforme*. *Journal of Chemistry of the Society of Chemical Community, 1988*, 743–745.

Bhat, R. V., & Miller, J. D. (1991). Mycotoxins and food supply. *Food Nutrition and Agriculture, 1*, 27–31.

Blane, P. J., Loret, M. O., & Goma, G. (1995). Production of citrinin by various species of Monoascus. *Biotechnology Letters, 17*, 291–294.

Blout, W. P. (1961). Turkey "X" disease. *Turkeys, 9*, 52–58.

Bucci, T., Hansen, D. K., & Laborde, J. B. (1996). Leucoencephalomacia and hemorrhage in the brain of rabbits gavaged with mycotoxin fumonisin B_1. *Natural Toxins, 4*, 51–52.

Burns, R. P., & Dwivedi, P. (1986). The natural occurrence of ochratoxin A and its effects in poultry. A review. Part II. Pathology and immunology. *World Poultry Science, 42*, 48–62.

Caldas, E. D., Silva, S. C., & Oliveira, J. N. (2002). Aflatoxinas e ochratoxina A em alimentos e riscos para a saúde humana. *Revista de Saúde Pública, 36*, 319–323.

Carlton, W. W., & Tuite, J. (1977). Metabolites of *P. viridacatum* toxicology. In J. V. Rodricks, C. W. Hesseltine, & M. A. Mehlman (Eds.), *Mycotoxins in human and animal health* (pp. 525–555). Park Forest South: Pathotox.

Castrillon, A. L., & Purchio, A. (1988). Contaminating fungi producing aflatoxins in Brazil nuts (*Bertholletia excelsa* Humb. & Bonpl 1808). *Acta Amazonica, 18*, 173–183.

Chu, F. S. (1974). Studies on ochratoxins. *Critical Reviews in Toxicology, 2*, 499–524.

Chu, F. S. (1991). Current immuno-chemical methods for mycotoxin analysis. In M. Vanderlaan, L. H. Stanker, B. E. Watkins, & D. W. Roberts (Eds.), *Immunoassays for trace chemical analysis: Monitoring toxic chemicals in humans, food and the environment* (pp. 140–157). Washington, D.C.: American Chemical Society.

Ciegler, A. (1977). Patulin. In J. V. Rodricks, C. W. Hesseltine, & M. A. Mehlman (Eds.), *Mycotoxins in human and animal health* (pp. 609–624). Park Forest South: Pathotox.

Ciegler, A., Cennell, D. J., Mintzlaff, H. J., & Leisthner, L. (1972). Ochratoxin synthesis by *Penicilium* species. *Naturwissenschaften, 59*, 365–366.

Ciegler, A., Detroy, R. W., & Lillejoj, E. B. (1971). Patulin, penicillic acid and other carcinogenic lactones. In A. Ciegler, S. Kadis, & S. J. Ajl (Eds.), *Microbial toxins* (pp. 409–434). New York: Academic Press.

Cotty, P. J., Bayman, P., Egel, D. S., & Elias, K. S. (1994). Agriculture, aflatoxins and *Aspergillus*. In K. A. Powell, A. Rewick, & J. F. Reberdy (Eds.), *The genus Aspergillus: From taxonomy and genetics to industrial application* (pp. 1–27). New York: Plenum Press.

Coulombe, R. A., Jr. (1993). Biological action of mycotoxins. *Journal of Dairy Science, 76*, 880–891.

Creppy, E. E. (1999). Human ochratoxicosis. *Journal of Toxicology and Toxin Review, 18*, 277–293.

Diener, U. L., Cole, R. J., Sanders, T. H., Payne, G. A., Lee, L. S., & Klich, M. A. (1987). Epidemiology of aflatoxin formation by Aspergillus flavus. *Annual Review of Phytopathology, 25*, 249–270.

El-Nezami, H., Polychronaki, N., Salminen, S., & Mykkanen, H. (2002). Binding rather than metabolism may explain the interaction of two food-grade *Lactobacillus* strains with zearalenone and its derative α-zearalenol. *Applied Environmental Microbiology, 68*, 3545–3549.

Fandohan, P., Hell, K., Marasas, W. F. O., & Winfgield, M. J. (2003). Infection of maize by *Fusarium* species and contamination with fumonisin in Africa. *African Journal of Biotechnology, 2*, 570–579.

FAO. (01 February, 2011). *Worldwide regulations for micotoxins in food and in feed in 2003*. FAO. Food and Nutrition Paper, 81. Available at: http://www.fao.org/docrep/007/y5499e/y5499e07.htm.

Fink-Gremmels, J. (1999). Mycotoxins: their implications for human and animal health. *Veterinary Quarterly, 21*, 115–120.

Flajs, D., & Peraica, M. (2009). Toxicological properties of citrinin. *Archives of Industrial Hygiene and Toxicology, 60*, 457–464.

Forgacs, J. (1962). Mycotoxicoses – the neglected diseases. *Feedstuffs, 34*, 124–134.

Freire, F. C. O., & Kozakiewicz, Z. (2005). Filamentous fungi, bacteria and yeasts associated with cashew kernels in Brazil. *Revista Ciência Agronômica, 36*, 249–254.

Freire, F. C. O., Kozakiewicz, Z., & Paterson, R. R. M. (1999). Mycoflora and mycotoxins of Brazilian cashew kernels. *Mycopathologia, 145*, 95–103.

Freire, F. C. O., Kozakiewicz, Z., & Paterson, R. R. M. (2000). Mycoflora and mycotoxins in Brazilian black pepper, white pepper and Brazil nuts. *Mycopathologia, 149*, 13–19.

Frisvad, J. C., & Samson, R. A. (1991). Filamentous fungi in foods and feeds: ecology, spoilage and mycotoxin production. In D. K. Arora, K. G. Mukerjii, & E. H. Marth (Eds.), *Handbook of applied mycology: Food and Feeds* (pp. 31–68). New York: Marcel Dekker.

Fuller, J. J. (1968). *The day of St. Anthony's fire*. Macmillan.

Furlong, E. B., Valente, S. L. M., Lasca, C. C., & Kohara, E. Y. (1995). Mycotoxins and fungi in wheat harvested during 1990 in test plots in the state of São Paulo, Brazil. *Mycopathologia, 131*, 185–195.

Gelderblom, W. C. A., Jaskiewickz, K., Marasas, W. F. O., & Thiel, P. G. (1991). Toxicity and carcinogenicity of the *Fusarium moniliforme* metabolite, fumonisin B_1 in rats. *Carcinogenesis, 12*, 1247–1251.

Gelderblom, W. C. A., Jaskiewicz, K., Marasas, W. F. O., Thiel, P. G., Horak, R. M., Vleggaar, R., et al. (1988). Fumonisins-novel mycotoxins with cancer-promoting activity produced by *Fusarium moniliforme*. *Applied Environmental Microbiology, 54*, 1806–1811.

Gelderblom, W. C. A., Smuts, C. M., Abel, S., Snyman, S. D., Cawood, M. E., Van Der Westhuizen, L., et al. (1996). Effect of fumonisin B_1 on protein and lipid synthesis in primary rat hepatocytes. *Food Chemistry Toxicology, 34*, 361–369.

Groopman, J. D., Kensler, T. W., & Wild, C. P. (2008). Protective interventions to prevent aflatoxin-induced Carcinogenesis in developing countries. *Annual Review of Public Health, 29*, 187–203.

Hagler, W. M., Towers, N. R., Jr., Mirocha, C. J., Eppley, R. M., & Bryden, W. L. (2001). Zearalenone: mycotoxin or mycoestrogen? In B. A. Summerell, J. F. Leslie, D. Backhouse, W. L. Bryden, & L. W. Burgess (Eds.), *Fusarium* (pp. 321–331) St. Paul: APS Press.

Hamilton, P. B., Huff, W. E., Harris, J. R., & Wyatt, R. D. (1982). Natural occurrences of ochratoxicosis in poultry. *Poultry Science, 61*, 1832–1836.

Harrison, L. R., Colvin, B. M., Greene, J. T., Newman, L. E., & Cole, J. R. (1990). Pulmonary edema and hydrothorax in swine produced by fumonisin B_1, a toxic metabolite of *Fusarium moniliforme*. *Journal of Veterinary Diagnostic Investigation, 2*, 217–221.

Hawksworth, D. L., Kirk, P. M., Sutton, B. C., & Pegler, D. N. (1995). *Ainsworth & Bisbys dictionary of the fungi*. Wallingford: CAB International.

Heenan, C. N., Shaw, K. J., & Pitt, J. I. (1998). Ochratoxin A production by *Aspergillus carbonarius* and *A. niger* isolates and detection using coconut cream agar. *Journal of Food Mycology, 1*, 67–72.

Hetherington, A. C., & Raistrick, H. (1931). Studies in the biochemistry of microorganisms. Part XIV. On the production and chemical constitution of a new yellow colouring matter, citrinin, produced from glucose by *Penicillim citrinum* Thom. *Phylosophical Transactions of the Royal Society of London, 220*, 269–295.

Hinkley, S. F., & Jarvis, B. B. (2001). Chromatographic method for *Stachybotrys* toxins. In M. W. Trucksess, & A. E. Pohland (Eds.), *Mycotoxins protocols* (pp. 173–194). Totowa: Humana Press.

Hirooka, E. Y., Shibata, M. M., Viotti, N. M. A., Carvalho, L., Takahashi, L. S. A., Souza, I. F., et al. (1991). Fumonisina: importância da nova micotoxina de *Fusarium moniliforme* em intoxicações animais no Norte do Paraná. *Revista de Microbiologia, 22*, 312.

Hirooka, E. Y., Yamaguchi, M. M., Aoyama, S., Sugiura, Y., & Ueno, Y. (1996). The natural occurrence of fumonisin in Brazilian corn kernels. *Food Additives and Contaminants, 13*, 173–183.

Jelinek, C. F., Pohland, A. E., & Wood, G. E. (1989). Worldwide occurrence of mycotoxins in foods and feeds, an update. *Journal of the Association of Official Analytical Chemists, 72*, 223–230.

Joffe, A. Z. (1978). *Fusarium poae* and *F. sporotrichioides* as principal causal agents of alimentary toxic aleukia. In T. D. Willie, & L. G. Morehouse (Eds.), *Mycotoxic fungi, mycotoxins, mycotoxicoses* (pp. 21–86). New York: Marcel Dekker.
Klich, M. A. (1987). Relation of plant water potential at flowering to subsequent cottonseed infection by *Aspergillus flavus*. *Phytopathology, 77*, 739–741.
Klich, M. A., & Pitt, J. I. (1988). Differentiation of *Aspergillus flavus* and *A. parasiticus* and other closely related species. *Transactions of the British Mycological Society, 91*, 99–108.
Krogh, P. (1987). Ochratoxin in foods. In P. Krogh (Ed.), *Mycotoxins in foods* (pp. 97–110). London: Academic Press.
Kruppa, P. C. (2004). Claviceps. *Biológico, 66*, 35–37.
Kuiper–Goodman, T., & Scott, P. M. (1989). Risk assessment of the mycotoxin ochratoxin A. *Biomedic Environmental Science, 2*, 179–248.
Kurtzman, C. P., Horn, B. W., & Hesseltine, C. W. (1987). Aspergillus nomius, a new aflatoxin-producing species related to *Aspergillus flavus* and *Aspergillus tamarii*. *Anton Leeuwenhoek, 53*, 147–158.
Kurtz, H. J., & Mirocha, J. (1978). Zearalenone (F_2) induced estrogenic syndrome in swine. In T. D. Willie, & L. G. Morehouse (Eds.), *Mycotoxic fungi, mycotoxins, mycotoxicoses* (pp. 1256–1264). New York: Marcel Dekker.
Larsen, T. O., Svendsen, A., & Smedsgaard, J. (2001). Biochemical characterization of ochratoxin A – producing strains of the genus Penicillium. *Applied and Environmental Microbiology, 67*, 3630–3635.
Leung, M. C. K., Diaz-Llano, G., & Smith, T. K. (2006). Mycotoxins in pet food: a review on worldwide prevalence and preventative strategies. *Journal of Agricultural and Food Chemistry, 54*, 9623–9635.
Lorenz, K. (1979). Ergot on cereal grains. *Critical Review in Food Science and Nutrition, 11*, 311–354.
Lourenço, A. (26 november, 2011). Estaquibotriose: não é só pela boca que morre o peixe. *Boletim Científico, 42*. Available at http://www.micotoxinas.com.br/boletim42.pdf.
Lutsky, I., Mor, N., Yagen, B., & Joffe, A. Z. (1978). The role of T-2 toxin in experimental alimentary toxic aleukia: a toxicity study in cats. *Toxicological Applied Pharmacology, 43*, 111–124.
Manabe, M. (2001). Fermented foods and mycotoxins. *Mycotoxins, 51*, 25–28.
Mannon, J., & Johnson, E. (1985). Fungi down on the farm. *New Scientist, 105*, 12–16.
Marasas, W. F. O., Kellerman, T. S., Gelderblom, W. C. A., Coetzer, J. A. W., Thiel, P. G., & Van Der Lugt, J. J. (1988). Leukoencephalomalacia in horse induced by fumonisin B_1 isolated from Fusarium moniliforme. *Onderstepoort Journal of Veterinary Research, 55*, 197–203.
Marquardt, R. R., & Frohlich, A. A. (1992). A review of recent advances in understanding ochratoxicosis. *Journal of Animal Science, 70*, 3968–3988.
Merrill, A. H., Van Echten, G., Wang, E., & Sandhoff, K. (1993). Fumonisin B_1 inhibits sphingosine (sphinganine) N-acyltransferase and de novo sphingolip biosynthesis in cultured neuron in situ. *Journal of Biological Chemistry, 268*, 2299–2306.
Miller, J. D., Apsimon, J. W., Blackwell, B. A., Greenhalgh, R., & Taylor, A. (2001). Deoxynivalenol: a 25 year perspective on a trichothecene of agricultural importance. In B. A. Summerell, J. F. Leslie, D. Backhouse, W. L. Bryden, & L. W. Burgess (Eds.), *Fusarium* (pp. 31–319). St. Paul: APS Press.
Moss, M. O. (2002). Mycotoxin review – 1. *Aspergillus* and *Penicillium*. *Mycologist, 16*, 116–119.
Moss, M. O., & Long, M. T. (2002). Fate of patulin in the presence of yeast *Saccharomyces cerevisiae*. *Food Additives and Contaminants, 19*, 387–399.
Musser, S. M., & Plattener, R. D. (1997). Fumonisin composition in culture of *Fusarium moniliforme, Fusarium proliferatum* and *Fusarium nygamae*. *Journal of Agricultural and Food Chemistry, 45*, 1169–1173.
Ngugi, H. K., & Scherm, H. (2006). Biology of flower-infecting fungi. *Annual Review of Phytopathology, 44*, 261–282.
Oliveira, C. A. F., Germano, P. M. L., Bird, C., & Pinto, C. A. (1997). Immunochemical assessment of aflatoxin M_1 in milk powder consumed by infants in São Paulo, Brazil. *Food Additives and Contaminants, 14*, 7–10.
Oliveira, M. S., Prado, G., Abrantes, F. M., Santos, L. G., & Veloso, T. (2002). Incidência de aflatoxinas, desoxinivalenol e zearalenona em produtos comercializados em cidades de Minas Gerais no período de 1998-2000. *Revista Do Instituto Adolfo Lutz, 61*, 1–6.
Oliveira, A. Q., & Soares, L. M. V. (2001). Avaliação de métodos para determinação de tricotecenos em milho por cromatografia gasosa. *Revista Do Instituto Adolfo Lutz, 60*, 129–134.
Peraica, M., Radic, B., Lucic, A., & Pavlovic, M. (1999). Toxic effects of mycotoxins in humans. *Bulletin of the World Health Organization, 77*, 754–766.
Pereira, M. M. G., Carvalho, E. P., Prado, G., Rosa, C. A. R., Veloso, T., Souza, L. A. F., et al. (2005). Aflatoxinas em alimentos destinados a bovinos e em amostras de leite da região de Lavras, Minas Gerais – Brasil. *Ciência Agrotécnica, 29*, 106–112.
Peterson, S. W., Ito, Y., Horn, B. W., & Goto, T. (2001). *Aspergillus bombycis*, a new aflatoxigenic species and genetic variation in its sibling species, A. nomius. *Mycologia, 93*, 689–703.
Pier, A. C., & Richard, J. L. (1992). Mycoses and mycotoxicoses of animals caused by *Aspergilli*. In J. W. Bennett, & M. A. Klich (Eds.), *Aspergillus: biology and industrial applications* (pp. 233–267). Maryland: Butterworth-Heinemann.
Pitt, J. I. (1987). *Penicillium viridicatum, Penicilium verrucosum*, and production of ochratoxin A. *Applied Environmental Microbiology, 53*, 266–269.
Pitt, J. I. (2000). Toxigenic fungi: which are important? *Medical Mycology, 38*, 17–22.
Pléstina, R. (1996). Nephrotoxicity of ochratoxin A. *Food Additives and Contaminants, 13*, 49–50.
Pozzi, C. R., Arcaro, J. R. P., Júnior, I. A., Fagundes, H., & Corrêa, B. (2002). Aspectos relacionados à ocorrência e mecanismo de ação de fumonisinas. *Ciência Rural, 32*, 901–907.
Pozzi, C. R., Correa, B., Xavier, J. G., Direito, G. M., Orsi, R. B., & Matarazzo, S. V. (2000). Effects of prolonged oral administration of fumonisin B_1 and aflatoxin B_1 in rats. *Mycopathologia, 151*, 21–27.
Prado, G., Oliveira, M. S., Abrantes, F. M., Santos, L. G., Veloso, T., & Barroso, E. S. (2000). Incidência de ochratoxina A em café torrado e moído e em café solúvel consumido na cidade de Belo Horizonte, MG. *Ciência e Tecnologia de Alimentos, 20*, 192–196.
Prado, G., Oliveira, M. S., Ferreira, S. O., Corrêa, T. B. S., & Ramos, B. R. (1997). Ocorrência natural de desoxinivalenol e toxina T2 em milho pós-colheita. *Ciência e Tecnologia Alimentar, 17*, 259–262.
Raisuddin, S. (1993). Toxic responses to aflatoxins in a developing host. *Journal of Toxicology Toxin Reviews, 12*, 175–201.
Reddy, L., & Bhoola, K. (2010). Ochratoxins — Food Contaminants: Impact on human health. *Toxins (Basel), 2*, 771–779.
Rosa, C. A. R., Cruz, L. C. H., Chagas, W. A., & Veiga, C. E. M. O. (1985). Ocorrência natural de nefropatia micotóxica suína causada pela ingestão de cevada contaminada com citrinina. *Revista Brasileira de Medicina Veterinária, 7*, 87–90.
Saito, M., Enomoto, M., & Tatsuno, T. (1971). Yellowed rice toxins: luteroskyrin and related compounds, chlorine-containing compounds and citrinin. In A. Ciegler, S. Kadis, & S. J. Ajl (Eds.), *Microbial toxins* (pp. 299–380). New York: Academic Press.
Santos, C. C. M., Lopes, M. R. V., & Kosseki, S. Y. (2001). Ocorrência de aflatoxinas em amendoim e produtos de amendoim comercializados na região de São José do RioPreto/SP. *Revista Do Instituto Adolfo Lutz, 60*, 153–157.
Schlatter, C. H., Studer-Rohr, J., & Rásonyi, T. H. (1996). Carcinogenicity and kinetic aspects of ochratoxin A. *Food Additives and Contaminants, 13*, 43–44.
Scholl, P. F., & Groopman, J. D. (2008). Long-term stability of human aflatoxin B1 albumin adducts assessed by isotope dilution mass spectrometry and high-performance liquid chromatography–Fluorescence. *Cancer Epidemiology, Biomarkers & Prevention, 17*, 1436–1439.
Scott, P. M. (1989). The natural occurrence of trichothecenes. In V. R. Beasley (Ed.), *Trichothecene mycotoxicosis: pathophysiologic effects* (pp. 1–26). Boca Raton: CRC Press.
Scudamore, K. A. (1996). Ochratoxin A in animal feed-effects of processing. *Food Additives and Contaminants, 13*, 39–42.
Sforza, S., Dall'asta, C., & Marchelli, R. (2006). Recent advances in mycotoxin determination in food and feed by hyphenated chromatographic techniques/mass spectrometry. *Mass Spectrometry Reviews, 25*, 54–76.
Shier, W. T. (1992). Sphingosine analogs: an emerging new class of toxins that includes the fumonisins. *Journal of Toxicology Toxin Reviews, 11*, 241–257.
Smith, J. E., Solomons, G., Lewis, C., & Anderson, J. G. (1995). Role of mycotoxins in human and animal nutrition and health. *Natural Toxins, 3*, 187–192.
Stafford, M. E., & McLaughlin, C. S. (1973). Trichodermin, a possible inhibitor of the termination process of protein synthesis. *Journal of Cell Physiology, 82*, 121–124.
Sydenham, E. W., Shephard, G. S., Thiel, P. G., Marasas, W. F. O., & Stockenstrom, S. (1991). Fumonisin contamination of commercial corn-based human food stuffs. *Journal of Agricultural Food Chemistry, 39*, 2014–2018.
Taveira, J. A., & Midio, A. F. (1999). Aflatoxina M_1 – a micotoxina do leite. *Boletim SBCTA, 33*, 115–126.
Teren, J., Varga, J., Hamari, Z., Rinyu, E., & Kevei, F. (1996). Immunochemical detection of ochratoxin A in black *Aspergillus* strains. *Mycopathologia, 134*, 171–186.
Trucksess, M. W., & Tang, Y. (2001). Solid phase extraction method for patulin in apple juice and unfiltered apple juice. In M. W. Trucksess, & A. F. Pohland (Eds.), *Mycotoxin protocols* (pp. 205–213). Totowa: Humana Press.
Ueno, Y. (1983). *Trichothecenes: chemical, biological and toxicological aspects*. Amsterdam: Elsevier.
Van Der Merwe, K. J., Steyne, P. S., Fourie, L. F., Scott, D. B., & Theron, J. J. (1965). Ochratoxin A, a toxic metabolite produced by *Aspergillus ochraceus* Wilh. *Nature, 205*, 1112–1113.
Van Egmond, H. P., & Speijers, G. J. A. (1994). Survey of data on the incidence and levels of ochratoxin A in food and animal food worldwide. *Natural Toxins, 3*, 125–144.
Wei, C. M., Campbell, I. M., McLaughlin, C. S., & Vaughn, M. H. (1974). Binding of trichodermin to mammalian ribosomes and its inhibition by other 12, 13–epoxytrichothecenes. *Molecular Cell Biochemistry, 3*, 215–219.