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Mini Review

Incidence, legislations and strategies of control of mycotoxins in North African countries

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Abstract

Mycotoxins are natural food and feed contaminants mainly produced by filamentous and ubiquitous fungi of genera *Aspergillus, Penicillium* and *Fusarium*. Due to the high stability of mycotoxins, contamination can occurs in the field, during storage, processing and post-processing steps, under favorable conditions of temperature and water activity. These compounds pose serious economic and health problems worldwide and show different toxicological effects in humans and animals. North African populations are exposed to the risk of mycotoxins due to consumption of contaminated food. These countries are surrounded by Mediterranean Sea and have a climate characterized by high humidity and temperature, which probably favors the growth of molds. During the last decades, many studies have reported the occurrence of different mycotoxins in food commodities in North African countries. Tolerable limits for mycotoxins have been established in these countries but legislations do not include all mycotoxins. In addition, researchers try to establish strategies to prevent and reduce mycotoxin contamination, but studies still rare and not include all mycotoxins and toxigenic fungi. This review presents an overview of the main investigations about the occurrence of mycotoxins and toxigenic mycobiota in food commodities commercialized in North African countries and the regulation limits which are in force in these countries.

Introduction

The problem of food insecurity predominantly occurs in developing countries and rural areas where populations are generally dependent on locally produced food and have inconsistent access to safe and nutritious food. Mycotoxins are one of the most significant contributors to food and feed insecurity in worldwide, especially in developing countries. Mycotoxins are secondary metabolites of fungi that naturally occur in various foodstuffs and agricultural commodities worldwide (Turner *et al*., 2009). Although hundreds of mycotoxins have been identified, the most widely investigated are aflatoxins (AFs), ochratoxin A (OTA), deoxynivalenol (DON), fumonisins (FUM), zearalenone (ZEA), trichothecenes (TRC) and patulin (PAT) (Miller, 1995; Miraglia and Brera, 2000), due to their frequent occurrence and their severe adverse effects on human and animals, including carcinogenicity, neurotoxicity, immunosuppression, nephrotoxicity, hepatotoxicity, mutagenicity, genotoxicity as well as reproductive and developmental toxicity.

During the past decades, a huge number of scientific papers have demonstrated that the list of raw materials and processed foods actually contaminated by mycotoxins is continuously increasing spanning from peanuts to cereals, spices, coffee, cocoa and dried fruits (D' Mello, 2003). Since those crops contaminated by mycotoxins are also used as feed for livestock, these compounds further affect animal growth rates and persist in meat, eggs, milk and dairy products due to their resistance to the decomposition in the digestive systems of animals (Prandini *et al*., 2009; Gizachew *et al.,* 2016). Mycotoxin contamination lowers product quality and reduces export values, which may lead to significant economic losses for producing countries. The Food and Agriculture Organization (FAO) of the United Nations has estimated that approximately 25% of foodstuffs consumed in the world are contaminated by mycotoxins (Duarte *et al.*, 2010). Regarding the effects on human health, animal productivity and economy, the prevalence of mycotoxins has led many countries to establish strict regulations for their content in food and feed (Juan *et al*., 2012). The growth of molds and the accumulation of mycotoxins in food and feed are influenced by multiple variables, including water activity (a_w), temperature, pH, atmosphere composition, substrate, interaction

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among species, and time. During cultivation, factors such as water stress, soil conditions and insect activity will cause the invasion of crops by mycotoxigenic fungi (Wagacha and Muthomi, 2008). During postharvest and storage, fungal growth and mycotoxin contamination increase under favorable conditions (Paterson and Lima, 2010). Additionally, socio-economic factors including unavailability of materials, inadequate marketing and transportation systems and inadequate governmental policy, lack of regulations and legislations can further contribute to favoring mycotoxin contamination.

As toxigenic fungi are ubiquitous, mycotoxins cannot be easily eliminated. Various physical and chemical methods have been recommended to reduce mycotoxins, but only a few have been accepted for practical use. Thus, the prevention of fungal growth and mycotoxin production through strategic interventions represent key steps in risk management. These strategies have been developed to minimize mycotoxin contamination to acceptable levels for consumption. However, various strategies have not been proven to be sustainable over extended periods and many are not economically and logistically realistic for poorer communities, which typically suffer the highest exposure to mycotoxins. In North African countries, researchers try to establish some strategies to reduce mycotoxin contamination, but studies are rare and not include all mycotoxins and can't be applied for all foodstuffs. To address mycotoxin problems in these countries, intervention strategies should provide improved incentives for management of toxigenic molds and increase public awareness and knowledge through education and extension.

Classification and toxicological aspects of mycotoxins

Aflatoxins

Aflatoxins, are a group of structurally related difurano-coumarin derivatives (Bhatnagar *et al*., 2003) synthesized via a polyketide pathway by certain species of *Apergillus* section *Flavi* such as *Aspergillus flavus, Aspergillus parasiticus, Aspergillus parvisclerotegenus, Aspergillus minisclerotigenes* and less commonly *Aspergillus nomius* (Kurtzman *et al*., 1987; Pleadin *et al*., 2014). There are more than 20 distinct structurally related aflatoxin compounds, but the four most commonly found are known as aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1) and aflatoxin G2 (AFG2) (Tam *et al*., 2006; Hernandez-Martinez and Navarro-Blasco, 2010). Normally, *Aspergillus flavus* produces B aflatoxins only, while *Aspergillus parasiticus* produce both B and G types (Creppy, 2002). These substances are extremely toxic and classified as group 1 carcinogens by the International Agency for Research on Cancer (IARC, 2002). Their detrimental effects on human and animal health include carcinogenic, mutagenic, teratogenic and immunosuppressive effects (Eaton and Gallagher, 1994). Among them, aflatoxin B1 (AFB1) is the most frequent and the most noxious and potent hepatocarcinogen known in mammals. Aflatoxin M1 and M2 (AFM1 and AFM2) are the main monohydroxylated derivatives of AFB1 and AFB2 occurring in milk of mammals whose diet are contaminated with AFB1 and AFB2 and formed in liver by means of cytochrome P450-associated enzymes. Approximately 0.3-6.2% of AFB1 is converted into hydroxylated metabolite AFM1, depending on several factors such as the genotype of the animals, milking practices, seasonal fluctuations and environmental conditions (Unusan, 2006). Wogan and Paglialunga (1974) reported that AFM1 has only 10% of the carcinogenicity of AFB1 *in vivo*. Since milk is a major commodity for introducing AFs in the human diet, evidence of hazardous human exposure to AFM1 through dairy products has been shown by several studies such as cytotoxicity and genotoxicity (Cole and Cox, 1981). AFM1 is classified as a Group 1 like carcinogenic to humans (IARC, 2002).

Aflatoxins are found in a wide range of food commodities including cereals, figs and nuts. The highest contamination has been found in corn, peanuts and cottonseed (Gourama and Bullerman, 1995). North African populations consume a great amount of cereals and cereal products, spices, dried fruits and olives. These kinds of foodstuffs are susceptible substrates for growth of aflatoxigenic molds.

Ochratoxin A

Ochratoxins (OTs) are phenylalanyl derivatives of a substituted isocoumarin produced by *Aspergillus ochraceus* and *Penicillium verrucosum* which initially believed to be the main OTs-producing species (Hesseltine *et al*., 1972; Pitt, 1987). Since *Penicillium verrucosum* is considered as more frequently associated with cereals in temperate climates, species of *Aspergillus ochraceus* are commonly found in warm and tropical climate (Pitt and Hocking, 199*7).* Furthermore, the significance of black Aspergilli as Ochratoxin A (OTA)-producing fungi has changed since the first description of OTA production by *Aspergillus niger* var. *niger* (Abarca *et al.,* 1994) and *Aspergillus carbonarius* (Horie, 1995). It is now considered that in food commodities such as grapes, raisins and wine, the OTA contamination is mainly due to *A. carbonarius* and some *A. niger*

aggregate species, mainly *A. niger* and *A. tubingensis* (Abarca *et al.,* 2001; Perrone *et al*., 2007; 2008). In the ochratoxins group, A-type is the most toxic compound; however B and C ones also exist. OTA has nephrotoxic, carcinogenic, immunotoxic, genotoxic and teratogenic properties of all animal species tested (Pitt *at al*., 2001). Consequently, the International Agency for Research on Cancer (IARC) has classified OTA in group 2B as a possible carcinogen compound to humans (IARC, 2002). Kidney function is most often affected by OTA, where both acute and chronic exposures cause lesions to form on the organs (Garcia-Cela *et al.*, 2012). Indeed, this substance has been associated with Balkan Endemic Nephropathy (BEN) in Southeastern Europe "Balkan" characterized by urinary tumors in humans (Krogh *et al.*, 1977; Pfohl-Leszkowicz *et al*., 2002; Monaci and Palmisano, 2004). When ingested as a food contaminant, OTA is frequently found in human blood due to its long elimination half-life (about 35 days in serum), as a consequence of its binding to plasma proteins, its enterohepatic circulation and its reabsorption from urine (Studer-Rohr *et al.*, 2000). Consequently, OTA is the most detected mycotoxin in human blood all over the world. In North African countries, many authors have shown a high incidence of chronic interstitial nephropathies associated with the consumption of OTA-contaminated food (Abid-Essafi *et al*., 2003). A preliminary survey reported that the Moroccan population is highly exposed to OTA (Filali *et al*., 2002). Indeed, 60% of the Moroccan human plasma sampled was positive for OTA with an average concentration of 0.29 ng/mL. In Tunisia, OTA was considered to be a casual agent of a Chronic Interstitial Nephropathy (CIN) (Bacha *et al*., 1993; Maaroufi *et al*., 1996; Abid-Essafi *et al.*, 2003). The crops mainly contaminated are cereals and cocoa (Gilmour and Lindblom, 2008; Copetti *et al*., 2010), coffee (Romani *et al.*, 2000; De Moraes and Luchese, 2003) as well as grapes (Zinedine and Mañes, 2009; Garcia-Cela *et al.*, 2012).

Zearalenone

Zearalenone (ZEA) is a non-steroid estrogen mycotoxin produced by Fusarium species including *Fusarium graminearum, Fusarium culmorum* (Bennett and Klich, 2003) and *Fusarium incarnatum*-equiseti species complex (FIESC) (Schroeder *et al.*, 1975; Kosiak *et al*., 2005; Leslie and Summerell, 2006; Aoyama *et al*., 2009). ZEA has been shown to competitively bind to estrogen receptors because of the similarity with the sex human hormone. Therefore, it is known to cause estrogenic effects in both humans and animals including infertility, reduced serum testosterone levels and sperm counts, reduced incidence of pregnancy, and change in the progesterone levels (Shier *et al*., 2001; Sherif *et al.,* 2009). ZEA was classified by IARC under group 3 according to the International Agency for Research on Cancer (IARC, 1999). Moreover, this toxin is responsible of hepatotoxic (Conkova *et al*., 2001) and haematotoxic complications. It causes several alterations of immunological parameters (Abbes *et al.*, 2006). Several studies have demonstrated that ZEA exhibits several genotoxic effects such as the induction of micronuclei, chromosome aberrations, DNA strand breaks and DNA adduct formation (Abbes *et al*., 2006, 2007). Cereals such as corn, wheat, barley, sorghum and rice are susceptible to be contaminated with ZEA (Manova and Mladenova, 2009). It can also be found in beverages made with contaminated crops (Chen *et al*., 2000).

Fumonisins

Fumonisins (FMs) are a class of mycotoxins mainly synthesized by different species of *Fusarium* section Liseola including: *Fusarium verticillioides* and *Fusarium proliferatum* (Chen *et al.*, 1992), but can also reportedelly be produced by *Aspergillus niger* strains. Several fumonisins have been isolated and characterized, but only fumonisin B1 (FB1), fumonisin B2 (FB2) and fumonisin B3 (FB3) are the predominating ones produced in foodstuffs. FB1 has the structure of a diester of propane-1,2,3-tricarboxylic acid. Fumonisins show different toxicological effects in humans and animals. Their natural occurrence in corn was associated with esophageal cancer in many countries (Marasas *et al*., 1988; Franceschi *et al.*, 1990; Sydenham *et al*., 1990; Gelderblom *et al*., 1992; Rheeder *et al*., 1992; Shephard *et al*., 2000) and with the promotion of primary liver cancer in certain endemic areas of China (Chu and Li, 1994). Links between exposure to FB1 and esophageal cancer can be found in many epidemiologic studies (Rheeder *et al.,* 2002). Accordingly, fumonisins are possible carcinogenic to humans and they are classified in class 2B carcinogens according to the International Agency for Research on Cancer (IARC, 2002). Sherif *et al*. (2009) mentioned that FMs can additionally disrupt sphingolipid metabolism by acting as secondary messengers for growth factors, differentiation factors and cytokines. These toxins may occur in cereals such as corn, wheat, barley and sorghum. Maize is the major food crop affected by FMs, although noteworthy incidence has been found in sorghum and rice (CAST, 2003; Vismer *et al.*, 2015).

Trichthecenes

Trichothecenes are a large group of mycotoxins produced mainly by species belonging to different fungal genera, including *Fusarium, Myrothecium, Phomopsis* and *Trichoderma*. All trichothecenes contain a common 12,13-epoxytrichothene skeleton and an olefinic bond with various side chain substitutions (Bennett and Klich, 2003). According to their chemical structure, they have been classified into four groups: types A-D (WHO, 1990). Trichothecenes primarily cause necrosis and hemorrhage throughout the digestive tube, tract depression of blood regenerative processes in the marrow and spleen, and changes in reproductive organs. Signs of disease include weight loss, reduced feed consumption, vomiting, diarrhea, abortion and death. Immunosuppression may be important in trichothecenes-affected animals (CAST, 1989).

Deoxynivalenol (DON) is the most widespread mycotoxin of the B-trichothecenes group, which are epoxy-sesquiterpenoids (Clear and Patrick, 2000; Eriksen and Pettersson, 2004). Presently, this toxin, also known as vomitoxin, is primarily produced by *Fusarium graminearium* and *Fusarium culmorum* (Desjardins and Proctor, 2001). Its accumulation in human and animal bodies can induce adverse health effects after acute or chronic administration (Pestka, 2010) resulting in teratogenic, neurotoxic, embryotoxic and immunosuppressive effects (Pestka, 2007).

Citrinin

Citrinin (CIT) is a polyketide mycotoxin produced by *Penicillium citrinum,* although it may also be produced by *Penicillium expansum, Penicillium verrucosum* and some species of *Aspergillus* and *Monascus* (Ei-Banna, 1987; Kurata, 1990; Li *et al*., 2003). Several studies showed that CIT possesses cytotoxic, genotoxic, mutagenic, immunotoxic and teratogenic properties (Wurgler *et al.*, 1991; Liu *et al.*, 2003; Iwahashi, 2007; Bouslimi *et al.*, 2008) and the most important toxic property of this mycotoxin is its nephrotoxic effect (Chagas *et al*., 1992). Presently, there is no specific legislation for citrinin worldwide. It is difficult to establish widely acceptable limits for this mycotoxin because its instability in foodstuffs.

Patulin

Patulin (PAT) is a polyketide mycotoxin mainly produced by Penicillium expansum (Baert *et al*., 2007). Patulin has received different names, such as clavacin, claviformin, expansin, micoinin C and penicidin (Ciegler *et al.*, 1971). In view of its antimicrobial properties, this mycotoxin has been used for the treatment of colds and skin infections (Ciegler *et al*., 1971; Ciegler, 1977). However, during the 1960s, it was shown that this substance is also toxic. Following these revelations, patulin was considered a true mycotoxin (Bennet and Klich, 2003). Acute symptoms of PAT exposure can include agitation, convulsions, edema, ulceration, intestinal inflammation and vomiting (Speijers, 2004). The chronic health effects of patulin include genotoxicity, immunotoxicity, embryotoxicity and neurotoxicity (Wouters and Speijers, 1996). However, no adequate evidence exists for carcinogenicity in experimental animals and humans. It is not classifiable as to its carcinogenicity to humans, and it is included in Group 3 of the International Agency for Research on Cancer (IARC, 1993). Apples, pears, cherries and other fruits can be infested with *Penicillium expansum* responsible for a pathology called "blue mold". Although *Penicillium expansum* is the most important producer of patulin, other species such as *Aspergillus clavatus, Aspergillus giganteus* and *Aspergillus terreus* are also able to produce this mycotoxin (Pier and Richard, 1992). It is commonly found in unfermented apple juice. This substance is not resistant to the fermentation process and is efficiently metabolized by yeast during the preparation of the cider and its derivatives (Moss and Long, 2002).

Mycotoxin and toxigenic fungi occurrence in food commodities in North African countries

Cereals

Cereals are the most important source of food in the world either through direct human consumption or indirectly through their use in feeding livestock. Latest FAO forecasts indicate that global cereal production in 2011 increased by 3.3% from 2010 to 2313 million tons (FAO, 2011). Obviously, this high production must comply with the safety standards of foodstuffs for humans and animals considering the economic and health impact of this type of food. Post harvest losses in food grains in developing countries have been estimated conservatively during the 1980s as 10-15% by the FAO's Special Action Program for the Prevention of Food Losses (FAO, 2004b). One of the main agents that cause these significant losses in cereals is fungi. Cereal plants may be contaminated by mycotoxigenic fungal strains during anthesis (Beyer *et al*., 2007) that continue their proliferation during harvest and storage under favorable conditions (Glenn, 2007). In addition, these fungi are capable of producing not only losses in the organoleptic quality of the grain but accumulating mycotoxins in cereals that can cause health problems to humans

Table 1. Maximum levels of mycotoxins in various foodstuffs for human (European Commission, 2002 ; 2006b ; 2007 ; 2010) and animal consumption (The European Parliament and Council, 2002; European Commission, 2006a)

Mycotoxin	Food commodity	Maximum limits (µg/kg)
Aflatoxin B1	Cereals and cereal-based-food for human consumption	2
	Unprocessed corn and rice intended for human consumption	5
	Raw material for animals	20
	Spices	5
	Dried fruits for direct consumption	2
	Peanuts	2
	Almonds and pistachios	8
Aflatoxin B1, B2, G1 and G2	All cereals and cereal-based-food intended for human consumption	4
	Unprocessed corn and rice for human consumption	10
	Spices	10
	Dried fruits for direct consumption	4
	Peanuts	4
	Almonds, pistachios and dried figs	10
Aflatoxin M1	liquid milk	0.05
Deoxynivalenol	Unprocessed cereals other than durum wheat, maize and oats	1250
	Unprocessed durum wheat and oats	1750
	Cereals intended for direct human consumption, flour, bran and germ in the form of a finished product for direct human consumption	750
	Bread, pastries, biscuits, cereal snacks and breakfast cereals	500
	Processed cereal-based foods and foods for infants and young children	250
	Cereals and cereal products for animals	8000
	Maize products for animals	12000
Zearalenone	Unprocessed cereals other than maize	100
	Unprocessed corn	350
	Cereals intended for direct human consumption, flour, bran and germ in the form of a finished product for direct human consumption	75
	Bread, pastries, biscuits, cereal snacks and breakfast cereals with the exception of maize products	50
	Corn intended for direct human consumption, snakes and breakfast products based on corn	100
	Processed cereal-based foods and foods for infants and young children	20
	Cereals and cereal products for animals	2000
	Corn products intended for animals	3000
Ochratoxin A	Unprocessed cereals	5
	Unprocessed cereal based-food, processed cereals and cereal products intended for direct human consumption	3
	Processed cereal-based foods and foods for infants and young children	0.05
	Cereals and cereal products for animals	250
	Instant coffee	10
	Roasted coffee beans	5
	Wines and grape juice	2
	Dried fruits for direct consumption	10
Fumonisin B1 and B2	Maize and maize-based food for direct human consumption	1000
	Corn-based snacks and breakfast cereals	800
	Processed maize-based foods for infants and young children	200
	Maize and maize products for animals	60

and animals (Thiel *et al*., 1992; Chu and Li, 1994). Devegowda *et al.* (1998) reported that about 25% of cereals consumed worldwide are contaminated with mycotoxins. The European Commission has set maximum permitted levels in processed cereal products for direct human consumption: 2 ng/g for AFB1 and 4 ng/g for the sum of AFB1, AFB2, AFG1 and AFG2; 3 ng/g for OTA and 75 ng/g for ZEA (table 1) (European Commission, 2006a, b; 2010).

North African and Tunisian populations consume cereals such as wheat, barley, corn and sorghum in form of couscous, pasta, bread, cookies, cakes and malted beverages. Moreover, cereals contribute to approximately 12% output and Tunisian households spend around 25% of their food expenditures on cereals. Tunisia and other North African countries, sourrounded by the Mediterranean Sea, are characterized by a hot and humid climate, which probably favors growth of molds.

Wheat is a primary foodstuff in North African countries. It is commonly consumed in form of bread, pasta, couscous and other processed products. Durum wheat is the most widely grown cereal in Tunisia covering about 700 000 ha each year, mainly located in the north of the country (Bensassi *et al*., 2010). Generally, wheat production systems are vulnerable to degradation by toxigenic fungal species. In 2004, Fusarium Head Blight (FHB) was observed on durum wheat in sub-humid and higher semi-arid region of Northern Tunisia. This disease is caused by the development of a complex of two genera of pathogenic fungi under warm and humid conditions: *Fusarium* and *Microdochium* (Simpson *et al.*, 2001). The most common *Fusarium* species associated with the disease are *Fusarium graminearium, Fusarium culmorum, Fusarium avenaceum* and *Fusarium poae* (Edwards *et al*., 2001). Gargouri Kammoun *et al*. (2009) showed that the most common species isolated from infested wheat spikes from the Northern area of Tunisia was *Microdochium nivale* var *nivale* (63.5%), followed by *Fusarium culmorum* (26%), *Fusarium pseudograminearum* (9%) and *Fusarium avenaceum* (1.5%). In another investigation, *Fusarium culmorum,* considered highly pathogenic, was the most abundant representing 36.6% of all single spore culture samples isolated from durum wheat samples collected from Northern Tunisia area during 2004 and 2007 (Fakhfakh *et al*., 2011).

The disease has become a serious problem causing significant reduction of grain yield and quality in most of durum wheat production areas (Olivier *et al.*, 2008). The most serious effect of FHB is the grain contamination with mycotoxins produced by *Fusarium* species, especially DON, and the potential health hazard for humans and animals (Placinta *et al*., 1999). Bensassi *et al.* (2010) showed that 83% of durum wheat samples cultured in Tunisia were contaminated with DON with averages ranging from 12.8 ± 5% to 30.5 ± 13.3% µg/g exceeding the maximum permitted limit of 1.75 µg/g set by the European Commission in wheat. In Morocco, 41.17% of wheat samples were contaminated by DON at levels below the limit proposed by EU legislation Hajjaji *et al*. (2006). Recently, Ennouari *et al.* (2013) showed that Moroccan wheat contained DON with an incidence of 11.1%. Other *Fusarium* toxins such as ZEA, T-2 and fusarin C were detected in Mediterranean and North African food due to the contamination of samples by *Fusarium moniliforme* and *Fusarium oxysporum* (El-Maghraby *et al.,* 1995; Aziz *et al*., 1997). Several studies showed that ZEA was detected in wheat from Egypt (Abd Alla, 1997; Aziz *et al*., 1997) and Tunisia (Zaied *et al.*, 2012b). Ochratoxin A was also detected in wheat samples from Algeria, Tunisia, Morocco (Hajjaji *et al.*, 2006; Zinedine *et al.,* 2006; Riba *et al*., 2008; Ghali *et al.,* 2009; Zaied *et al.*, 2009). Studies on the mycobiota of wheat grains originated from North African countries revealed that *Aspergillus, Penicillium, Alternaria, Rhizopus* and *Fusarium* were predominant (Hajjaji *et al*., 2006; Riba *et al.*, 2008; Riba *et al*., 2010; Embaby *et al.,* 2012). According to Ghali et al. (2010), AFs were detected in 28.6% of cereal samples such as wheat. In Algeria, the frequency of AFB1 contamination in pre-harvest and stored wheat was 56.6% and the highest level of AFB1 was found in a wheat sample stored for 12 months (Riba *et al*., 2010). In one study, Tunisian wheat was surveyed for the presence of CIT. Analyzed samples were contaminated with an incidence of 50% (Zaied *et al*., 2012a).

In Egypt, corn is an important product for human and animal consumption and for the industrial processing for starch, glucose, and syrup obtention. Corn flour is also used for stable bread (balady). In order to lower the price, corn and corn flour was detected as partial substitute for wheat flour in balady and tortilla production (Hussein *et al*., 2013). Corn was proved to be a good substrate for the growth of *Aspergillus, Penicillium* and *Fusarium*. Madbouly *et al*. (2012) reported that the mycobiota of maize samples was represented by *Aspergillus flavus* and *Aspergillus niger* with an incidence of 33% and 40%, respectively. According to Ghali *et al*. (2010), AFs were detected in 28.6% of cereal samples including maize and about 15.5% of cereal samples had AFB1 levels higher than the European maximum limit for AFB1 in cereals intended for human consumption (2 ng/g) while 9.4% of them exceeded the European maximum limit for AFs (4 ng/g). Total aflatoxins were detected in maize purchased from retail market in Cairo (Egypt) (Madbouly *et al*., 2012). Fadl Allah (1998) showed that the majority of *F. moniliforme* isolates from Egyptian corn produced FB1 and FB2. In Egypt, T-2 was detected in yellow corn samples and in white corn and popcorn samples (Abd Alla El-Sayed *et al.,* 2003). Several cereal samples were reported to contain ZEA in Egypt, especially wheat, corn and rice with levels up to 45 mg/kg (Abd Alla, 1997). The incidence of contamination of aflatoxins in corn flour commercialized in the retail markets of Rabat (Morocco) was 80% with a maximum value of 11.2µg/kg (Zinedine, Juan, Soriano *et al*., 2007).

Sorghum *(Sorghum bicolor)* is the fifth most important cereal crop in the world, after wheat, rice, maize and barley and the second most important crop (after maize) in sub-Saharan Africa (FAO, 1994). It constitutes the main grain food for over 750 million people who live in semi-arid tropics of Africa, Asia and Latin America (Codex Alimentarius Commission, 2012). It is mainly cultivated in semi-arid and subtropical regions because of its resistance to harsh weather conditions and its efficient use of water makes it the crop of choice to boost food security in drought stricken regions. Sorghum grains are used as feedstock for poultry, pigs and cattle feed, but also for human beings as staple foods in some African and Asian countries (Veiga, 1986). However, sorghum grains is susceptible to colonization by several toxigenic fungi during cultivation as well as after harvest (Waliyar *et al.*, 2007), which constitutes a major constraint to an increase in sorghum production worldwide. Several species of A*spergillus, Alternaria, Fusarium, Cladosporium, Curvularia* and *Penicillium* are among the prevalent grain mold pathogens in sorghum (Bandopadyay *et al*., 2000; Lahouar *et al.,* 2015). Toxigenic species of *Aspergillus flavus, Aspergillus niger* aggregates and *Fusarium incarnatum* has been associated with sorghum seeds in Tunisia (Lahouar *et al.*, 2015). Therefore, sorghum may contain zearalenone, fumonisins, aflatoxins and ochratoxin A. However, there is limited information about mycotoxins in sorghum. In Tunisia, preliminary surveys of mycotoxins showed relatively high levels of AFs contamination in sorghum (Boutrif *et al*., 1977a). Since 1977 several studies have confirmed

mycotoxin contamination in Tunisian sorghum (Ghali *et al*., 2008; Ghali *et al*., 2010; Serrano *et al*., 2012; Oueslati *et al.*, 2012; Oueslati *et al*., 2014).

Fusarium was the most dominant genus in Egyptian rice (El-Maghraby, 1996) of which *F. tricinctum* and *F. oxysporum* were proved to be producers of T-2 toxin and ZEA. Ghali *et al*. (2010) reported that no rice samples were contaminated with aflatoxins. However, Total aflatoxins were detected in rice purchased from retail market in Cairo (Egypt) (Madbouly *et al.*, 2012).

Milk

The occurrence of AFM1 in pasteurized milk samples was surveyed in Morocco. The incidence of AFM1 was very high (88.8%) and 7.4% of total samples exceeded the maximum level of 0.05 µg/kg set by both Moroccan and European regulations for AFM1 in liquid milk (Table 1 and 2) (Zinedine, Gonzales-Osnaya, Soriano *et al*., 2007). These results indicate that feed for cows in Morocco were contaminated with AFB1. The contamination of dairy cattle and cow's plasma with AFB1 and the contamination of raw milk by AFM1 have been studied in Tunisia (Abbes, Ben Salah-Abbes, Bouraoui *et al*., 2012). Results revealed the presence of AFB1 in 84.4% of the feed samples, and in 39.2% of the plasma-examined samples. AFM1 was detected in 60.7% of the cow raw milk samples examined.

Olives

Postharvest storage conditions could result in the production of olive oil with a high risk of contamination by mycotoxins (Tantaoui-Elaraki *et al*., 1983a). Several studies have reported that olives can be a substrate for mold growth. Strains of *Penicillium, Aspergillus, Alternaria, Rhizopus* and *Geotrichum* were detected in Morocan olives (Gourama and Bullerman, 1988; Roussos *et al.,* 2006). Some species, in particular, *Aspergillus flavus* and *Aspergillus ochraceus* were able to produce aflatoxin B1 and ochratoxin A, respectively, in olives. The development of fungi on olives is responsible for the reduction of nutritional quality of olive because they can disturb the synthesis of the fatty acids. The oil resulting from such olives contains small quantities of such mycotoxins (Tantaoui-Elaraki *et al*., 1983a). OTA was found in Moroccan olive oil (Tantaoui-Elaraki *et al*., 1983b; Belaiche, 2001). Moreover, the olive cake resulting from such olives could present a danger for animals because of the preferential concentration of mycotoxins in oil cakes (Tantaoui-Elaraki *et al.*, 1983a). Maaroufi *et al.* (1995) reported the contamination of one sample of black olives from Tunisia with a high level of OTA (46.83 µg/kg). A survey of the contamination of black olives commercialized in Morocco reported that OTA was detected in 36% of analyzed samples with concentrations ranging from 0.62 to 4.8 µg/kg (Zinedine *et al.,* 2004). El Adlouni *et al.* (2006) showed that there were more OTA contaminated samples from retailers than from supermarkets. This is probably due to the storage conditions, which may be relatively better in supermarkets. The same researchers showed that 80% of olive samples contained also CIT.

Spices

Spices are largely used in North African countries for flavoring foods. Few countries around the world have effectively established regulations for mycotoxins in spices. For instance, the maximum tolerable limit for AFs allowed in some spices such as chili, paprika, black and white pepper, ginger and curcuma, in EU member states have been set at 10µg/kg for total AFs and 5 µg/kg for AFB1 (table 1) (European Commission, 2002). El Mahgubi el al. (2013) observed a widespread contamination of paprika, cumin and pepper from Egypt by *Aspergilli* section *Flavi* with 57% of isolates able to produce AFB1, AFB2 and AFG1. In Tunisia, Ghali *et al.* (2010) reported that about 69.2% of spice samples contained aflatoxins with a high occurrence of AFB1. In Morocco, red paprika was highly contaminated with AFB1 but also cumin, ginger and black pepper contained AFB1 (Zinedine *et al*., 2006). El-Kady *et al.* (1995) reported that aflatoxins were detected in anise, black pepper, caraway, black cumin, fennel, peppermint, coriander and marjoram, and citrinin in black cumin from Egypt. OTA did occur also in spices. The contamination frequency of OTA in spices commercialized in Tunisia such as, red pepper, cumin and black pepper was 57.1% (Ghali *et al.*, 2008). More recently, OTA was found in 30% of total analyzed samples (Ghali *et al*., 2009). The contamination frequency of ZEA in red pepper, cumin and black pepper was 2.8% of samples from retail market in Tunisia (Ghali *et al.*, 2008).

Beverages

Many studies have shown that ochratoxin A is frequently present in wine and grape juice (Zimmerli and Dick, 1996). In fact, wine is the second source of OTA intake after cereals (Codex Alimentarius Commission, 1999). Furthermore, OTA is a restrictive factor for exporting viticultural products. Since January 2005 and according to the "Organisation Internationale de la Vigne et du Vin

(OIV)" proposal, the European Union authorities have set the acceptable limit for OTA in wine at 2 µg/l (table 1) (European Commission, 2006a). There is a great concern about OTA in the Mediterranean region because of the climatic conditions favorable for invasion of grapes by black *Aspergilli,* in particular *Aspergillus carbonarius* (Battilani *et al*., 2003; Bellí *et al.*, 2004; Bejaoui *et al.*, 2006). *Aspergillus* and *Penicillium* species are reported as the main producers of ochratoxin A on grape (Pitt, 1987; Zimmerli and Dick, 1996). In the Tunisian vineyard, the main disease observed on grapes so far is the grey rot caused by *Botrytis cinera* (Chebil *et al*., 2004). However, in the last four years, the presence of *Aspergillus* species is significantly increasing on both table and wine grapes, especially at the maturation stage. *Aspergillus* species belonging to the section Nigri can cause considerable damage on the yield and the quality of the harvest. Studies showed that Tunisian vineyards were contaminated essentially with *Aspergillus* spp., *Botrytis cinerea* and *Alternaria* spp. (Lasram *et al.*, 2007, Melki Ben fredj *et al.*, 2007). Among the potential OTA-producing fungi, only black *Aspergilli (Aspergillus* section *Nigri*) were the most abundant mycobiota isolated from Tunisian grapes. The number of *A. carbonarius* isolates increased from early veraison to the maturity. Of the *A. carbonarius* isolates, 94% produced OTA. However, only 3% *A. niger* aggregates isolates were ochratoxigenic (Lasram *et al*., 2007). Grapes and grape products are widely consumed in Tunisia as fresh fruit, raisins and wine, and 30% of the Tunisian grape products are exported. To study the occurrence of OTA in Tunisia, grapes purchased during the 2004 season from the northern area were analyzed, for the first time, for their OTA content. OTA was found in 37% of musts obtained from grape samples at levels varying between 0.59 and 2.57µg/L (Lasram *et al*., 2007). More recently, another survey involving four viticultural regions of Tunisia was performed. Results showed that 58% of grape samples contained detectable levels of OTA, between 0.05 and 5.85 µg/L. In another report, Melki Ben Fredj showed that the concentration of OTA in Tunisian grape samples was between 1.1 and 4.3 µg/L (Melki Ben Fredj *et al*., 2007). According to Lasram *et al.* (2013), OTA levels in Tunisian wines and beers were below the European regulatory limit and there were no toxicological risks for Tunisian consumers. Filali *et al.* (2001) showed that the red wines from Morocco were contaminated with OTA. In one study, Zaied *et al.* (2013) showed that apple based food such as apple and mixed juice marketed in Tunisia were contaminated with patulin and 18% of the total juice samples and 28% of the baby food samples exceeded the tolerable limit recommended by the European Commission, which are respectively 50 and 10 µg/l.

Dried fruits

North African population consumes huge amounts of dried fruits directly or as ingredients in special foods. Traditional techniques of transformation and conservation of dried fruits used in North African countries consist in direct exposition of fruit to a maximum sunning. During the process of fruits drying, the sugar is concentrated as the moisture content decreases resulting in an almost selective medium for xerotolerant molds such as *Aspergillus* section *Nigri* species. According to Pitt and Hocking (1997), *A. flavus* and *A. niger* were reported as being the most common species in dried figs which was explained by their high sugar content. Among black *Aspergilli, A. carbonarius* was the OTA producer species isolated more frequently. The mycobiota of dried fruits such as apricots, figs, raisins and plums from Egypt was composed of *Penicillium chrysogenum, Aspergillus niger, Cladosporium cladosporioides, Penicillium aurantiogriseum, Aspergillus fumigatus, Aspergillus flavus, Alternaria tenuissima* and *Pleospora herbarum* (Zohri and Abdel-Gawad,1993). AFB1 and AFG1 were detected in dried figs from Morocco (Juan *et al*., 2008). OTA was detected in dried figs, dried raisins, apricots and plum (Zohri and Abdel-Gawad, 1993; Zinedine, Soriano, Juan *et al*., 2007). The European Commission has set maximum limits for AFB1, AFs and OTA in dried fruits and nuts intended for direct human consumption (table 1) (European Commission, 2006a, b; 2010).

Nuts

Nuts are a good substrate for mold infection and production of mycotoxins. Preliminary reports have shown relatively high aflatoxins levels in Aleppo pine nuts from Tunisia (Boutrif *et al*., 1977a, b; Said *et al*., 1999). Fername *et al*. (2010) have studied the mycobiota of 31 pistachio samples collected from retail outlets from different regions of Algeria. The most frequently found fungi were *Penicillium* spp. (38%), *Aspergillus* section *Nigri* (30%) and *Aspergillus* section *Flavi* (22%). A total of 56.5% of *A. flavus* isolates were able to produce AFB1 and AFB2, whereas OTA production capacity was detected in 33.3% of the *A.* section *Nigri* biseriate. However, only two samples contained aflatoxins (0.4 and 0.7 µg/kg) and only one sample showed ochratoxin A contamination (170 µg/kg) (Fernane *et al.*, 2010). Juan *et al*. (2008) showed the presence of

aflatoxins in nuts commercialized in Rabat especially in walnuts and pistachios which were found contaminated with high levels of AFB1 ranging from 0.56 to 2500 µg/kg and from 0.04 to 1430 µg/kg, respectively. Zinedine, Soriano, Juan *et al*. (2007) found that the incidence of OTA in walnuts and peanuts commercialized in Morocco was 35% and 25% respectively, while pistachio samples were free of OTA. In Tunisia, Ghali *et al.* (2010) showed that aflatoxin levels in pistachios were around 4.9 ng/g (45.7% of samples were contaminated) and around 5.1ng/g in groundnuts (42.4% of samples were contaminated). Abdel-Hafez and Saber (1993) have studied fungal colonization of walnut and hazelnut seeds commercialized in Egypt. The mycobiota was composed by species from *Aspergillus (Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger), Penicillium (Penicillium citrinum), Eurotium, Fusarium (Fusarium equiseti, Fusarium moniliforme), Cladosporium* genera but only AFs and ZEA were detected in all samples. The major mycotoxins found in peanuts commercialized in Egypt were aflatoxins, OTA, DON and ZEA. Samples are predominantly contaminated with *Aspergillus niger, Aspergillus flavus, Aspergillus ficuum, Penicillium citrinum* and *Fusarium oxysporum* (Youssef *et al.*, 2008; Sultan and Magan, 2010).

Environmental conditions modulating mycotoxin accumulation

Over the past decades, the world has experienced a remarkable climate change characterized by a trend of warming. Scientists have described how plausible changes in temperature, precipitation, drought and CO_2 increase pose a significant risk to the food availability and quality (Miraglia *et al.*, 2009). Longer and more severe droughts periods are projected for West Africa and Southern Europe, while periods of drought have been shorter in Central Europe and America (IPCC, 2012). Drought is a major stressor for plants. It affects their natural immunity against pathogens including mycotoxigenic fungi. Precipitation is also a key environmental factor in the development of mycotoxins. Heavy rains during anthesis (flowering) of the plants are associated with the dispersion of Fusarium in corn ears leading to a higher production of mycotoxins (Parry *et al.*, 1995). Finally, unseasonable rains at the time of harvest causes the invasion of dry crops by mold. Therefore, mycobiota (fungal flora) and the nature of mycotoxins contaminating any commodity vary from year to year depending on climatic conditions. Thus, new strategies recently developed to monitor and predict mycotoxin contamination either in specific foods or in geographic areas can be very useful in the future. The modeling of fungal growth and the production of mycotoxins under the influence of ecological factors is an essential step in understanding the physiology of these microorganisms, predicting final levels of contamination by fungi or mycotoxins and determining storage conditions. Predictive mycology is a very useful tool for decision-making and the implementation of relevant solutions to prevent risks to human and animal health. In this regard, many kinetic models have been developed and used to model the growth of toxigenic molds in various food substrates. The Baranyi model was applied to identify the growth rate of many *Aspergillus* and *Penicillium* species, while the linear model was used to predict Fusarium species growth. In North African countries, mathematical modeling studies of the influence of ecological factors on fungal growth and mycotoxin accumulation are rare. The growth of molds and the accumulation of mycotoxins in food and feedstuff are influenced by multiple variables, such as water activity (a_w), temperature, pH, atmosphere composition, substrate, interaction among species, and time (Samson *et al*., 2000; Astoreca *et al.*, 2014). Temperature and water activity (a_w) are primary determining factors that modulate mycilial growth and mycotoxin production and were the most studied ecological factors in worldwide. In general, *Fusarium* growth is more common in temperate weathers at temperatures ranging from 26 to 28°C and water activity >0.88, while *Aspergillus (A. flavus)* grows under warm temperatures. Thus, optimal temperature for aflatoxin production vary from 24 to 30°C depending to the strain and the substrate composition (Klich, 2007). Recent studies evaluating the effect of temperature and aw on AFs production by *A. flavus* in rice showed that the highest AF concentrations were observed under aw ranges of 0.9- 0.92 a_w (Mousa *et al.,* 2013). Lahouar *et al*. (2016) showed that fungal growth and aflatoxin production were optimal at 0.99 aw and 37°C for *Aspergillus flavus* strains from Tunisia which are cultivated in sorghum seeds. In another study, Lahouar *et al.* (2017) reported that the growth rate of the Tunisian *Aspergillus tubingensis* strains was optimal at 37°C and 0.99 aw but OTA production was optimal at 0.97 aw and 37°C. It seems that the Tunisian strains are adapted to the hot and humid climate of the country. In another study, Lasram *et al.* (2016) showed that optimal conditions for OTA and AFB1 production were 0.98 aw and 20°C and 0.95 - 0.98 aw and 28°C by *A. niger* and *A. flavus,* respectively when cultivated in barley meal extract agar. However, in this study, temperatures over 30°C haven't been investigated. Kinetic models were also

used to evaluate the influence of aw and temperature on the OTA production by Tunisian *A. carbonarius* cultivated in synthethic grape medium. Thus, Marin *et al*. (2006) showed that the OTA production was higher at 20°C. In another study, Lasram *et al.* (2010) showed that optimal aw level was 0.99 for both growth and OTA production by ochratoxigenic *A. carbonarius* isolated from Tunisian grapes. About *Fusarium* species, we know only one study carried out with toxigenic *F. incarnatum* strains isolated from Tunisian sorghum where the researchers showed that growth was optimal at 25°C and 0.99 aw but ZEA accumulation varied from one isolate to another and it seems to be stimulated by stress temperature (15°C) (Lahouar *et al*., 2017).

Legislations and mycotoxin regulations in worldwide and North African countries

As mycotoxins can never completely removed from the food supply, many countries have defined maximum levels in foods that are unlikely to be of health concern and are reasonable to achieve by following good practices of agriculture, manufacturing and storage. Various factors may influence the establishment of mycotoxin limits and regulations including: availability of toxicological data, availability of data on the occurrence of mycotoxins in various commodities, legislation in other countries with which trade contacts exist and need for sufficient food supply (Van Egmond *et al.*, 2007). Regulations in individual countries usually depend on the ultimate use, with the strictest limits defined for human consumption, and export products and the lowest for individual uses. Indeed, safe limits of AFs for human consumption range 4-20 µg/kg. The EU has set the strictest standards, such that any products for direct human consumption can only be marketed with concentrations of AFB1 and total AFs not higher than 2 µg/kg and 4 µg/kg, respectively (European Commission, 2007; European Commission, 2010). The European Union's (EU) integrated strategy aims to ensure a high level of food safety, animal health and plant disease control in the European Union (EU) countries through measures coherent and adequate supervision, while maintaining high production and ensuring the functioning of the internal market. The European Food Safety Authority (EFSA) is the European Union body responsible for assessing the safety risks of food and feed. Risk assessment is done at two levels: European and International where the evaluation is carried out by JECFA (Joint Expert Commitee of Food and Additives), which also analyzes the toxicity of mycotoxins and develops recommendations at the Codex Alimentarius level (Van Egmond *et al.*, 2007). European legislation and Codex Alimentarus standards are not necessarily identical. In the case of mycotoxins, European legislation is often more severe than Codex standards. EU regulations and recommendations related to different foodstuffs are summarized in Table 1. Comparing the worldwide situation in 1995 and 2002, apparently in 2002 more countries were known to have regulations for more mycotoxins in more commodities and products. Table 2 shows the limits for mycotoxins in several foodstuffs and commodities in North African countries. In Africa, fifteen countries are known to have specific mycotoxin regulations. Most of the existing mycotoxins regulations in Africa concern the aflatoxins. Tunisia has established the maximum tolerable level of AFs in various foodstuffs at 2 ng/g (INORPI, 1983). In Egypt, the tolerable limit was set at 5 µg/kg in cereals, oil seeds and peanuts and at 10 µg/kg in maize for AFB1 and at 10 and 20 for AFs respectively (Mazumdar and Sasmal, 2001). The maximum level for AFB1 in Algeria is 10 µg/kg (FAO, 2004a). In Morocco, mycotoxins regulations were prepared by the interdepartmental committee for food control and the repression of frauds (CIPCARF). These regulations concern limits of AFB1, OTA and ZEA in cereals intended for human consumption, the limit of AFM1 in milk and dairy products for adults and children and the maximum limit of patulin in fruits and juices. Legal limits for AFB1 in animal feeds were also established. Morocco seemed to have the most detailed mycotoxin regulation (FAO, 2004a).

Stratigies to reduce mycotoxin contamination in food commoditties

Possible origins of fungal infection and mycotoxin contamination are multiple. Thus, strategies to prevent or minimize fungal contamination should be applied throughout the food chain. Three intervention steps were identified. The first is to prevent fungus infestation. The second step is during the invasion of plants by fungi and the production of mycotoxins. The third is initiated when agricultural products have been identified as contaminated by fungi and their mycotoxins. The most effective prevention steps are those carried out before the fungal infestation and before mycotoxin production occur on plant. Several agricultural practices can minimize the contamination of crops by fungi without completely eradicating them, including: crop rotation, tillage, planting date, chemical and biological control of toxigenic fungi especially Fusarium, insect and weed control (Jouany, 2007). The control of mycotoxin contamination can

Table 2. Maximum levels of mycotoxins (µg/kg) in various foods destined for humans in North Africa countries

Mycotoxin	Food commodity	Morocco	Tunisia	Algeria	Egypt
Aflatoxin B1	Wheat flour	3			
	Cereals	10	2	10	5
	Corn				10
	Peanuts, pistachios, almonds and nuts	1			
	Peanuts and oilseeds				5
Aflatoxin B1, B2, G1 and G2	Cereals other than maize				10
	Maize				20
	Peanuts and oilseeds				10
Aflatoxin M1	Milk intended for adults	0.05			0.5
	Milk intended for children	0.03			
Ochratoxin A	Cereals	30			
	Coffee				5
Zearalenone	Cereals	200			
Deoxynivalenol	Wheat and wheat flour				700
	Barley and barley flour				1000

also occur during and after harvest. These practices include the elimination of infested crops and grains, the control of temperature and humidity level after harvest and during storage, thermal treatment, Gamma irradiation, chemical treatment of infested grains, biological decontamination of mycotoxins using bacteria, yeasts or fungi and the use of adsorbents (Jouany, 2007).

In North African countries, researchers tried to find solutions and to develop strategies to prevent mycotoxin contamination. In one study, Abbès *et al.* (2008) demonstrated that the Tunisian montmorillonite, a clay mineral, was safe and successful in the prevention of aflatoxin toxicity and cytotoxicity. Recently, the Tunisian montmorillonite clay, the living *Lacotobacillus plantarum* MON03 cells and their composite were tested for the ability to accumulate zearalenone (ZEA) from liquid medium (Abbes, Ben Salah-Abbes, Sharafi *et al.,* 2012). Results indicated a high capacity of absorbing ZEA by both montmorillonite (87.2%) and *L. plantarum* (78%), however, the combination between the montmorillonite clay and the lactic bacteria showed the higher ability to remove ZEA (94.2%). *In vivo*, both montmorillonite clay, *L. plantarum* and their composite showed a high capacity to counteracting ZEA-immunotoxicity in Balb/c mice (Abbes, Ben Salah-Abbes, Sharafi *et al.*, 2012). *Lactobacillus paracasei* BEJ01 (LP) isolated from Tunisian artisanal butter was found to display significant binding ability to ZEA in phosphate-buffered saline (96.6%) within 24hr of incubation. *In vivo*, mice receiving ZEA- *L. paracasei* co-treatment haven't displayed adverse immunotoxic effects as compared to Balb/c mice exposed to ZEA only (Abbes *et al*., 2013). Zinedine *et al.* (2005) showed that *Lactobacillus* strains are able to remove aflatoxin B1 and suggest that lactic acid bacteria isolated from Moroccan traditional sourdough ferments can be exploited as an approach of detoxification of aflatoxins from foods. Soil microorganisms can also be used to reduce the level of contamination of mycotoxins. Thus, strains of mycelial actinobacteria isolated from the Saharan soils of Algeria were tested in vitro for the efficacy to reduce AFB1 content. Among the tested strains, two strains belonging to the genus Streptomyces and one to the genus Saccharothrix showed the highest ability to reduce the level of aflatoxin B1 (Lahoum *et al*., 2017). Therefore, limiting the toxicity of mycotoxins by using clays and bacteria to adsorb or degrade these toxins may represent an alternative strategy for decreasing food and feed contamination. These include adding clay or bacteria to feeding livestock to mitigate the adverse effects of mycotoxins on animals, reducing the level of contamination of food products of animal origin (milk, for example) by mycotoxins and subsequently reduce economic losses.

To ensure food safety in cereal products, the SMID (Société des Minoteries et des Industries Diverses), a wheat grinding company of the region of Sahel in Tunisia, has implemented during 2005 and 2006 the ISO 22000 system in order to monitor the chemical, physical and microbial hazards including fungi invasion and mycotoxin production (Gaaloul *et al.*, 2011). Finally, it can be concluded that all these studies are not sufficient to minimize the contamination of agricultural products by mycotoxins. It is very interesting to sensiblize farmers and to inform them about the importance of certain good agricultural practices such as crop rotation, deep tillage, avoiding irrigation during flowering and control moisture after harvest.

Conclusion

North African population is exposed to the risk of mycotoxins due to consumption of contaminated food. Toxigenic molds were frequently detected in several commodities known to be favorable substrates for mycotoxin production. The presence of

toxigenic fungi and their mycotoxins was explained by the Mediterranean climate characterized with high temperature and humidity. Reducing fungal growth is a primordial step to minimize contamination levels by establishing good agricultural practices, good manufacturing practices and the hazard analysis and critical control point system.

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