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Aflatoxin in Agricultural Commodities and Herbal Medicine

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1. Introduction

Aflatoxins are a group of mycotoxins produced by *Aspergillus* species, including *A. flavus*, *A. parasiticus*, and *A. nomius*. A quarter of the world's food crops are estimated to be affected by mycotoxins; creating a large economical loss in the developed and developing countries (Kumar, Basu, & Rajendran, 2008; Reddy, Reddy, Abbas, Abel, & Muralidharan, 2008; Wagacha & Muthomi, 2008; Xu, Han, Huang, Li, & Jiang, 2008). Other reports indicate even higher contamination rate of aflatoxin (Njobeh, et al., 2009) . Exposure to higher levels of aflatoxin contamination increases cancer incidence, including risk of hepato-cellular carcinoma especially in 6- to 9-year-old girls and neural tube defects (Peng & Chen, 2009; Sun, et al., 2011a; Umoh, et al., 2011; Woo, et al., 2011).

One of the reason which makes aflatoxins one of the most challenging mycotoxin is the fact that it could be produced by the responsible fungi not only at pre-harvest time but also at post harvest stages including storage. However, later on, lack of regulations or poor enforcement, which make the use of such contaminated commodities inevitable, could lead to severe human and animal diseases too. Aflatoxin B1, B2, G1 and G2 are the most important members of the aflatoxin group, which chemically are coumarin derivatives with a fused dihydrofurofuran moiety. Presence of aflatoxin B1, B2, G1 and G2 may naturally occur in different ratios depending on different matrices. However, it was concluded that when aflatoxins are limited only to AFB1 and AFB2, such ratio is 1.0 to 0.1, while when all four aflatoxins occur (AFB1, AFB2, AFG1 and AFG2), they may be found in a ratio of 1.0:0.1:0.3:0.03 (Abbas, et al., 2010; Kensler, Roebuck, Wogan, & Groopman, 2011). Cereals notably corn, nuts such as peanuts, pistachio and Brazil nuts, oil seeds such as cottonseed, as well as copra, the dried meat of coconut, are some of the commodities with greater risk of aflatoxin contamination (Cornea, Ciuca, Voaides, Gagiu, & Pop, 2011; Head, Swetman, & Nagler, 1999; Idris, Mariod, Elnour, & Mohamed, 2010; Jelinek, Pohland, & Wood, 1989; Liang, Wang, Zhang, Chen, & Li, 2010; Moghadam & Hokmabadi, 2010; Pacheco & Scussel, 2009; Sun, et al., 2011b; Yassin, El-Samawaty, Moslem, Bahkali, & Abd-Elsalam, 2011).

Because peanuts, cottonseed and copra constitute the most important source of edible oils, they are of particular interest (Idris, Mariod, Elnour, & Mohamed, 2010). Commodities which

are resistant or only moderately susceptible to aflatoxin contamination in the field include wheat, oats, millet, barley, rice, cassava, soybeans, beans, pulses and sorghum. However, when any of these commodities are stored under high moisture and temperature conditions, aflatoxin contamination may occur (Smith & Moss, 1985). Other commodities such as cocoa beans, linseeds, melon seeds and sunflower seeds have been infrequently contaminated with mycotoxins with lower importance rate compared to other commodities (Bankole, Adenusi, Lawal, & Adesanya, 2010; de Magalhaes, Sodre, Viscogliosi, & Grenier-Loustalot, 2011; Mngadi, Govinden, & Odhav, 2008; Pittet, 1998; Sanchez-Hervas, Gil, Bisbal, Ramon, & Martinez-Culebras, 2008). Aflatoxin is the single most important contaminant on The Rapid Alert System for Food and Feed (RASFF) of the European Union in a way that in 2008, aflatoxins alone were responsible for almost 30% of all the notifications to the RASFF system (902 notifications)(Energy., 2009). With increasing knowledge and awareness of aflatoxins as a potent source of health hazard to both human and animals, a great deal of effort has been made to completely eliminate the toxin or reduce its content in foods and feedstuffs to significantly lower levels. Although prevention is the most effective intervention, chemical, biological and physical methods have been investigated to inactivate aflatoxins or reduce their content in foodstuffs (Rustom, 1997). We will discuss the natural occurance and recent approaches on the fate and decontamination of aflatoxins in foods, herbs and feeds.

2. Natural occurrence of aflatoxin contamination in raw agricultural products

Natural occurrence of aflatoxins in raw agricultural products poses severe health and economic risks worldwide. The Food and Agriculture Organization (FAO**)** estimates that many basic foods could be contaminated with mycotoxin producing fungi, contributing to huge global losses of foodstuffs, about 1000 million metric tons each year (Bhat, Rai, & Karim, 2010). Contamination of feed materials with mycotoxins is an important issue for farmers due to both acute and chronic intoxication in animals. The economic impact of feed contamination with mycotoxins include productivity reduction and organ damage (Upadhaya, Park, & Ha, 2010). Aflatoxins, zearalenone, trichothecenes, fumonisins and ochratoxin A are the most frequently investigated toxins, although there are more than 300 recognized mycotoxins in animal feed (Griessler, Rodrigues, Handl, & Hofstetter, 2010; Rustemeyer, et al., 2010). Mycotoxin contamination reports in animal feed indicate a variety of contamination levels (de Oliveira, Sebastiao, Fagundes, Rosim, & Fernandes, 2010; Monbaliu, et al., 2010). Fungi which produce mycotoxin belong to *Aspergillus*, *Penicillium* and *Fusarium* species (Rustemeyer, et al., 2010). *Aspergillus* and *penicillium* constitute a major part of the fermented feed microbiota (Roige, et al., 2009). Intrinsic and extrinsic factors during storage and at field condition may interact with mycotoxin contamination (Griessler, Rodrigues, Handl, & Hofstetter, 2010). Animal feeds, such as hay and straw, might be contaminated during pre-harvest or drying stages (Bhat, Rai, & Karim, 2010). Mycotoxin contaminated animal feed causes serious effect on monogastric animals. However, the ruminants may be more resistant to mycotoxins due to biotransformation ability of the rumen microbiota. Other factors such as age, aflatoxin concentration and duration of exposure might also have some effect (Rustemeyer, et al., 2010; Upadhaya, Park, & Ha, 2010). The affected commodities by aflatoxins are corn, peanuts, cottonseed, millet, sorghum and other feed grains. In ruminants, a part of aflatoxin B_1 is degraded into aflatoxicol and the remaining is hydroxylated in the liver into aflatoxin M_1 (Upadhaya, Park, & Ha, 2010). Aflatoxin B_1 is considered as a group I carcinogen for humans by International Agency for

Research on Cancer (IARC) (Seo, Min, Kweon, Park, & Park, 2011). Aflatoxicosis may cause death in ruminants (Pierezan, et al., 2010). Despite extensive research done during the last few decades, which helped authorities around the world to establish control measures, still aflatoxin contamination in food and agricultural commodities remains as one of the most challenging and serious food safety problem.

Close study of the annual reports in the last decade (2003-2009) of the Rapid Alert System for Food and Feed (RASFF) showed four aforementioned groups contributed to the most aflatoxin contamination. Although, one should be careful in jumping to a bigger conclusion as these data also depends on the policy of EU countries, on products that go on a 100% check and those checked randomly. The detailed results are included in Table 1.

Literature review by Vinod Kumar, M.S. Basu, T.P. Rajendran (2008) on the incidence of mycotoxins in some commercially important agricultural commodities concluded that high-risk commodities for mycotoxin contamination were corn and groundnut (Kumar, Basu, & Rajendran, 2008).

Year	Total		nuts, nut products & seeds		fruit & vegetables		cereal products		herbs & spices		feed for food producing animals		pet food	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%
2003	763	95	695	91	33	4	6	1	5	1	-	NA	-	NA
2004	844	95	699	83	42	5	12	1	7	1	-	NA	-	NA
2005	943	95	827	88	81	9	9	1	57	6	2	0	-	NA
2006	800	91	684	86	69	9	5	1	37	5	4	1	-	NA
2007	705	93	568	81	70	10	21	3	35	5	6	1	4	1
2008	902	97	710	79	103	11	46	5	26	3	11	1	3	0
2009	638	95	517	81	64	10	13	2	23	4	9	1	11	2

Summarized by the author's from the RASFF published reports(RASFF, 2011).

Table 1. Comparison of number of aflatoxin allert notifications according to product category reports in the RASFF system in years 2003–2009.

2.1 Nuts, nut products and seeds

As it is clear from Table 1 based on RASFF reports; nuts, nut products & seeds were the most rejected lots, and thus the most contaminated products in general too. These serve as very good substrates due to their high fat content. Also, aflatoxin producing fungi can cause toxin production in all steps including pre-harvest, drying process as well as storage.

Environmental conditions such as prolonged drought stress, play a major role in increasing the risk of aflatoxin contamination (Kumar, Basu, & Rajendran, 2008). Similar conclusion was also drawn by Wagacha and Muthomi (2008) from the African perspective too, in which aflatoxins widely occured in groundnuts (Wagacha & Muthomi, 2008). A close study of all mycotoxins rejected lots (1000 reports of 5979 at the time) based on online available information of RASFF from 16/12/2009 till 02/05/2011 revealed that highest aflatoxin levels were found again in this group (Table 2).

A Korean survey of different nuts and their products marketed in South Korea showed that 9 out of 85 samples including peanuts, peanut butter, and pistachios were contaminated with aflatoxins (10.6% of incidence). The most contaminated nut was peanut (roasted) with values ranging from 2.00–28.24 μg/kg and a mean of 10.67 ± 12.30 μg/kg for total aflatoxins

[7.97 ± 7.75 µg/kg for aflatoxin B1]. Similar data at slightly lower levels was found in one assorted nuts and 2 peanut butter samples (Chun, Kim, Ok, Hwang, & Chung, 2007). A Turkish study conducted from September 2008 to February 2009, detected aflatoxin B1 contamination in almost 49.2% (59/120) of unpacked and packed pistachio nut samples at levels lower than action limits of 5 µg/kg (Set & Erkmen, 2010). A.H.W. Abdulkadar et al (2004) found aflatoxin B1 contamination in different nuts in the range of not detected (ND)–81.64 µg/kg (Abdulkadar, Al-Ali, Al-Kildi, & Al-Jedah, 2004). In a study by Ismail et al 2010, from about 196 nuts and their products in Malaysia, 16.3% of the products showed contamination between 17.2 to 350 µg/kg (Ismail, Leong, Latif, & Ahmad, 2010). Forty-eight samples out of 95 were contaminated within a range of 0.007 to 7.72 µg/kg in pistachio nuts (Set & Erkmen, 2010).

Raw	Origin	Commodity	Maximum Contamination Levels (µg/kg)		Date of case	References
			B1	Total		
1	United States	Almonds	43800*	47800*	13/04/2010	2010.ARG
2	Italy, with raw material from Afghanistan	Shelled roasted pistachios	973	------	22/07/2010	2010.0996
3	Georgia	Hazelnut kernels	638	713	24/03/2011	2011.0396
4	Ghana	Groundnut paste	622	810	25/10/2010	2010.BVI
5	Egypt	Groundnuts in shell	614.0	646.4	07/12/2010	2010.CES
6	Turkey	Pistachios in shell	594	665	25/11/2010	2010.CCV
7	Iran	Pistachios	562	597.7	30/04/2010	2010.ATY
8	Syria	Pistachio kernels	333	369	29/03/2011	2011.ASB
9	Algeria	Dried Apricot kernels	333	342.5	16/12/2009	2009.CDC
10	Iran	Pistachio nuts	210	230	21/03/2011	2011.APX
11	China	Peanuts in shell	192	214	24/03/2010	2010.AOA
12	Italy	Dried sweet chestnut flakes	184		26/11/2010	2010.1615
13	Nigeria	Ground melon seeds	136.3	154.1	03/02/2011	2011.AGG
14	United States	Raw pistachios	120	134	18/03/2010	2010.AMX
15	India	Groundnut kernels	118.0	281.0	15/04/2011	2011.AWB
16	United States	Salted almonds	95.1	127.3	04/02/2010	2010.0130
17	United States	Almonds	61.5	69.2	12/11/2010	2010.BZI
18	Ukraine	Hulled walnuts	38		08/02/2011	2011.AHH

Table 2. Some of the highest values of aflatoxin contamination in the rejected lots of Nuts, nut products & seeds, based on The Rapid Alert System for Food and Feed (RASFF) Database*

* Both are very high value but it was reported as B1 = 43.8; Tot. = 47.8 mg/kg – ppm, Only changes has been made was modification of units from mg/kg (ppm) to µg/kg (ppb) Retrieved by the author's from the RASFF online Data Base(RASFF, 2011).

2.2 Fruits and vegetables

Close study of all mycotoxin rejected lots (277 reports of 672 at the time) from 01/01/2008 till 19/04/2011, based on online information from RASFF, revealed that highest aflatoxin levels were found in dried figs from Turkey followed by dried figs from Greece (Table 3).
Natural occurrence of aflatoxin in fruits came to light more in the recent years.
Reports indicated that figs, dates and citrus fruits grown in susceptible regions (the high temperature conditions) could get contaminated with aflatoxins (Rivka Barkai-Golan, 2008), of which fig is most vulnerable to aflatoxin contamination. The reason for such high susceptibilities apart from their chemical properties is based on the fact that A. *Flavus* is able to enter and colonize in the internal cavity of the fruit (Doster, Michailides, & Morgan, 1996; Rivka Barkai-Golan, 2008). Although some surveys found only trace amount of aflatoxins in fig (Blesa, Soriano, Molto, & Manes, 2004), others found quite high levels and the contamination levels might go as high as 77,200 ng/g (Doster, Michailides, & Morgan, 1996). Aflatoxins were also reported, but in lesser extent, in other fruits such as dates, citrus fruits, raisins and olives (El Adlouni, Tozlovanu, Naman, Faid, & Pfohl-Leszkowicz, 2006; Ferracane, et al., 2007; Shenasi, Aidoo, & Candlish, 2002) . In case of citrus fruits, at least there is sound evidence of potential contamination risk (Bamba & Sumbali, 2005).

Raw	Origin	Commodity	Maximum Contamination Levels (μg/kg)		Date of case	References
1	Turkey	Dried figs	91.1	133.4	4/7/2008	2008.BAZ
2	Turkey	Dried figs	76	84	18/01/2008	2008.ADD
3	Greece	Dried figs	70.6	76.4	22/12/2010	2010.1742
4	Turkey	Dried figs	63.5	117.5	3/1/2008	2008.AAI
5	HUNGARY raw material from TURKEY	Dried figs	62.2	104.2	22/12/2008	2008.1672
6	Turkey	Dried figs	55	113	26/11/2010	2010.CDE
7	Turkey	Dried figs	54.2	58.3	20/10/2010	2010.BUC
8	Greece	Sun dried figs	47.9	86.7	3/12/2009	2009.1674
9	Turkey	Dried figs	41.80	51.23	19/11/2008	2008.BUT
10	Turkey	Dried figs	25.0	36.25	17/01/2008	2008.ACT

Table 3. Some of the highest values of aflatoxin contamination in the rejected lots of fruit & vegetables, based on The Rapid Alert System for Food and Feed (RASFF)*

2.3 Cereal products

Aflatoxin contamination of foodstuffs in Iran has been reviewed by Yazdanpanah (Yazdanpanah, 2006). Fifty-one maize samples, intended for animal feed and human

* Retrieved by the author's from the RASFF online Data Base(RASFF, 2011)

consumption, were collected from the four main maize production provinces in Iran and analyzed by high-performance liquid chromatography for contamination by four naturally occurring aflatoxin analogues (AFB1, AFB2, AFG1, and AFG2). AFB1 was detected in 58.3%, and 80% of the maize samples obtained from Kermanshah and Mazandaran provinces, respectively(Ghiasian, Shephard, & Yazdanpanah, 2011).

High levels of aflatoxin B1 contamination in rain-affected maize and rice at a level of 15600 and 1130 μg/kg respectively, was reported. Also, high levels of aflatoxin was found in parboiled rice (max 130 μg/kg). However, relatively lower values were reported in normal crops (Vasanthi S, 1998).

The crops with higher risk of aflatoxin contamination were groundnuts, maize and chilies. In one study, 21% and 26% of groundnuts and maize samples respectively, exceeded their national maximum limit of 30 μg/kg of aflatoxin contamination (Vasanthi S, 1998).

Vargas (2001) reported that 38.3% of maize samples were contaminated with aflatoxin B1 with a mean of 9.4 μg/kg and a maximum of 129 μg/kg. The investigators have reported that only 3.7% showed levels above 20 μg/kg. They found the co-occurrence of aflatoxin B1 and fumonisin B1 in all of the 82 aflatoxin-contaminated samples. Co-occurrence of these 2 mycotoxins with zearalenone was observed only in 18 samples (Vargas, Preis, Castro, & Silva, 2001).

Maize and groundnuts were reported to be a major source of aflatoxin contamination around the globe particularly in India, South America and the Far East in the late 90's. Other commodities which raised concerns with regard to high susceptibility to aflatoxin contamination were tropical and subtropical cereals, oilseeds, and tree nuts as well as cotton-seed meal.

The largest and the most severe documented aflatoxin poisoning has been reported at a level as high as 8,000 μg/kg in Kenya in 2004, causing 125 deaths out of 317 case-patients (Wagacha & Muthomi, 2008).

According to a study conducted by Sugita-Konishi et al (2006) about the contamination in various Japanese retail foods with aflatoxin B1, B2, G1, and G2, and other mycotoxins, between 2004 and 2005, aflatoxins were detected only in almost half of the peanut butter samples with the highest concentration of aflatoxin B1 at about 2.59 μg/kg. While in other products such as corn products, corn, peanuts, buckwheat flour, dried buckwheat noodles, rice, or sesame oil, aflatoxin contamination was not detected (Sugita-Konishi, et al., 2006).

Aflatoxin was also detected in the majority of dried yam chips samples surveyed in Benin with levels as high as 220 μg/kg, although the average was much lower (14 μg/kg).

More than 54% of dried yam chips in Nigeria were found positive for aflatoxin contamination, while high levels of aflatoxins ranging from 10–120 μg/kg was detected in slightly more than one third of the tiger nut (Cyperus esculentus) samples in the same country (Bankole & Mabekoje, 2004).

High aflatoxin levels in maize, in some other African countries, notably Benin and Togo have been reported and one third of the household grain, contained aflatoxins in the range of five-fold the safe limit (Wagacha & Muthomi, 2008).

Maize (Zea mays L.) grain was shown to be a good substrate for mould infection including A. *flavus*, A. *parasiticus* and production of aflatoxins. Indian scientists have reported several cases of aflatoxin epidemic in humans over the last decade mainly due to

the consumption of heavily contaminated maize, that nominates maize as a high risk crop. Rice is another member of the cereal family which shows high level of aflatoxin contamination, as high as 2830 μg/kg, which according to some reports was even higher than levels compared to wheat and maize. Aflatoxin contamination in rice occurs in the preharvest stage. Delayed drying as well as high moisture content and crop storage can cause postharvest contamination. Although both white rice and parboiled rice could be contaminated with aflatoxin, parboiled rice (boiled rice in the husk), despite improvement in its nutritional profile especially its vitamin-B content (Beri-beri disease is common among the white rice-eating people), is more suitable for the storage fungi to enter if later drying is not adequate (Kumar, Basu, & Rajendran, 2008). Minh Tri Nguyen et al (2007) investigated the possible coexistence of aflatoxin B1, citrinin and ochratoxin in Vietnam. From 100 rice samples collected countrywide, 35 samples showed values higher than the limit of quantification (LOQ) of 0.22 μg/kg, with a mean of 3.31 μg/kg and a highest value of 29.8 μg/kg, for aflatoxin B1. The results also indicated a high percentage in co-occurrence of aflatoxin B1 and ochratoxin A in rice. Their findings showed significant effect of monsoons that increased the average of quantifiable samples of AFB1 and the ratio of detectable samples in rice, compared to those in the dry season. In some provinces, these were 5 times higher [mean of 10.08 μg/kg compared to 1.77 μg/kg] or even more [mean of 4.5 μg/kg compared to less than LOQ of 0.22 μg/kg]. Given the average daily intake of rice by aVietnamese adult to be 500 g, there is a cause for concern (Nguyen, Tozovanu, Tran, & Pfohl-Leszkowicz, 2007). Reports raised concern over the presence of citrinin in red yeast rice (Monascus fermented rice), a traditional natural food colorant in Asia, while no reports on aflatoxin was obtained (Lin, Wang, Lee, & Su, 2008). A study on Turkish wheat samples published in 2008 revealed 60% contamination level in a very low range indeed (maximum of 0.644 μg/kg)(Giray, Girgin, Engin, Aydin, & Sahin, 2007).

No aflatoxin was found in the 60 samples of corn meal and flour obtained from Sao Paulo Market in 2000 (Bittencourt, Oliveira, Dilkin, & Correa, 2005). A market research of various food products (cereal and cereal products, nuts and nut products, spices, dry fruits and beverages) in Qatar in 2002, revealed no detected levels of aflatoxin contamination in rice and wheat (Abdulkadar, Al-Ali, Al-Kildi, & Al-Jedah, 2004).

The highest aflatoxin levels were found in stone ground corn meal from India followed by mixed snacks from India, and rice from Thailand. Aflatoxin contamination in raw and processed food can be monitored using chromatography or antibody platforms (Seo, Min, Kweon, Park, & Park, 2011). Aflatoxin B1 was detected at the following levels in all samples of Nigerian grains : 17.01-20.53 μg/kg in wheat, 34.00-40.30 μg/kg in millet, 27.22-36.13 μg/kg in guinea corn, and 40.06-48.59 μg/kg in bread fruit (Odoemelam & Osu, 2009).

Close study of all mycotoxins rejected lots (249 reports of 249 at the time) from 14/02/2000 till 28/04/2011, based on online information available from RASFF, revealed that the third highest aflatoxin levels were found in this group (Table 4).

2.4 Herbs and spices

Medicinal plants are various plants with medicinal properties, which were the core of traditional therapy for the most of human history. Although the toxic effect of some were known for centuries, only in the recent modern time, the safety of these plants from the contamination point of view come to light.

Raw	Origin	Commodity	Maximum Contamination Levels (µg/kg)		Date of case	References
			B1	Total		
1	India	Stone ground corn meal	410	430	08/08/2008	2008.0970
2	Ghana	Dried roasted corn	336	383.6	15/10/2007	2007.CJI
3	India	Mixed snacks	184.07	188	12/12/2007	2007.CXJ
4	United Kingdom with raw material from Ghana	Kenkey (maize based product)	134	153	28/04/2011	2011.0553
5	Ghana	Fermented banku flour	57	127	03/09/2010	2010.BNA
6	Ghana	Maize flour	56	67	04/07/2008	2008.BAX
7	Thailand	Black rice	52.2	72.2	01/07/2004	2004.BMS
8	India	Corn meal in retail packs	47	51	6/02/2009	2009.AHE
9	India	Unpolished basmati rice	46.2	50.7	07/12/2007	2007.CVW
10	Hong Kong	Egg cake	45	54	01/12/2006	2006.CTX
11	----------	Rice - red	35,0	43,6	14/08/2001	2001.JB
12	Malaysia	Glutinous rice balls with peanut butter	35*		19/03/2008	2008.AMU
13	Canada	Roasted red rice flour	32	37	18/09/2009	2009.1229
14	Pakistan	Broken rice	28	32.3	15/05/2006	2006.0315
15	Pakistan	Brown basmati rice	27		01/03/2007	2007.ANN
16	Pakistan	Brown basmati rice	22.1	23.7	13/03/2008	2008.ALH
17	Pakistan	Long grain white rice	18.9	25.6	03/03/2008	2008.AJX
18	Poland	Long grain white rice	16.7	18.4	23/03/2007	2007.0227
19	Bangladesh	Rice flakes	12.7	16.8	23/12/2008	2008.CBG
20	Pakistan	Basmati rice	12	14	27/11/2009	2009.1650
21	Pakistan	Broken rice	11.5	13	25/02/2009	2009.AKY

Table 4. Some of the highest values of aflatoxin contamination in the rejected lots of cereals and cereals products, based on The Rapid Alert System for Food and Feed (RASFF)**

One of the safety concerns in herbal medicine now a days is the presence of mycotoxins, notably aflatoxins, as their use have been increasing in the recent years after a decline in their use for almost a century. It has been reported that spices and herbs that was used for the improvement of some forms of liver disorder might be contaminated with high concentrations of aflatoxins, with aflatoxin B1 at an alarming level of 2230 µg/kg (Moss, 1998). Abdulkadar et al (2004) found aflatoxin B1 contamination in mixed spices powder in the range of 0.16–5.12 µg/kg, while chilli powder showed a higher range of 5.60–69.28 µg/kg (Abdulkadar, Al-Ali, Al-Kildi, & Al-Jedah, 2004).

* It might be because of presence of peanut butter

** Retrieved by the author's from the RASFF online Data Base(RASFF, 2011)

A Turkish study conducted from September 2008 to February 2009, detected aflatoxin B_1 contamination in 80% (48/60) of unpacked and packed ground red pepper samples within the range of 5-55.9 µg/kg (Set & Erkmen, 2010). Zinedine et al (2006) reported relatively low contamination levels in spice samples including paprika; ginger, cumin, and pepper. The highest level of aflatoxin was found in red paprika (9.68 µg/kg)(Zinedine, et al., 2006). Close study of all mycotoxin rejected lots (211 reports of 432 at the time) from 06/12/2007 till 19/04/2011, based on online information available from RASFF, revealed that the highest aflatoxin levels were found in curry powder from Nigeria, whole nutmeg from Indonesia, dried paprika from Peru and suya pepper from Ghana, followed by paprika powder from UK (Table 5). Contrary to the long history and the wide use of herbal medicines, there are only a few publications in regard to their mycotoxin contamination compared to the large number of publications on the contamination of cereals and oil seeds (Trucksess & Scott, 2008). The European Pharmacopeia has set limits for aflatoxin B1 and total aflatoxins at 2 and 4 µg/kg respectively, for some medicinal herbs (Pharmacopeia, 2007). Although in one study in South Africa, no aflatoxin contamination was found in some medicinal plants (Sewram, Shephard, van der Merwe, & Jacobs, 2006), while others reported levels ranging from 2.90–32.18 µg/kg (Yang, Chen, & Zhang, 2005). Roy et al. (1988) reported both high incidence (>93%) and high levels ranging from 90–1200 µg/kg in some common drug plants. *Piper nigrum* with a concentration of 1200 µg/kg was the highest contamination level reported. The second highest reported value was in the seeds of *Mucuna prurita* at a level of 1160 µg/kg. The third highest value was 1130 µg/kg, which found in the roots of *Plumbago zeylanica* (Roy, Sinha, & Chourasia, 1988). Aflatoxins were only found in 1 out of 5 Aerra lanata medicinal plant samples from Sri Lanka at 500 µg/kg (Abeywickrama & Bean, 1991). In another survey in India, 60% samples of medicinal plant seeds were contaminated with AFB1, ranging from 20 to 1180 µg/kg (Trucksess & Scott, 2008). In Thailand, five out of 28 herbal medicinal products were found to be contaminated with aflatoxins at 1.7–14.3 µg/kg using an immunoaffinity column (IAC) and high performance liquid chromatography (HPLC) method (Tassaneeyakul et al. 2004). None of the samples contained aflatoxins at levels above 20 ng/g (Tassaneeyakul, Razzazi-Fazeli, Porasuphatana, & Bohm, 2004). In Malaysia and Indonesia, 16 of the 23 commercial traditional herbal medicines, jamu and makjun, analyzed using IAC/LC method contained a low level of total aflatoxins (0.36 µg/kg)(Ali, et al., 2005). Romagnoli et al (2007) analyzed aflatoxins in 27 aromatic herbs, 48 herbal infusions and medicinal plants using LC with post-column derivatization and fluorescence detection. They found no contamination with aflatoxins (Romagnoli, Menna, Gruppioni, & Bergamini, 2007). In a study by Hitokoto et al., aflatoxins were not detected in the 49 powdered herbal drugs (Hitokoto, Morozumi, Wauke, Sakai, & Kurata, 1978). Ten percent of the tablets of Cascara sagrada dried bark were contaminated with aflatoxins in Argentina (Trucksess & Scott, 2008).

In a study on garlic samples, no aflatoxins were found at levels >0.1 µg/kg. However, aflatoxin levels between 4.2-13.5 µg/kg were detected in ginger (Patel, Hazel, Winterton, & Mortby, 1996).

A detailed UK study of aflatoxin contamination in some herbs and spices including curry powder, pepper, cayenne pepper, chilli, paprika, ginger, cinnamon and coriander showed 95% contamination below 10 µg/kg of total aflatoxins, while only 9 out of the 157 retail samples had higher levels (Macdonald & Castle, 1996). Study of ginseng root samples, both simulated wild and cultivated ones by D'Ovidio et al. (2006), showed approximately 15 µg/kg of total aflatoxins in only 2 of the simulated wild roots while none of the cultivated roots were contaminated with aflatoxins. Similar results (16 µg/kg) were found in just one

mouldy ginseng root purchased from a grocery store (D'Ovidio, et al., 2006). Trucksess and Scott (2008) found that 30% of the ginseng products purchased in USA were contaminated with AFB1 at levels of about 0.1 μg/kg (Trucksess & Scott, 2008). In an aflatoxin survey done in Turkey, 17.1% and 23.1% of unpacked and packed ground red peppers respectively, were contaminated with total aflatoxins and aflatoxin B_1, with one out of the 82 samples over the legal limit (Set & Erkmen, 2010).

Raw	Origin	Commodity	Maximum Contamination Levels (μg/kg)		Date of case	References
1	India	Ground turmeric and whole nutmeg	700	1200	18/10/2010	2010.1405
2	Nigeria	Curry powder	570	1100	03/09/2008	2008.BJQ
3	Indonesia	Whole nutmeg	384.5	455.3	20/12/2007	2007.0950
4	India	Ground and broken nutmeg	230	249	03/09/2008	2008.BJM
5	Peru	Dried paprika	216	221	23/12/2009	2009.CER
6	Ghana	Suya pepper	169	215.9	04/01/2008	2008.AAZ
7	Spain	Paprika powder	145.3	160.8	10/08/2010	2010.1102
8	United Kingdom with raw material from Spain	Paprika powder	120.3	135.	11/2010	2010.1495
9	Indonesia	Nutmeg	120	140	03/12/2009	2009.CBP
10	Spain	Nutmeg	98	105	04/04/2011	2011.0444
11	India	Nutmeg powder	79+/-24	97+/-29	21/01/2010	2010.ACO
12	Indonesia	Nutmeg shrivels	57		26/10/2010	2010.BVK
13	Indonesia	Ground nutmeg	56	70.5	19/08/2010	2010.1143
14	India	Ground nutmeg	50	58.2	27/04/2010	2010.0515
15	India	Turmeric powder	48	53	24/12/2010	2010.CIJ
16	India	Turmeric powder	48	52	29/04/2009	2009.AWC
17	India	Chili powder	47.2	48.7	05/11/2010	2010.BXR
18	India	Organic ground nutmeg	41.1		28/05/2010	2010.0671
19	India	Crushed chillies	38	40	27/08/2010	2010.BMA
20	Pakistan	Chilli powder	30.3	32.1	16/08/2010	2010.BJO
21	India	Clove powder		29	17/02/2009	2009.AIU
22	India	Curry powder	26.4	27.4	14/07/2010	2010.BFZ
23	India	Chilli powder	24	25	31/08/2010	2010.BMK
24	India	Dried red chilli	23	25	17/12/2010	2010.CGS
25	China	Red pepper powder	22	26	09/07/2010	2010.0926
26	India	Dry whole chillies	20	21	24/11/2010	2010.CCP
27	India	Ginger	13.2	24	19/04/2011	2011.AXB

Table 5. Some of the highest values of aflatoxin contamination in the rejected lots of herbs & spices, based on The Rapid Alert System for Food and Feed (RASFF)*

* Retrieved by the author's from the RASFF online Data Base(RASFF, 2011)

2.5 Other foods

Tajkarimi et al. reported the contamination levels in milk within 0.057 µg/kg and between 0.041–0.065 µg/kg in another study in Iran (Tajkarimi, Aliabadi-Sh, et al., 2008; Tajkarimi, et al., 2007). Sixty two percent of the samples in North Western Iranian state were contaminated with values higher than 50 ng/l of aflatoxin M1 (Ghazani, 2009). Aflatoxin levels were 3.12- 3.65 fold more in whey, during an experimental Cheese production (Kamkar, Karim, Aliabadi, & Khaksar, 2008).

2.6 Feed

Aflatoxin contamination was detected in more than 60% of animal feed samples with an average concentration of 130.63 µg/kg. The most common contaminant was aflatoxin B_1 (Elzupir, Younis, Fadul, & Elhussein, 2009) , that was also similar with another study (Aksoy, Yavuz, Das, Guvenc, & Muglali, 2009). In a study conducted by Diaz et al., 2009, more than 50% of the feed samples were contaminated with *Aspergillus* spp. Maize (100%), cottonseed meal (80%), sorghum (60%) and wheat middlings (60%), showed the highest contamination level. Aflatoxin contamination range in this study was detected between 0.2 and 240.4 µg/g (Diaz, Lozano, & Acuna, 2009). Feed samples showed about 80% contamination in imported feed lots in Kuwait (Dashti, et al., 2009). In Lebanon, 4% of the commercial corn shipments were found to contain between 6 and 30 µg/kg of AFB_1 (Barbour, Farran, Usayran, & Daghir, 2008). Maize contamination in animal feed showed lower concentration compared to maize samples used for human consumption (Trung, et al., 2008). In Brazil, aflatoxin B_1 was found in 42% of the feed samples at levels of 1.0-26.4 µg/kg, with a mean of 7.1 +/- 7.2 µg/kg (Oliveira, Sebastiao, Fagundes, Rosim, & Fernandes, 2008). However, reported aflatoxin levels in South Africa was at a lower level of 0.8 +/- 0.2 µg/kg (Odhav, Mngadi, & Govinden, 2008). Goat feed and barely in Brazil were contaminated with aflatoxin B_1 at about 44% and 47% respectively, with a contamination range of 2.4 - 8.7 ng/g (Keller, et al., 2008). Aflatoxin B_1 contamination in maize in south Ethihopia was 22.72 µg/kg (Alemu, Birhanu, Azerefgne, & Skinnes, 2008). A study done on the composition and nutritional adequacy of six complete commercial feeds for pet rabbits, showed an aflatoxin B1 content of 11.36 ppb, which was slightly higher than the European recommended maximum amount of 10 µg/kg (Ricci, Sartori, Palagiano, & Zotte, 2010).

Seasonal variation in aflatoxin contamination may vary based on the feed type, processing and storage conditions. For example, Tajkarimi et al. (2008) demonstrated that the aflatoxin contamination was higher in winter (Tajkarimi, Aliabadi-Sh, et al., 2008; Tajkarimi, Faghih, et al., 2008). Higher rate for contamination during winter has also been indicated by Sugita-Konishi et al (2008), in corn samples (Sugita-Konishi, Sugiyama, & Hiraokai, 2008). However, in another study by Elzupir et al (2010), the level of aflatoxin contamination in summer was higher compared to winter (Elzupir & Elhussein, 2010). Early harvesting, proper drying, sanitation, proper storage and insect management are some other methods to control aflatoxin contamination (Wagacha & Muthomi, 2008).

3. Fate of aflatoxins during processing

Aflatoxins, like most of the mycotoxins, are stable compounds. Therefore, most of the processing steps during food production such as temperatures below 250 °C have little or no

effect on their content, which may lead to contaminated finished cereal based products. However, there are some other processing steps such as alkaline cooking, nixtamalization (tortilla process), extrusion, roasting, flaking and modified processing methods that may reduce the aflatoxin content, but cannot eliminate the aflatoxin completely(Arzandeh & Jinap, 2011; Bullerman & Bianchini, 2007; Park, 2002; Perez-Flores, Moreno-Martinez, & Mendez-Albores, 2011; Yazdanpanah, Mohammadi, Abouhossain, & Cheraghali, 2005). Physical sorting is also another effective measure in the reduction of aflatoxins, as high as 40–80%(Bullerman & Bianchini, 2007). Marginal losses are considerable only if they are beyond the uncertainty of measurements at the given concentration. Some reports indicated a total destruction, at 1600 µg/kg of aflatoxin, in yellow dent contaminated corn by frying process (Magan, 2004). Using aflatoxin degradation enzyme named myxobacteria aflatoxin degradation enzyme (MADE), obtained from the extracellular enzyme of *Myxococcus fulvus,* was proposed to be an effective decontamination material with wide temperature range, pH tolerance and reasonable cost (Ji, et al., 2011). Application of different microorganisms to degrade aflatoxin was started in 1960 with a positive demonstration of removing aflatoxin by *Flavobacterium aurantiacum* in milk, vegetable oil, corn, peanut, peanut butter and peanut milk. It has been shown that pH and temperature influenced the uptake of toxin by the cells. However, the bright orange pigmentation caused by *Flavobacterium aurantiacum* ,limits its application in food (Smiley & Draughon, 2000). Other microorganisms also have aflatoxin degradation such as *Rhodococci* spp., *Lactobacillus rhamnosus and Enterococcus faecium* (Markov, Frece, Cvek, Lovric, & Delas, 2010; Topcu, Bulat, Wishah, & Boyaci, 2010). *Myxococcus fulvus,* with high activity and wide temperature and pH range, showed successful degradation activity against different aflatoxins (Ji, et al., 2011). Genetically modified plants could have aflatoxin lowering potential and also other applications (Davison, 2010; Halasz, Lasztity, Abonyi, & Bata, 2009; Montes, Reyes, Montes, & Cantu, 2009). Aqueous and organic extracts of plant materials such as viz. *Tagetes minuta, Lippia javanica*, *Amaranthus spinosus* and *Vigna unguiculata* have been successfully used against *Aspergillus flavus* and *A. parasiticus* (Houssou, et al., 2009; Katerere, Thembo, Vismer, Nyazema, & Gelderblom, 2010).

3.1 Cereal grains

Fandohana et al. studied the fate of aflatoxins through the traditional processing of naturally contaminated maize-based foods in West Africa. Aflatoxin levels were reduced by 7%, 8% and 60% during the preparation of makume, akassa and owo, respectively. The unit operations that resulted in marked mycotoxin removal included sorting, winnowing, washing and crushing, combined with dehulling of maize grains (Fandohan, et al., 2005). Stability of aflatoxins was more affected under alkaline, which led to partial degradation in cereals under heat based process. Reports indicated that fermentation process could destroy almost half of the aflatoxin B1 and G1 in wheat dough. Most of the aflatoxins remain intact during the baking of bread from contaminated wheat or corn flour with nil to maximum a quarter loss (Cheng, et al., 2010; Gumus, Arici, Daglioglu, & Velioglu, 2009; Magan, 2004). Reduction of aflatoxin B1 content in wheat through various cooking treatments such as washing, heating and steaming have been investigated by Hwang et al. (2006). Although the aflatoxin reductions were increased by increasing washing time (Jalili, Jinap, & Son, 2011), the most effective element was the temperature, irrespective of the origin of the wheat (J. H. Hwang & K. G. Lee, 2006).

Heating aflatoxin-contaminated corn grains at 160–180 ºC, resulted in aflatoxin reduction from 383 to 60 µg/kg (Magan, 2004). The level of AFB1, during ordinary and pressure cooking of rice, reduced by 34% and 78–88%, respectively (Bullerman & Bianchini, 2007). The steam and aqueous treatment processes such as boiling may affect the aflatoxin content of the cereal matrix by degradation or extraction into the cooking liquid. In contrast, aflatoxins are relatively stable under dry conditions, which is affected at variable degrees in the presence of moisture. Reduction of aflatoxins in cooked rice was reported at variable ranges between 6–88%, depending on the ratio of water to rice used or the cooking condition. Similar range of aflatoxin reduction was reported for pasta, boiled buckwheat and for corn flour and corn grits with aflatoxin contamination. However, no substantial reduction in aflatoxin was reported in the preparation of 'Nshima' by boiling a thick paste. It might be because of the presence of other ingredients in cooking process (Magan, 2004). Dehulling and further pre-milling and soaking (eg. for 24 h) of corn kernels during corn flour processing at a village, reported by Njapau *et al.* (1998), resulted in 85–90% loss in their aflatoxin contents.

Different strategies have been applied for the elimination or inactivation of aflatoxins. However, problems still remain with the efficacy, safety and cost requirements for these methods (Ji, et al., 2011).Fermentation process is a very important step in reducing and controlling aflatoxins in storage and silage (Uegaki, Tsukiboshi, & Cai, 2010).

Tortillas production by alkaline cooking and steeping of the corn, also resulted in the reduction of aflatoxin content, which vary from almost 52% (tortillas) to 84% (tortilla chips) (Bullerman & Bianchini, 2007). Other tortilla production which involved the use of calcium hydroxide showed only a limited effect on Aflatoxin content (Magan, 2004). Generally, similar results were obtained by Elias-Orozco et al. (2002) while they used the extrusion process in the production of corn tortillas. They found that the use of 0.3% lime and 1.5% hydrogen peroxide was the most effective reducing process (Elias-Orozco, Castellanos-Nava, Gaytan-Martinez, Figueroa-Cardenas, & Loarca-Pina, 2002). Acidic conditions such as the use of 1N aqueous citric acid reported to inactivate aflatoxins *in-vitro* and in maize almost close to 100% (Mendez-Albores, Arambula-Villa, Loarca-Pina, Castano-Tostado, & Moreno-Martinez, 2005; Mendez-Albores, Del Rio-Garcia, & Moreno-Martinez, 2007).

3.2 Nuts

Effect of roasting on the aflatoxin content of pistachios have been recently investigated (Yazdanpanah, Mohammadi, Abouhossain, & Cheraghali, 2005). At 200 °C, most of the aflatoxins were destroyed (Jun-Ho Hwang & Kwang-Geun Lee, 2006). Microwave field (500 MHz–10 GHz) exposure could also result in aflatoxin destruction. Both microwave power and exposure time play a major role in the extent of such destruction. Reports indicated that only 16 min exposure of contaminated peanuts to a microwave power level of 1.6 kW resulted in a loss of almost 95% in its aflatoxin content. Similar results were obtained by higher power and lower exposure time (5 min treatment at a power level of 3.2 kW)(Magan, 2004). The presence of other substances, especially those alkaline in nature, also could considerably vary their destruction (Magan, 2004). Report by Hameed (1993) showed that addition of ammonia, either as hydroxide (0.7 and 1.0%) or as bicarbonate (0.4%) could increase the aflatoxin loss from 50–80% to 95%. Similar results were found through

extrusion cooking of peanut meal, from 23–66% to 87% reduction, in the presence of ammonium hydroxide (2–2.5%) (Bullerman & Bianchini, 2007).

Yazdanpanah et al. (2005) studied the effect of roasting on the reduction of AF content in pistachio nuts. Although all treatment protocols showed some degree of AF degradation (ranging from 17% to 63%), roasting spiked samples at 120 °C for 120 min and 150 °C for 30–120 min, caused substantial reduction of aflatoxin in samples. Treatment of naturally contaminated whole pistachio kernels at 150 °C for 30 min, significantly reduced the level of aflatoxin contamination in samples. Degradation of aflatoxin was both time and temperature dependent. Roasting at 150 °C and 120 min condition, degraded more than 95% of aflatoxin B1 in pistachio(Yazdanpanah, Mohammadi, Abouhossain, & Cheraghali, 2005).

The efficiency of ozone on the degradation of aflatoxins in pistachio kernels and ground pistachios was evaluated. The efficiency of ozone on aflatoxin degradation in pistachios increased with increasing exposure time and ozone concentration. When pistachio kernels were ozonated at 9.0 mgL−1 ozone concentration for 420 min, the level of AFB1 and total aflatoxins reduced by 23 and 24%, respectively. While for ground pistachio nuts, under the same conditions, only a 5% reduction in AFB1 and total aflatoxin levels were obtained (Akbas & Ozdemir, 2006). The effectiveness of ozonation and mild heat in the degradation of aflatoxins in peanut kernels and flour were assessed. Degradation of aflatoxins were evaluated in peanut samples subjected to gaseous ozonation under various temperatures (25, 50, 75 °C) and exposure times (5, 10, 15 min). Higher temperatures and longer treatment times showed synergic effect on ozonation aflatoxin reduction effect. Among all aflatoxins, AFB1 and AFG1 showed the highest degradation levels. Greater efficiency in aflatoxin destruction was achieved in peanut kernels compared to flour. It was concluded that ozonation at room temperature for 10-15 min could be both economical as well as effective (Proctor, Ahmedna, Kumar, & Goktepe, 2004).

3.3 Other foods

Extrusion cooking is a technique that cooks the food product by heating under high pressure, while passing through continuous processing machinery, considerably reducing the food moisture content. Low transient time within the extruder can lead to limited aflatoxin loss despite high temperature and pressure.

Zorlugenc et al (2008) evaluated the effectiveness of the use of ozone and ozonated water on aflatoxin B_1 content of dried figs. Treatment of spiked dried fig samples with aflatoxins showed higher degradation of AFB_1 as ozonation time was increased in favour of the gaseous ozone compared with ozonated water (Zorlugenc, Kiroglu Zorlugenc, Oztekin, & Evliya, 2008). High temperature roasting of green coffee beans at 200 °C for 12 min reported 79% aflatoxin loss, which increased to 94% as the exposure time increased to 15 minutes (Magan, 2004). The aflatoxin reduction in coffee bean during roasting was also found to be dependent on the type and temperature of roasting with moderate reductions of approximately 42 to 56%(Bullerman & Bianchini, 2007). Gamma irradiation was also reported to decrease the total aflatoxins and aflatoxin B_1 levels gradually, with increase in gamma irradiation dose from 0 to 10 kGy (Ghanem, Orfi, & Shamma, 2008; Gupta, Bajpai, Mishra, Saxena, & Singh, 2009; Kumari, et al., 2009). However, in another study a 24-43% reduction in aflatoxin contamination was observed with irradiation at 60 kGY (Jalili, Jinap, & Noranizan, 2010). Gaseos ozone was effectively used against aflatoxin B1 at 13.8 mg/L (Zorlugenc, Kiroglu Zorlugenc, Oztekin, & Evliya, 2008).

3.4 Animal feed

Contaminated feed poses health risk, causes outbreaks in animals and leads to significant economic losses (Griessler, Rodrigues, Handl, & Hofstetter, 2010; Pierezan, et al., 2010). To protect severe loss and control the contamination of aflatoxin, the levels in many countries for food and feed is 20 μg/kg or less (Dorner, 2008; van Egmond, Schothorst, & Jonker, 2007). Contaminated feed with mycotoxins pose a health risk to animals and indirectly affects humans as well.

Principally, there are three possibilities to avoid the harmful effect of contamination of food and feed caused by mycotoxins: (1) prevention of contamination, (2) decontamination of mycotoxin-containing food and feed, and (3) inhibition of mycotoxin absorption into the digestive tract (Halasz, Lasztity, Abonyi, & Bata, 2009).

Direct and indirect effect of ammonia in feed can reduce aflatoxin levels (Safamehr, 2008; Tajkarimi, Riemann, et al., 2008). It has been demonstrated that vitamins such as A and pro vitamins such as carotene, carotenoids, phenolic compounds, curcuminoids, and sulfur containing compounds such as glutathione and glucomannan are capable of delivering antioxidant activity against aflatoxin B_1 toxicosis as well as mycotoxicosis (Donmez & Keskin, 2008; Gowda & Ledoux, 2008)

Citric acid was successfully used to reduce the aflatoxin level in sorghum from 17-92% with acceptable product color, viscosity, functional and textural properties (Mendez-Albores, Veles-Medina, Urbina-Alvarez, Martinez-Bustos, & Moreno-Martinez, 2009). High-grade sodium bentonite (HGSB) in broilers and dairy feed demonstrated reduction in aflatoxin toxicity (Manafi, Umakantha, Swamy, & Mohan, 2009; Schatzmayr, Fruhauf, & Vekiru, 2007). However, in another study, clinoptilolite and bentonite showed lower absorption index compared to hectorite (Dakovic, et al., 2008). Sodium and calcium aluminum silicate on silver catfish (*Rhamdia quelen*) fingerlings did not effectively reduce the aflatoxin levels (Lopes, et al., 2009).

3.4.1 Chicken feed

Poultry are highly susceptible to aflatoxin contamination (Diaz, Calabrese, & Blain, 2008; Souza, Vilar, Stamford, Bastos, & Filho, 2008). Aflatoxins can have severe effect on body weight, poultry organism, particularly liver and kidney and renal malfunction of laying hens (Khan, et al., 2010; Khan, Khan, Khan, & Hussain, 2010; Valdivia, et al., 2010). Several methods have been applied for the control and reduction of aflatoxins in feed including the application of different supplemental diet , *Canarium schweinfurthii* Engl. seed or maize cob (Kana, Teguia, Mungfu, & Tchoumboue, 2011). Sodium bentonite (0.5%), yeast (Saccharomyces cervisiae) 0.20%, hydrated sodium calcium aluminosilicate (HSCAS) (0.5%), ammonia (0.5%), formycine (0.1%), and toxiban (0.1%) demonstrated effective activity against aflatoxin B_1 as feed additives (Abousadi, Rowghani, & Honarmand, 2007). 0.5% sodium bentonite in another study demonstrated better results than 1% concentration of the chemical (Pasha, Farooq, Khattak, Jabbar, & Khan, 2007). Application of hydrated sodium calcium aluminosilicates (HSCAS) showed promising anti-aflatoxin effects compared to a combination of clay and yeast cell wall in preventing aflatoxicosis in broilers (Li, Suo, & Su, 2010; Zhao, et al., 2010). However, non selective nature of some of the anti-aflatoxin food additives may cause some nutritional materials unavailable due to the binding interaction. Sodium bentonite has been used as an effective anti-aflatoxin at 55 ppm in diet

(Chiacchiera, Magnoli, Monge, et al., 2011; Chiacchiera, Magnoli, Texeira, et al., 2011). Application of a combination of sodium treatments in itself and with the addition of 0.5% or 1.0% acetic acid, positively affected broiler performance (Magnoli, et al., 2008; Pasha, Mahmood, Khattak, Jabbar, & Khan, 2008). Application of hydrated aluminosilicate positively influenced some physiological parameters in broiler chicken meat (Prvulovic, Kojic, Grubor-Lajsic, & Kosarcic, 2008; Sehu, et al., 2007). *Bacillus subtilis* and *Bacillus lichenformis* are two bacterial strains that showed successful detoxification rate against mycotoxins and could be applied for aflatoxin (Wei, et al., 2010). Hydrated sodium calcium aluminosilicates and turmeric *Curcuma longa* powder (TMP) was effective against aflatoxin B_1 on growth performance and improving liver damage (Gowda, Ledoux, Rottinghaus, Bermudez, & Chen, 2008; Zhao, et al., 2010). Application of diatomaceous earth as a type of tectosilicate at levels of 30 ppm was suggested as an alternative treatment to other mycotoxin binders (Modirsanei, et al., 2008). Ribeiro et al (2009), reported that gamma irradiation can eliminate all Aspergillus spp. and other fungi strains at 8 kGy (Ribeiro, Cavaglieri, Vital, Kruger, & Rosa, 2009). Reduction of aflatoxin by turmeric (Curcuma longa) powder (TMP) supplementation in diets has also been demonstrated (Yarru, et al., 2009). Chlorophylin showed to reduce and prevent aflatoxin contamination by scavenging the free radicals and restoring the antioxidant defense mechanism activity (Thakur, Kumar, Reddy, Reddy, & Reddy, 2008).

3.4.2 Other feed

Despite the fact that mycotoxin contamination could be reduced in rumen flora due to various biotransformations (Fink-Gremmels, 2008; Upadhaya, Park, & Ha, 2010; Zain, 2011), there is still a need to develop different methods to control and reduce contamination levels in ruminants because the rumen barrier malfunction may increase absorption rates (Fink-Gremmels, 2008). In a study, application of freeze dried citrus peel (FDCP) showed reduction on aflatoxin contamination level without disrupting rumen fermentation (Ahn, Nam, & Garnsworthy, 2009). However, *Nocardia corynebacteroides* was successfully used against chicken feed contaminated with aflatoxin (Tejada-Castaneda, et al., 2008).

4. Conclusion

Temperature, food substrate, strain of the mould and other environmental factors are some parameters that effect mycotoxin production. Preventing mycotoxin production at farm level is the best way to control mycotoxin contamination (Sengun, Yaman, & Gonul, 2008).

Advances in molecular techniques and other decontamination methods such as gamma-irradiation and microwave heating could help to deal with these issues (Herzallah, Alshawabkeh, & Al Fataftah, 2008). Mycotoxins could be used as an energy source for a group of aerobic microorganisms, which are suitable to mycotoxin biodegradation. Several protocols have been provided to biodegrade mycotoxins in food and feed using potential bacteria such as Lactobacillus and Bifidobacterium (Awad, Ghareeb, Bohm, & Zentek, 2010; Fuchs, et al., 2008; Halasz, Lasztity, Abonyi, & Bata, 2009; Kabak & Var, 2008; Wei, et al., 2010).

However, there are varieties of responses between different microorganisms against mycotoxins. For example, *Bacillus brevis* were not affected by high concentrations of trichothecene.

Application of microorganisms needs to be evaluated from a safety point of view. Application of microorganisms on mycotoxin degradation, food and feed materials also need to be investigated (Halasz, Lasztity, Abonyi, & Bata, 2009). Further studies need to be conducted to address the seasonal variation of aflatoxin contamination in food and feed. Understanding the seasonal variation could help demonstrate and develop more effective decontamination methods. For example, it is postulated that mycotoxin issues due to monsoons in Hungary could possibly be concluded to technical difficulties in pre- and post-harvest operations. Application of advanced methods such as DNA biosensors and infrared spectroscopy for rapid and accurate detection of mycotoxin and related fungi is increasing dramatically (Fernandez-Ibanez, Soldado, Martinez-Fernandez, & de la Roza-Delgado, 2009; Maragos, 2009; Mascini, Tombelli, Scherm, Battacone, & Migheli, 2009; Tombelli, Mascini, Scherm, Battacone, & Migheli, 2009). Application of new and advanced detection techniques could enable the agricultural industry to deal more effectively with the occurrence of aflatoxin contamination.

5. Acknowledgement

Sangeetha Viswanathan is appreciated for her excellent editing in this chapter.
Professor Dean O. Cliver, recently deceased scholar is also gratefully acknowledged.

6. References

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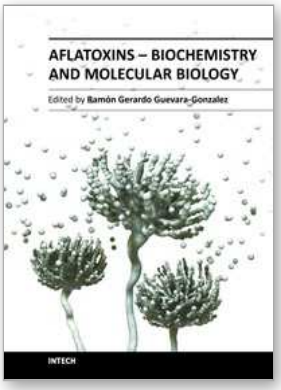

Aflatoxins - Biochemistry and Molecular Biology

Edited by Dr. Ramon G. Guevara-Gonzalez

ISBN 978-953-307-395-8
Hard cover, 468 pages
Publisher InTech
Published online 03, October, 2011
Published in print edition October, 2011

Aflatoxins â€“ Biochemistry and Molecular Biology is a book that has been thought to present the most significant advances in these disciplines focused on the knowledge of such toxins. All authors, who supported the excellent work showed in every chapter of this book, are placed at the frontier of knowledge on this subject, thus, this book will be obligated reference to issue upon its publication. Finally, this book has been published in an attempt to present a written forum for researchers and teachers interested in the subject, having a current picture in this field of research about these interesting and intriguing toxins.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Mehrdad Tajkarimi, Mohammad Hossein Shojaee, Hassan Yazdanpanah and Salam A. Ibrahim (2011). Aflatoxin in Agricultural Commodities and Herbal Medicine, Aflatoxins - Biochemistry and Molecular Biology, Dr. Ramon G. Guevara-Gonzalez (Ed.), ISBN: 978-953-307-395-8, InTech, Available from: http://www.intechopen.com/books/aflatoxins-biochemistry-and-molecular-biology/aflatoxin-in-agricultural-commodities-and-herbal-medicine

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