Japanese Journal of Veterinary Research 65(3): 173–183, 2017

JJVR

REVIEW ARTICLE

Mycotoxin contamination in foodstuffs and feeds-health concerns in Thailand

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Received for publication, October 30, 2015; accepted, May 10, 2017

Abstract

Many studies on mycotoxins have been carried out in various parts of the world. Thailand is one of many tropical countries to continuously encounter problems associated with mycotoxin contamination in foodstuffs and animal feed, and faces health concerns associated with humans and animals. This review has gathered background information from mycotoxin studies in Thailand in order to update the information on mycotoxin issues from 1967 until the present. The first report of mycotoxin contamination in animal feed was published in 1983. Among the various known mycotoxins, aflatoxins (AF) have been the main concern in human foodstuffs and animal feed, followed by deoxynivalenol (DON), fumonisin (FUM) and trichothecene (T) toxins respectively, while zearalenone (ZEA) has primarily been a concern regarding animal feed in Thailand. Hepatocellular carcinoma has been reported in association with patients consuming foods contaminated with AF. In addition, the standard limit of total aflatoxin (TAF) for foodstuffs has been set at 20 µg/kg in Thailand. It is therefore necessary to improve the control strategies and regulations for all mycotoxins in human foodstuffs and animal feed in Thailand.

Key Words: food, feed, health, mycotoxins, safety

Introduction

Mycotoxins are secondary metabolite toxins produced by fungi primarily belonging to the *Aspergillus*, *Penicillium* and *Fusarium* genera. These naturally occurring chemical compounds are to be found in a wide range of agricultural commodities in various regions of the world[1,2]. The most prevalent mycotoxins are aflatoxin (AF), ochratoxin (OT), deoxynivalenol (DON), zearalenone (ZEA), fumonisin (FUM), trichothecenes (T), of which the latter four toxins are all produced by the *Fusarium* species[3]. The contamination of human foodstuffs and animal feed by mycotoxins represents a major threat to the health of both humans and animals, as it can induce cancer, mutagenicity and estrogenic gastrointestinal, urogenital, vascular, kidney and nervous disorders, in addition to immune-toxicity[1]. AF are the most well-studied mycotoxins due to their established

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doi: 10.14943/jjvr.65.3.173

association with carcinogenesis[2,4]. *Aspergillus flavus* is known to produce aflatoxin B1 and B2[5] and *A. parasiticus* and *A. nomius* are known to produce Aflatoxin B1, B2, G1 andG2, which are classified as total AF. These *Aspergillus* species have been isolated from various types of soil in Thailand and endemic aflatoxin has been reported for maize and ground nuts[6,7].

Research on mycotoxins and contamination in Thailand

The first research on mycotoxins in Thailand

We herein summarise the data gathered thus far on the contamination of food products by mycotoxins in Thailand, from the first report published in 1967 through to the present day. The information focuses mainly on AF contamination in rice, peanuts, corn and various spices. There have been numerous studies on mycotoxin contamination to date, as shown in Table 1.

According to the data gathered here, the main focus of mycotoxin studies in human foodstuffs appears to be that of total aflatoxin (TAF), FUM and DON, in decreasing order of importance as shown in Fig. 1a. On the other hand, for animal feed, the study of mycotoxin contamination since 1983 appeared to have concentrated mainly on AF, followed by DON and ZEA as shown in Fig. 1b.

Thailand is located in a tropical zone with a hot and highly humid climate throughout the year. Thailand exports large quantities of agricultural products to many different countries. It has accordingly established an action plan to mitigate food safety issues under the supervision of the Department of Agriculture and the National Plant Protection Organisation, and the guidance of the Ministry of Agriculture and Cooperatives. The latter is in charge of food safety control for both local consumption and export. Since 1985, collaborative research on TAF in Thailand has been ongoing with support from several other countries and organisations, such as the United Kingdom, the United States Agency for International Development, and The United Nations Development Program (UNDP). In addition, the Tropical Agricultural Research Center (Japan) has approved the performance of a cooperative project on quality and preservation of maize from AF contamination. From 1986 to 1991, the Japanese International Cooperative Agency (JICA) provided financial support for the activities of the Maize Quality Improvement Center, within the Department of Agriculture in Thailand with a budget which financed advancedequipment[8]. Nevertheless, many reports have demonstrated evidence of food contamination, such as the case with coconut cream flavoured peanuts exported to the Netherlands in 2004 and to the United Kingdom in 2006. These were found to be contaminated with a concentration of AF that exceeded the legal limits established by the Rapid Alert System for Food and Feed (RASFF), managed by the European commission[9]. During the period from 2004–2006, basil seed (*Ocimum basilicum*) and Job's tear (*Coixlacryma L.*) exported to Japan were rejected by the Ministry of Public Health, Labour and Welfare, via the Office of Agricultural Affair s because the cargo was found to be over the legal contamination limit for AF (10 μg/kg AFB1) [9].

Mycotoxin contamination in foodstuffs in Thailand

An overview study of AF contamination in various foods and products was first reviewed and carried out in Thailand between 1967–2001. The contamination data, obtained using thin layer chromatography (TLC)[10], showed that 38.9% of all samples (1,248/3,206 samples) were contaminated with TAF, and that more than half of the contaminated samples (728/1,248 samples) were composed of peanuts, milk and poultry. In addition, a surveillance study of mycotoxins in foodstuffs and feeds collected in Bangkok in 1999 reported that 30.5% (11/36 samples) of peanuts, corn, rice, coix seed and other common products showed an AFB1 contamination ranged from 0.01–626 μg/kg, as tested by HPLC. No ochratoxin A (OTA) contamination was detected in corn and

Table 1. Incidence of mycotoxin contamination in human foodstuffs in Thailand during the period from 1967–2013

Sampling year	Foodstuffs Samples (N)	Aflatoxin % positive	AFM1 % positive	DON % positive	FUM % positive	T2/HT2 % positive	OTA % positive	Reference (35, 36)
1967	Rice (364)	2						Waenlor & Wiwanitkit, 2003(10)
1967	Peanut (216)	49						〃
1967	corn (62)	35						〃
1967	spice (248)	4.8						〃
1967	Dried seafood (139)	5						〃
1972	Peanut product, corn, plant	30						Shank *et al.*, 1972 (45)
1972	Seed, Chilli pepper (2000)	30						〃
1975	Peanuts (29)	75						Thasnakorn, 1975 (46)
1976	Peanuts (354)	55						Karunyavanich, 1976
1976	Peanut (121)	20.6**						Glinsukon *et al.*, 1976
1977	Peanut, grround & roasted	75.9**						Thasnakorn *et al.*, 1977
1977	Peanut, ground & roasted (34)	96**						Suttajit *et al.*, 1977
1977	Peanut oill, crude (10)	100**						〃
1981	Peanut butter and fermented rice (120)	5, 10						Sripathomswat *et al.*, 1981
1985	Peanuts (170)	34.7						〃
1987	Rice (40)	10						Imwidthaya *et al.*, 1987 (44)
1987	Peanuts (30)	43						〃
1987	Corn (20)	20						〃
1987	Soybean (40)	25						〃
1990	Peanut product (33)	97**						Som-ngern, Suttajit 1990
1991	Rice grains, uncooked (20)	63						Som-ngern, Suttajit 1991
1994	Peanut product (24)	46.4**						Limtrakul *et al.*, 1994
1994	Corn seeds (24)	66.7**						〃
1995	Corn (27)	63						Yamashita *et al.*, 1995 (41)
1996	Corn (18)	72						Yoshizawa *et al.*, 1996 (42)
1997	Peanut oil, crude (4)	100**						Kachareon *et al.*, 1997
1997	Milk and dairy products (270)	95.56						Saitanu, 1997 (10)
1997	Poultry tissue (450)	48.67						Bintvihok *et al.*, 1997 (43)
1999	Dried Seafood (180)	100						Pasura, 1999 (10)
1999	Peanut, corn, rice, coix seed, dairy products (36)	30.55			5.55			Suprasert&Kamimura,1999 (11)
1999	Corn seed (28), Ground peanut (28)	78.57, 64.28						Lipigorngoson *et al.*, 1999 (40)
2000	Cereal grains (270)				33 to 54			Suprasert *et al.*, 2000 (16)
2002	Quail (20), Duck (6), Hen (6), Broiler (6); meats	100						Bintvihok *et al.*, 2002(33)
2002	Quail (20), Duck (6), Hen (6), Broiler (6); livers	100 (only Quail)						〃
2003	Cereal grains (270)			10 to 47				Suprasert *et al.*, 2003 (15)
2005	Noodle soup without ground peanut (80)	40						Thannitwesku *et al.*, 2005
2005	Noodle soup with ground peanut (40)	90						〃
2005	Cereal grains (270)					27 to 57 (T2)		Suprasert *et al.*, 2005 (14)
2006	Roasted coffee (44)						6.81	Chompurat *et al.*, 2006(12)
2006	Corn (24)						58	〃
2006	School Milk (150)		–					Ruangwises&Ruangwises, 2003 (22)
2008	Coffee beans (64)						98*	Noonim *et al.*, 2008 (18)
2013	Unpolished rice (30)	–						Tansakul *et al.*, 2013 (20)
2013	Unpolished glutinous rice (10)	10**						〃
2013	Chilli powder (30)	96.66						〃
2013	Dried chilli pods (30)	36.66						〃
2013	Raw peanut (25)	36						〃

Data adapted from references[35,36)]
Depending on the analytical method used, the sample levels that exceeded the LOQ (limit of quantification) were considered to be positive samples.
**AFB1concentration was determined to be higher than 20 ppb.
*AFM1concentration was determined to be higher than 0.5 ppb.
*OTA concentration was in some samples determined to be higher than 5 ppb.
(–) indicates an analysis was done, however, the concentration was lower than the LOD (limit of detection).

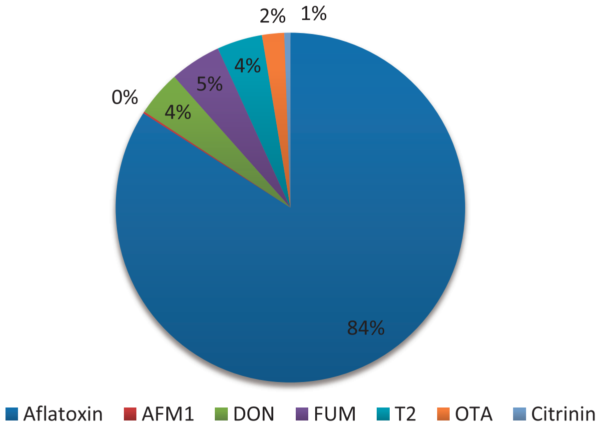

Fig. 1a. Distribution of mycotoxin contamination in human foodstuffs during the period from 1967–2013 in Thailand.

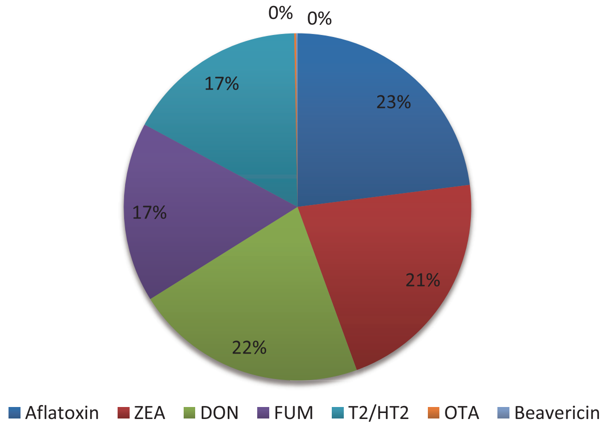

Fig. 1b. Distribution of mycotoxin contamination in animal feed during the period from 1983–2014 in Thailand.

cereal products, while citrinin contamination was found in 50% (4/8 samples) in the range of 0.4–4.0 μg/kg, FUM(B1) and FUM(B2) contamination were detected in 25% (2/8 samples) at level of 130 and 630 μg/kg, and 20 and 160 μg/kg, respectively; however, no patulin contamination was found in juice products [11]. There were also reports of mycotoxin contamination in coffee products. A surveillance study on OTA contamination in roasted coffee and corn, in the Bangkok area, was performed for a period from 2004–2005. In this study, immune-affinity chromatography (IAC) combined with high performance and thin layer chromatography (HPTLC) was used. As a result, 58% (14/24) of the corn samples were found to be OTA-positive; however, none of these samples had OTA levels above 5 μg/kg (the standard amount allowed by the EU). In contrast, 6.81% (3/44) of the roasted coffee samples were found to have OTA contaminations within the range of $<$1–4.6 μg/kg[12].

Concerning the analysis of 3,269 samples of export rice collected during 2006–2009, the AF levels were less than 20 μg/kg. While for AF contamination in commercial red paste curry from fresh markets in Thailand, ELISA assays detected AF-Positives for 58.3%, 58.3%, 50.0%, 45.4% and 41.7% in Bangkok, Suphanburi, Nakhon-Pathom, Samut Songkhram and Saraburi provinces, respectively[13]. T-2 toxin contamination in cereal grains was investigated in oatmeal, rice, brown rice, red rice, sticky brown rice, wheat, barley, Job's tear, and lotus seeds using an ELISA. The result showed that oatmeal was contaminated with T-2 toxin at the highest level of 31.6 μg/kg, while Job's tear was contaminated at the lowest level at 9.5 μg/kg, and a moderate level was found in the other samples ranging from 9.5–31.6 μg/kg[14]. However, DON contamination was assayed in nine similar cereals using an ELISA, revealing DON levels ranged from the limit of detection (LOD)–1.0 mg/kg. Among the nine cereals investigated, red rice had the highest level of DON, 1.0 mg/kg, while brown rice demonstrated the highest frequency of contamination at 47% and an average level of 0.09 mg/kg[15]. FUM contamination in nine cereal grains was also surveyed and was found in the range of 0.08–2.87 mg/kg. Oatmeal showed the highest FUM contamination level (2.87 mg/kg), while lotus seed was the lowest contaminated at 0.08 mg/kg [16].

Additionally, a study was carried out on mycotoxin contamination in rice noodles coated with peanut oil, as rice noodles are a very popular in Thailand and in other Asian countries. To determine the reduction ratio during cooking, rice noodles from Chiang Mai province were analysed using TLC and fluorometry. The AFB1 contents of samples before and after cooking in boiling water were 20.24 ± 41.16 and 15.75 ± 37.88 μg/kg, respectively. While, AFB1 levels in peanut oil were shown to be higher with 343.35 ± 298.17 μg/kg. The results indicated that peanut oil was a main source of AFB1 contamination in this product[17]. In 2006 and 2007, 32 Thai dried coffee bean samples collected from Chiang Mai and 32 Thai dried coffee bean samples from Chumphon provinces were tested for the presence of OTA. Sixty-four coffee bean samples were analysed using ELISA and 94% were found to be contaminated with OTA at levels of <0.6–5.5 μg/kg (Arabica) and 1–27 μg/kg (Robusta). *A. melleus* was the predominant fungal species found in Arabica coffee beans, while *A. carbonarius* and *A. niger* were the dominant fungi isolated from Robusta coffee beans. However, it was interesting to note that *A. ochraceus* was not detected in any of the coffee samples[18]. In 2008 and 2009, AFB1 contamination was reported in rice sold to Canada, of which the five most highly contaminated samples contained 1.44–7.14 μg/kg in 2008 and 1.45–3.48 μg/kg in 2009. These contaminated samples consisted mostly of basmati rice from India and Pakistan and black and red rice from Thailand. In the same study, 15.15% (15/99 samples) of samples were contaminated with FUM(B1) at level of ≥ 0.7 μg/kg and FUM (B2) and (B3) were also presented at level of ≥ 1 μg/kg in year 2008. Of the 100 rice samples analyzed in 2009, only one case of FUM contamination was found at a level of 14 μg/kg in black sweet rice from Thailand [19]. In a recent report from 2013, 120 samples of domestic commodities in Thailand including unpolished rice, unpolished glutinous rice, chili powder, whole dried chili pods and raw peanuts were surveyed for total AF contamination using HPLC-FL methods. The mean concentration of totalAF were 0.16, 25.43, 14.18, 6.62 and 1.43 μg/kg with positive incidence of 4%, 20%, 97%, 37% and 30%, respectively. Chili powder demonstrated the highest incidence of TAF, followed by chili pods, peanuts and rice[20]. FUM contamination in Thai red cargo rice, a type of unpolished rice similar to brown rice, was monitored and 3.44% (2/58 samples) of the samples from retail markets were found to be contaminated with FUM(B1) at a trace level (< 5.0 μg/kg), while FUM(B2) was not found in any samples[21].

There was also a report on mycotoxin contamination in milk in Thailand. The occurrence of aflatoxin M1 (AFM1) in pasteurized milk from a school milk project was studied. One hundred and fifty pasteurised milk samples were collected from 50 schools in the central region of Thailand during three different seasons from May 2006 until January 2007 and analysed using IAC and HPLC-FL. Milk samples were found to be contaminated with AFM1, however, the concentrations were below the US regulation limits of 0.5 μg/litre. The highest AFM1 concentration was 0.114 μg/litre and AFM1 in milk collected during the winter season (December 2006 to January 2007) showed significantly higher contamination levels than the samples collected in the rainy and summer seasons in Thailand[22].

Mycotoxin contamination in animal feed in Thailand

One decade after the first reports on AF contamination in food were published in 1967, a report on the contamination of animal feed was published in1983, which mainly focused on TAF, rather than other mycotoxins, as shown in Table 2.

There was a report of mycotoxins contamination in roughage feed for dairy cattle in Nakhon Pathom, Ratchaburi and Phetchaburi provinces in Thailand. AFB1, AFB2, AFG1, AFG2, OT, FUM(B1), FUM(B2), DON and ZEA contamination was found at mean levels of 15.35 ± 14.55, 1.39 ± 1.23, 1.90 ± 3.49, 0.16 ± 0.37, 3.99 ± 5.26, 62.92 ± 105.92, 8.97 ± 49.93, 66.90 ± 88.27 and 40.13 ± 36.67 μg/kg, respectively. Among the feed samples, 35% (11/31) were compliant with the EU regulation of < 5 μg/kg for AFB1 and 61% (19/31) were compliant with the FDA regulation at < 20 μg/kg for AFB1[23]. These surveys revealed that AF contamination is still a main concern for dairy cattle feed in Thailand

Table 2. Incidence of mycotoxin contamination in animal feed in Thailand during the period from 1983–2014

Sampling year	Foodstuffs Samples (N)	Aflatoxin % positive	AFM1 % positive	Zearalenone % positive	DON % positive	FUM % positive	T2/HT2 % positive	OTA % positive	Reference (35, 36)
1983	Mixed feeds (185)	72							karunyavanich *et al.*, 1983
1987	Animal feeds (24)	88***							suttajit *et al.*, 1987
1995	Mixed feeds (98)	72							karunyavanich *et al.*, 1995
1997	Corn used as animal feeds (224)	82.6***							Kachareon *et al.*, 1997
1997	Peanut meal used as animal feeds (26)	100***							〃
2000	Corn, Soybean mill, peanut product, cassava, rice brand	24.02**		8.11*	7.5*				Tangmunkhong *et al.*, 2003 (39)
2001	Corn, Soybean mill, peanut product, cassava, rice brand	10.98**		1.33*	1.33*				Total sample of 1373 samples &
2002	Corn, Soybean mill, peanut product, cassava, rice brand	5.68**		6.18*	0.83*				Total complete feeds of 915 samples
2003	Corn, Soybean mill, peanut product, cassava, rice brand	4.29**		0.71*	–				from year 2000-2003
2000	Complete feeds	14.29**		11.7*	12.33*				〃
2001	Complete feeds	13.39**		1.79*	1.79*				〃
2002	Complete feeds	7.53**		6.63*	2.11*				〃
2003	Complete feeds	1.39**		1.39*	–				〃
2006	Commercial Animal feed (25)	92			86		100 (T2)	30	Charoenpornsook & kavisarasai 2006 (25)
2008	Corn, Soybean mill, peanut products, cassava, rice bran, DDGS	6.11**		4.38*		11.47*	–		Tangmunkhong *et al.*, 2011 (24)
2009	Corn, Soybean mill, peanut products, cassava, rice bran, DDGS	7.10**		7.94*		10.55*	–		Total sample of 5527 samples &
2010	Corn, Soybean mill, peanut products, cassava, rice bran, DDGS	7.87**		4.84*		11.11*	–		Total complete feeds of 2358 samples
2011	Corn, Soybean mill, peanut products, cassava, rice bran, DDGS	5.36**		3.46*		7.80*	–		from 2008-2011
2008	Complete feeds	3.40**		1.51*		2.89*	–		〃
2009	Complete feeds	3.57**		11.50*		4.39*	–		〃
2010	Complete feeds	6.50**		6.70*		4.23*	–		〃
2011	Complete feeds	28.68**		1.69*		15.38*	–		〃
2012	Dairy feeds (31)	39**							Yawongsa *et al.*, 2013 (23)
2013	Corn-DDGS (59)			81.35	49.15	98.3			Tansakul *et al.*, 2013 (26)
2014	Commercial dog food (30)	100						23.33	Tansakul *et al.*, 2014 (27)
2014	Commercial cat food (30)							30	〃

Data adapted from references[35,36)]
Depending on the analytical method used, the sample levels that exceeded the LOQ (limit of quantification) were considered to be positive samples.
**AFB1concentration was determined to be higher than 20 ppb.
***AFB1 concentration was determined to be higher than 100 ppb.
*ZEA concentration was determined to be higher than 200 ppb.
*DON concentration was determined to be higher than 1000 ppb.
*FUM concentration was determined to be higher than 1000 ppb.
(–) indicates an analysis was done, however, the concentration was lower than the LOD (limit of detection).

and monitoring of other mycotoxins in feed must be carried on in long term. Moreover, a study of mycotoxin contamination in animal feed samples and commercial animal feed collected between 2008–2011, using the ELISA method to analyse AF, ZEA, FUM and T-2/HT-2 contamination, was carried out[24]. A total number of 5,527 raw samples from imported and domestic corn, soybean mill, peanut products, cassava rice bran, and Dried Distillers Grains with Solubles (DDGS) were examined. In raw materials, the ratios of Total AF levels above 20 μg/kg were 6.11%, 7.10%, 7.87% and 5.36% in samples taken in 2008, 2009, 2010, and 2011, respectively. The ratios of ZEA levels above 100 μg/kg were 4.38%, 7.94%, 4.84%, 4.84% and 3.46% and of FUM levels above 1,000 μg/kg were 11.47%, 10.55%, 11.11% and 7.80%, respectively, while none of the samples showed T-2/HT-2 levels of more than 100 μg/kg according to the ELISA test's limit of detection (LOD). The above results could not make the conclusion of the increasing trend of mycotoxin contamination since the ratio of contamination were varies with yearly basis. In commercial feeds, the ratios of AF levels above 20 μg/kg were 3.40%, 3.57%, 6.50% and 28.68%; ZEA levels above 100 μg/kg were 1.51%, 11.50%, 6.70% and 1.69%; and FUM levels above 1,000 μg/kg were 2.89%, 4.39%, 4.23% and 15.38% in 2008, 2009, 2010 and 2011, respectively. None of the commercial feeds showed T-2/HT-2 levels of more than 100 μg/kg in any of the above mentioned years.

AFB1 was detected in 92% of the samples (23/25 samples) with an average level of 7.56 μg/kg. OTA was detected in 30% (3/10 samples) of these feed at levels of 10.48, 11.14 and 12.35 μg/kg. DON was detected in 86% of the samples (13/15) at an average level of 33.77 μg/kg. T-2 toxin was detected in all samples (10/10) with an average level of 6.91 μg/kg. Three out of ten samples were contaminated with four mycotoxins, suggesting a high risk of multi-contamination (exposure to several toxins at the same time) due to indirect exposure to meat and other products from animals consuming contaminated animal feed[25]. Remarkably, heavy contamination of AF, ZEA and FUM were found in corn-DDGS and rice bran[24]. Nevertheless, in 59 DDGS samples, five contaminants were identified, including FB1, FB2, DON, ZEA and beauvericin A (BEA) using LC-MS/MS. In addition, 50.8% of all samples were found to be co-contaminated with all five mycotoxins and none of the samples were free of mycotoxins. The mean toxin levels detected were 9 mg/kg FB1, 6 mg/kg FB2, 1.2 mg/kg DON, 0.9 mg/kg ZEA and 0.35 mg/kg BEA, while the maximum level of FB1 and FB2 was 143 mg/kg and 125 mg/kg, respectively, which is of acute toxicological relevance[26]. Moreover, a survey of AF and OTA in pet food was carried out from April 2011 to February 2012 using HPLC. All dog food samples showed AF contamination at trace levels of approximately 3.17 ± 2.43 μg/kg while none were reported for cat food. However, seven out of 30 dog food samples and nine out of 30 cat foods samples were found to be contaminated with OTA at mean values of 14.04 ± 9.44 μg/kg and 2.46 ± 2.10 μg/kg, respectively[27].

An examination of mould in commercial animal feed samples in 2006 revealed the presence of *Aspergillus* spp., *Penicillium* spp., *Fusarium* spp., and non-septate fungi, cultivated from the samples, thus suggesting that the risk of mycotoxin contamination from these fungi could increase during storage.

Public health concerns regarding mycotoxins in Thailand

It has long been known that dietary AF reduces the growth rate and compromises productivity in animals and human. The risk of liver cancerdue to AF in carriers of the chronic hepatitis B virus and AF is 30 times greater than in non-carriers exposed to AF[4,28]. Mycotoxin contamination is considered to be a major problem which affects both human and animal health and also has damaging economic consequences.

The regulation value of mycotoxins has been establishedin Thailand (Table 3). The frequency of mycotoxin contamination in foodstuffs and

Table 3. Food mycotoxin regulations for main countries trading with Thailand

	Maximum tolerated levels of mycotoxins (μg/kg) in foods								
Country/Organization	AFB1	TAF	AFM1	Patulin	DON	OTA	FUM	ZEA	Citrinin
Thailand		20							
Japan	10			50	1100				
Vietnam		10	0.5						
Indonesia		20	5						
Malaysia		35							
Singapore		5	0.5	50		2.5			
EU	2, 12	4	0.05	25, 50	500, 750	2	800, 1000	50, 75	2,000
Australia/Newzealand		15							
USA		20	0.5	50	1000		2000–4000		
India		30							
Codex		15	0.5	50		5			
China	5, 10, 20		0.5	50	1000				

Adapted from references [37,38,47]
Abbreviations: AFB1, aflatoxinB1;TAF, total aflatoxin; AFM1, aflatoxin M1; DON, deoxynivalenol; OTA, ochratoxin A; FUM, fumonisin (including FB1, FB2and FB3); ZEA, zearalenone.

animal feed in Thailand shows that many products are contaminated or co-contaminated with AFM1, DON, FUM, T-2, and OTA, in addition to AF. However, the mycotoxin regulations for imported/exported food primarily depends upon the partner with Thailand, as shown in Table 3. Considering the impact of adverse health effects, mycotoxin regulations should be aligned on the CODEX Alimentarius international food standard.

The monitoring of AF exposure using biomarkers has been mentioned with respect to the incidence of hepatocellular carcinoma (HCC) in Thailand, as previously reported by Makarananda *et al.*, in 1998 who used an ELISA to conduct epidemiological studies and to monitor short-term exposure to AF[29]. The presence of albumin-AFB1 adducts in peripheral blood counts has also been previously reported in a long-term exposure assessment of the prevalence of the p53 mutation at codon 249[29,30]. AF contamination has long been reported to be a major problem related to hepatic diseases in Egypt and in many African countries[32]. AF contamination has an incidence of 43.75% among African countries, followed by FUM and OTA at 21.87% and 12.5 %, respectively[31,32]. AF residues can be found in the liver, muscle and eggs of domestic fowl according to the results of feeding experiments with a diet containing AFB1 in Thailand[33]. There has been only one report regarding AFM1 found in human breast milk samples[34]. In that study, 73 breast milk samples from women from Victoria, Australia and 11 samples from women from Thailand were analysed for AFM1 contamination using an ELISA. AFM1 was detected in 11 of the 73 samples from Victoria and in five of the 11 samples from Thailand at a median concentration of 0.071 ng/ml (range: 0.028 to 1.031 ng/ml) and 0.664 ng/ml (range: 0.039 to 1.736 ng/ml), respectively[34].

In conclusion, there are a number of reasons for Thailand to be concerned about mycotoxin contamination in human foodstuffs and animal feed and associated health issues. One of the main reasons behind this contamination resides is the geographical location of Thailand, which is located in a tropical zone with a hot and humid atmosphere. Mycotoxin contamination in human foodstuffs is largely due to AF contamination, which potentially induces hepatocellular carcinoma and is genotoxic to humans and/or animals [48]. Moreover, further detailed studies on mycotoxins contamination such as ZEA, OTA, T2/HT2, DON and BEA and its metabolic effects are needed to better elucidate the consequences of their toxicity.

In addition, the food safety control strategies for mycotoxin must be re-evaluated in order to ensure the safety of foodstuffs and feed in Thailand.

Acknowledgements

This work was supported by the Faculty of Veterinary Medicine, Kasetsart University and The Graduate School of Life and Environmental Science, Azabu University. This study could not have been completed without the valuable support of Associate Prof. Prapeuk Tangmunkhong, Associate Prof. Dr. Natthasit Tansakul and Associate Prof. Adisorn Yawongsa.

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