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Mycotoxins in Asia: is China in danger?

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REVIEW ARTICLE

Abstract

Mycotoxins such as aflatoxins, ochratoxins, fumonisins, deoxynivalenol and zearalenone are considered to be of particular concern in relation to human and animal health. Contamination of agricultural products by mycotoxins has become an important issue worldwide over the last three decades. Asia contributes a very large part of the globe with most developing countries in the tropical and subtropical regions favouring the growth of fungal species. There is a high potential of mycotoxin occurrence and a number of important mycotoxin outbreaks in Asia. In recent years, increasing number of survey in Asia with regard to prevalence of mycotoxins has evidenced the seriousness of mycotoxins problem in this continent. Among Asian countries, China is the most populous nation with a population of over 1.3 billion. Due to extensive and complex topography, diverse climate zones in China have provided various optimal environments for the growth of mycotoxins-producing fungi. It is evident that people in China have been exposed to various mycotoxins simultaneously in a frequent and chronic manner. Effort on investigation and monitoring with regard to mycotoxins contamination and exposure is necessitated for the sake of public health in this populous country. This review presents several mycotoxins exhibiting strong ecological link with human food supply in Asia. Human mycotoxicoses relating to these mycotoxins, especially in Asia, are highlighted and their contaminations of human foodstuffs in the 21st century in Asian countries are summarized. In particular, the current situation and control measures with regard to mycotoxin contamination in China are discussed.

Keywords: aflatoxins, Asia, China, deoxynivalenol, fumonisins, ochratoxin A, zearalenone

1. Introduction

Mycotoxins are highly toxic secondary metabolites naturally produced by molds or fungi. Due to the significant economic loss associated with their impact on human and animal health, a potential problem with mycotoxins has been increasingly recognized, particularly, after the discovery of Turkey X disease in the UK in the early 1960s. This contemporary issue has become a subject of international importance over the last three decades (Bhat and Miller, 1991).

Asia contributes a very large part of the globe with most developing countries in the tropical and subtropical regions. Considering the environmental conditions in these countries with warm and humid climate, agricultural commodities are particularly susceptible to fungal contamination and hence mycotoxins accumulation. Although there is a high potential of mycotoxin occurrence and a number of previous mycotoxin outbreaks in Asia (Table 1), research and monitoring on mycotoxins are relatively limited comparing to western countries. There is very little information with regard to the extent of the mycotoxins problem in Asia. The actual situation of mycotoxins contamination is not known in this region. In recent years, rising number of survey with regard to prevalence of mycotoxins has indicated the seriousness of mycotoxins problem among Asian countries.

In this review, we will briefly present the mycotoxicoses associating with mycotoxins of Asian concern and their occurrence in Asian countries. The current situation of mycotoxins problem in China as well as control measures will also be discussed.

Table 1. Mycotoxins outbreak in Asia (Malloy and Marr, 1997).

Year	Event	Country
1971	'yellow rice' metabolites associated with liver tumors	Japan
1980s	'yellow rain' biological warfare controversy	Cambodia
1987	tricothecene mycotoxicoses from moldy bread	India
1990	Saddam Hussein develops mycotoxins for use as biological warfare agents	Iraq

2. Mycotoxins of worldwide importance

Mycotoxins are extremely diverse groups of biological compounds that are toxic to vertebrates in low concentration (Bennett and Klich, 2003). Their molecular structures range from single heterocyclic ring with molecular weight of 50 Da to groups of 6 or 8 membered rings with total molecular weight greater than 500 Da (Pitt, 2000). The wide range of structural difference contributes to their diverse chemical and physical properties. Mycotoxins can be classified as hepatotoxic, nephrotoxic, immunotoxic, neurotoxic and so forth according to the target organs or as mutagenic, carcinogenic, teratogenic, estrogenic and so forth according to biological effects. Individual mycotoxin can target various organs and elicit diverse biological effects.

Currently more than 300 fungal metabolites are potentially toxic for humans and animals, and increasing number of mycotoxins are likely to be discovered (Bennett and Klich, 2003). Mycotoxin-producing fungal species are ubiquitous that are able to grow on various substrates under suitable temperature and humidity conditions. They have a strong ecological link with human food supplies (Pitt, 2000). Humans expose to mycotoxins typically via dietary exposure to contaminated food and its derived products. Food related mycotoxins are mainly produced by three fungal genera, *Aspergillus*, *Fusarium*, and *Penicillium*, that contaminate a wide range of agricultural commodities under both pre-harvest and post-harvest conditions (Bhat and Miller, 1991) (Table 2). It has been reported that as much as a quarter of the world grain supply is contaminated with known mycotoxins (Devegowda, 1998). Global occurrence of toxigenic fungi and globalization of crop trade greatly contribute to worldwide mycotoxins exposure nowadays (Altomare *et al.*, 2007). A leading figure in the risk assessment field has ranked mycotoxins as the most important chronic dietary risk factor even higher than synthetic contaminants, plant toxins, food additives, or pesticide residues (Kuiper-Goodman, 1998). These natural contaminants have already posed a worldwide risk to both animal and human health. Among numerous of mycotoxins, those causing health hazards to human and economic loss are always of great concern. Aflatoxins (AFLs), ochratoxin A (OTA), fumonisins (FUM), deoxynivalenol (DON) and zearalenone (ZEA) are the mycotoxins of worldwide importance and monitored by Asian countries nowadays.

3. Aflatoxins

AFLs have been extensively studied since the epidemic of Turkey X disease causing the death of more than 100,000 turkey poults in 1960s (Blount, 1961). Among the family of AFLs, four major members, B_1, B_2, G_1 and G_2, occur naturally in a wide variety of food and feed are of significant concern. They are mainly produced by *Aspergillus parasiticus* and *Aspergillus flavus*. In addition, AFM_1, a metabolite of AFLs, is also closely monitored in dairy products. They are classified according to their

Table 2. Mycotoxins of worldwide importance.

Mycotoxins	Major fungal species	Human mycotoxicoses	References
Aflatoxins	*Aspergillus parasiticus* *Aspergillus flavus*	aflatoxicosis liver cancer	Williams *et al.* (2004)
Deoxynivalenol	*Fusarium graminearum* *Fusarium culmorum*	scabby grain toxicosis	Pestka and Smolinski (2005)
Fumonisins	*Fusarium verticillioides* *Fusarium proliferatum*	oesophageal cancer neural tube defects	Weidenbörner (2001); Scott (2012)
Ochratoxin A	*Aspergillus ochraceus* *Penicillium verrucosum*	Balkan endemic nephropathy	Duarte *et al.* (2010)
Zearalenone	*Fusarium graminearum* *Fusarium culmorum*	hyperestrogenism scabby grain toxicosis	Zinedine *et al.* (2007)

fluorescence (blue or green) under ultraviolet light and relative thin-layer chromatographic mobility. 'M' denotes milk or mammalian metabolites. The subscript number, 1 and 2, indicates major and minor compounds, respectively.

AFLs have been suggested to be the most toxic and potent carcinogenic mycotoxins. AFLs have been associated with diverse toxicities and carcinogenicity in both animals and human, primarily targeting the liver but also kidney, lung (Hayes *et al.*, 1984) or colon (Deger, 1976). AFB_1 is classified as a human carcinogen (group 1) while AFM_1 as a possible human carcinogen (group 2B) by the International Agency of Research on Cancer (IARC) (IARC, 1993). Poisoning resulting from the consumption of AFLs is classified as aflatoxicosis. Acute aflatoxicosis (acute severe intoxication) results in hemorrhagic necrosis of liver, bile duct proliferation, edema, and even death (Cullen and Newberne, 1993). Over the years, a number of acute aflatoxicosis outbreaks in humans have been reported. The most severe reported outbreak of acute aflatoxicosis is the recent outbreak in rural Kenya in 2004 resulting in over 300 recognized cases and 125 deaths (Azziz-Baumgartner *et al.*, 2005; Lewis *et al.*, 2005). In Asia, acute aflatoxicosis was reported in western India in 1974 causing 397 recognized cases and 106 deaths (Krishnamachari *et al.*, 1975). In addition, acute hepatic encephalopathy in children resulting from the consumption of AFLs-contaminated noodles was also reported in Malaysia (Lye *et al.*, 1995).

Chronic aflatoxicosis is due to chronic sub symptomatic exposure of AFLs. It is associated with cancer, immunologic suppression and nutritional interference. Confounding relationship between AFLs exposure and hepatitis B virus as well as hepatitis C virus infection on hepatocellular carcinoma has been extensively investigated (IARC, 2002; Wogan, 1999). Studies in several African and Asian countries have demonstrated a strong synergy between AFLs and these biological agents for liver cancer in developing countries (Allen *et al.*, 1992; Chen *et al.*, 2007; Henry *et al.*, 2002; Ross *et al.*, 1992; Turner *et al.*, 2000; Wang *et al.*, 1996, 2001a).

In animal studies conducted in poultry, pigs, and rats, immunologic suppression caused by AFLs is well documented (for a review see Williams *et al.*, 2004). Although there is insufficient evidence for such counterpart immunotoxic effects in human, Turner *et al.* (2003) have observed modifications in the immunity in children, who were exposed to AFLs. Significant alterations in cellular immune system in Ghanaian subjects with high AFB_1 level were also observed (Jiang *et al.*, 2005).

Chronic AFLs exposure has been shown to reduce the food conversion efficiency and growth rate in animals, hence, productivity (Dalvi, 1986; Iheshiulor *et al.*, 2011; Marin *et al.*, 2002). In human, developmental effects such as early childhood growth faltering (Turner *et al.*, 2003, 2007), stunting and underweight (Gong *et al.*, 2002), as well as still-birth and neonatal mortality (Hendrickse, 1997) were also observed in children exposed to AFLs. Although the etiology and pathogenesis of Kwashiorkor, a disease which is usually attributed to nutritional deficiencies in undernourished populations, still remain unclear, it has been speculated to associate with AFLs exposure based on observational studies (Hendrickse *et al.*, 1982; Lamplugh and Hendrickse, 1982; Ramjee *et al.*, 1992). With increasing evidence with regard to the relationship between AFLs exposure and nutritional factors, further effort is required for the emergence of nutritional interference by AFLs. A review covering the possible role of AFLs in malnutrition and infections has been published by Williams *et al.* (2004).

Among numerous mycotoxins, AFLs are the major identifiable problem in Asia. AFLs contamination predominantly occurs during post-harvest stage related to poor storage and transportation. They are predominantly detected in corn (maize), peanuts, cereals as well as dairy and meat products, which are due to animal consumption of AFLs-contaminated feedstuffs (Table 3). The provisional maximum tolerable daily intake (PMTDI) for AFB_1 established by Kuiper-Goodman is 1 ng/kg body weight (Kuiper-Goodman, 1998).

According to the economic evaluation report prepared in 1994, economic losses due to AFLs in maize and peanuts were estimated to approximately AUS$ 477 million per year in Thailand, Indonesia, and the Philippines (Lubulwa and Davis, 1994). However, cost estimation for human health effect had only considered costs associated with mortality of primary liver cancer. When the additional costs associated with other aflatoxicosis and intangibles as well as inflation are taken into account, the loss would probably increase significantly nowadays.

4. Ochratoxin A

Ochratoxins are a group of secondary metabolites produced by *Aspergillus* and *Penicillium* genera, in particular *Aspergillus ochraceus* (Turner *et al.*, 2009). The family of ochratoxins consists of three members, A, B and C with slightly structural difference (O'Brien and Dietrich, 2005). Despite of the structural similarity, the most commonly detected OTA has the highest toxic potentials followed by ochratoxin B (OTB) and ochratoxin C (OTC) (Hussein and Brasel, 2001). Because of its diverse toxicities and widespread contamination, OTA has been increasingly recognized and studied in the last 40 years.

OTA is considered to be primarily an acute nephrotoxin (Pitt, 2000). It has been postulated to associate with the human fatal disease, Balkan endemic nephropathy and associated urothelial tract tumors (Pfohl-Leszkowicz,

Table 3. Examples of aflatoxins (AFLs) contamination in Asian food in the 21st century.

Country	Commodity	Toxins	Number of analysed samples	Frequency (%)	Level (µg/kg or µg/l)	References
China	barley	AFLs	25	4	0.04[a]	Haubruge *et al.* (2003)
	brown rice (dehusked)	AFLs	37	97	0.88[a]	Liu *et al.* (2006)
	cereals and cereal products	AFLs	92	4	1.3-5.8	RAS (2001)
	fermented tea and plant perfume	AFLs	95	-	1->20	Liu (2011)
	kidneys (pig, chicken, duck)	AFLs	72	0	-	Liu *et al.* (2008)
	maize and maize products	AFB_1	7	100	-	Cai *et al.* (2011)
		AFLs	40	45	9-2,816	Li *et al.* (2001)
		AFB_1, AFB_2	204	25	1.7-453.9	Li *et al.* (2011)
		AFLs	73	97	0.99[a]	Liu *et al.* (2006)
		AFLs	36	-	500-7,600	Liu *et al.* (2008)
		AFLs	215	100	0.1-581.3	Ma *et al.* (2011)
		AFB_1	108	100	0.1-136.8	Sun *et al.* (2011)
		AFLs	74	70	0.02-1,098.36	Wang and Liu (2006)
		AFB_1	30	77	0.4-128.1	Wang *et al.* (2001a)
		AFB_1	41	100	2.58-66.06	Wang *et al.* (2011)
	milk	AFM_1	135	72	0.16-0.5	Pei *et al.* (2009)
	peanut oil	AFB_1	30	67	0.1-52.5	Wang *et al.* (2001a)
	peanuts and peanut products	AFLs	115	23	1.6-26	RAS (2001)
		AFLs	132	-	500-41,600	Liu *et al.* (2008)
		AFLs	292	100	0.1-339.6	Ma *et al.* (2011)
		AFLs	66	24	0.03-680.08	Wang and Liu (2006)
	pine nut	AFLs	12	17	0.19-0.25	Wang and Liu (2006)
	plant oil	AFB_1	39	100	0.2-114.4	Sun *et al.* (2011)
	rice	AFB_1	10	100	0.57[a]	Cai *et al.* (2011)
		AFLs	16	100	3.87[a]	Liu *et al.* (2006)
		AFLs	18	100	0.08-6.9	Ma *et al.* (2011)
		AFB_1	29	100	0.1-1.4	Sun *et al.* (2011)
		AFLs	84	27	0.15-1.58	Wang and Liu (2006)
		AFB_1	30	23	0.3-2.0	Wang *et al.* (2001a)
	vegetable oil and fat	AFLs	245	4	0.1-5.8	RAS (2001)
	walnut	AFLs	48	65	0.02-1.2	Wang and Liu (2006)
	wheat and wheat products	AFLs	125	100	0.08-2.1	Ma *et al.* (2011)
		AFB_1	16	100	0.1-0.9	Sun *et al.* (2011)
India	chillies	AFB_1	182	59	0.1-969	Reddy *et al.* (2001)
	parboiled rice	AFB_1	1,511	38	5-361	Toteja *et al.* (2006a)
	rice	AFB_1	1,200	68	0.1-308	Reddy *et al.* (2009)
	sorghum	AFB_1	1,606	73	0.01-263.98	Ratnavathi *et al.* (2012)
	wheat and wheat products	AFB_1	1,646	40	5-606	Toteja *et al.* (2006b)
Indonesia	milk	AFM_1	113	58	5-<50	Nuryono *et al.* (2009)
Iran	bean	AFB_1	30	17	0.21-0.29	Fakoor Janati *et al.* (2011)
	maize and maize products	AFLs	51	33	0.1-316.9	Ghiasian *et al.* (2011)
	milk	AFM_1	33	100	0.193-0.259	Gholampour Azizi *et al.* (2007)
		AFM_1	210	55	0.012-0.249	Heshmati and Milani (2010)
		AFM_1	111	77	0.015-0.28	Kamkar (2005)
		AFM_1	52	100	0.053-0.094	Kamkar (2008)
		AFM_1	272	94	0.00007-0.115. 93	Mohammadian *et al.* (2010)
		AFM_1	10	50	<5 ng/l[a]	Movassagh *et al.* (2011)
		AFM_1	236	90	0.012-0.218	Rahimi *et al.* (2009)
		AFM_1	311	42	5->50	Rahimi *et al.* (2010)
		AFM_1	150	47	0.008-0.115	Rahimi and Ameri (2012)
		AFM_1	72	100	0.1788-0.2535	Sefidgar *et al.* (2011)
		AFM_1	319	54	0.057[a]	Tajkarimi *et al.* (2008)
	pistachio nuts	AFLs	10,068	28	0.4->500	Cheraghali *et al.* (2007)

Table 3. Continued.

Country	Commodity	Toxins	Number of analysed samples	Frequency (%)	Level (µg/kg or µg/l)	References
Japan	almond	AFLs	24	25	0.21-1.06	Sugita-Konishi *et al.* (2010)
	bitter chocolate	AFB_1	42	52	0.11-0.6	Kumagai *et al.* (2008)
	buckwheat flour	AFLs	28	7	0.21-0.99	Sugita-Konishi *et al.* (2010)
	cacao products	AFB_1	12	42	0.2-0.6	Tabata *et al.* (2008)
	chocolate	AFLs	64	53	0.21-0.88	Sugita-Konishi *et al.* (2010)
	cocoa	AFLs	11	73	0.21-0.85	Sugita-Konishi *et al.* (2010)
	coix seed	AFB_1	2	50	1.1	Tabata *et al.* (2008)
	job's tears	AFLs	17	35	0.21-9.71	Sugita-Konishi *et al.* (2010)
	maize and maize products	AFLs	30	7	0.21	Sugita-Konishi *et al.* (2010)
	milk	AFM_1	208	100	0.001-0.029	Nakajima *et al.* (2004)
		AFM_1	299	-	-	Sugiyama *et al.* (2008)
	peanut	AFLs	150	1	28	Sugita-Konishi *et al.* (2010)
	peanut butter	AFLs	21	48	0.12-2.59	Kumagai *et al.* (2008)
		AFLs	21	48	0.12-2.59	Sugita-Konishi *et al.* (2006)
		AFLs	62	34	0.21-3.92	Sugita-Konishi *et al.* (2010)
	pistachio	AFLs	5	20	0.38	Sugita-Konishi *et al.* (2010)
	red pepper	AFLs	6	17	1	Sugita-Konishi *et al.* (2010)
	white pepper	AFLs	5	80	0.21-0.5	Sugita-Konishi *et al.* (2010)
Korea	barley food	AFB_1	32	13	19-35	Park *et al.* (2002a)
	dairy products	AFM_1	180	79	0.002-0.331	Kim *et al.* (2000)
	maize and maize products	AFB_1	47	9	14-25	Park *et al.* (2002a)
	meju	AFB_1	60	42	2.1-23.5	Kim *et al.* (2001)
	milk	AFM_1	100	48	0.002-0.08	Lee *et al.* (2009)
	nuts	AFLs	85	11	0.15-28.2	Chun *et al.* (2007)
	rice	AFB_1	88	6	2.1-7.7	Park *et al.* (2004)
	spice	AFLs	88	14	0.08-4.66	Cho *et al.* (2008)
Malaysia	nuts and nut products	AFLs	196	16	16.6-711	Leong *et al.* (2010)
	7 types of food (rice, wheat, corn, and oats based, oilseeds, nuts, and spices)	AFB_1	95	73	0.54-15.33	Reddy *et al.* (2011)
Nepal	areca nut	AFB_1, AFB_2	80	25	-	Koirala *et al.* (2005)
	maize and maize products	AFB_1, AFB_2	345	32	60-859	Koirala *et al.* (2005)
	peanut	AFB_1, AFB_2	200	34	54-1,806	Koirala *et al.* (2005)
	peanut butter/vegetable oil	AFB_1, AFB_2	101	43	64-1,736	Koirala *et al.* (2005)
	wheat flour	AFB_1, AFB_2	106	30	109-693	Koirala *et al.* (2005)
Pakistan	maize and maize products	AFLs	40	85	21->30	Ahsan *et al.* (2010)
		AFLs	65	28	5-850	Khatoon *et al.* (2012)
		AFB_1	36	83	8.56-30.96	Shah *et al.* (2010)
	milk	AFM_1	168	100	0.01-0.70	Hussain and Anwar (2008)
		AFM_1	480	45	-	Hussain *et al.* (2008)
		AFM_1	79	11	0.0293-0.3426	Raza (2006)
		AFM_1	232	76	0.002-1.9	Sadia *et al.* (2012)
	rice	AFLs	40	70	0.8-18	Hussain *et al.* (2011)
		AFLs	413	45	0.04-68.3	Iqbal *et al.* (2012)
	sweets	AFM_1	138	97	0.01-1.5	Sadia *et al.* (2012)
Qatar	custard powder	AFLs	6	33	0.17-1.2	Abdulkadar *et al.* (2004)
Qatar	peanut and butter	AFLs	11	82	0.17-13.26	Abdulkadar *et al.* (2004)
Qatar	pistachio nuts	AFLs	6	50	0.23-81.64	Abdulkadar *et al.* (2004)
Qatar	rice	AFLs	9	33	0.14-0.24	Abdulkadar *et al.* (2004)
Taiwan	dairy product	AFM_1	113	38	0.002-0.1	Lin *et al.* (2004)
Thailand	milk	AFM_1	240	100	0.014-0.197	Ruangwises and Ruangwises (2010)
Vietnam	rice	AFB_1	100	51	0.07-29.8	Nguyen *et al.* (2007)

[a] Values are expressed as mean.

2009). Several studies also demonstrated its mutagenicity, teratogenicity, neurotoxicity, immunotoxicity, and carcinogenicity in animals (O'Brien and Dietrich, 2005). It is classified as a possible human carcinogen (group 2B) by the International Agency for Research on Cancer (IARC, 1993). It is the most potent renal carcinogen known to date with the highest tumour incidence after very low doses administration to rats (Lock and Hard, 2004). Further experimental data and epidemiological studies have also speculated the possible relationship between testicular cancer and OTA exposure (Jennings-Gee *et al.*, 2010; Schwartz, 2002).

Similar to AFLs, OTA contamination predominantly occurs during post-harvest stage. Humans are mainly exposed to OTA by consumption of contaminated food or food products derived from contaminated plants or exposed animals (EFSA, 2004). It has been reported in a wide variety of matters including cereals, oilseed, nuts, dried peanuts, beans, spices, green coffee beans and dried fruits, even milk, processed meat and smoked, and salted fish (Babu *et al.*, 2002; Ringot *et al.*, 2006; Schrickx *et al.*, 2006). Because of the strong ecological link of OTA-producing fungi to human food supplied, high incidence of OTA exposure has been reported in epidemiological studies from more than 20 countries (Miraglia and Brera, 2002; Pfohl-Leszkowicz and Manderville, 2007; Scott, 2005). However, comparing to western countries, there are relatively less information with regard to OTA exposure in Asia (Table 4). The provisional maximum tolerable weekly intake (PMTWI) established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) is 100 ng/kg body weight (JECFA, 2008).

5. Fumonisins

FUM were discovered and characterised in 1988 after the field outbreak of equine leukoencephalomalacia (ELEM) in South Africa in 1970 (Bezuidenhout *et al.*, 1988; Gelderblom *et al.*, 1988; Kellerman *et al.*, 1972; Marasas *et al.*, 1976). They are produced by 15 *Fusarium* species including *Fusarium verticillioides* (formerly *Fusarium moniliforme*), which is commonly found in China (for a review see Rheeder *et al.*, 2002). The family of FUM consists of four series, A, B, C and P with distinct structurally groups. Fumonisin B_1 (FB_1) is the most prevalent and toxic mycotoxin in this family, accounting for approximately 70%-80% of the total FUM in naturally contaminated products (Rheeder *et al.*, 2002).

Table 4. Examples of ochratoxin A contamination in Asian food in the 21st century.

Country	Commodity	Number of analysed samples	Frequency (%)	Level (µg/kg or µg/l)	References
Asian countries	coffee	-	-	1.6-31.5	Pardo *et al.* (2004)
China	barley	25	52	1-46	Haubruge *et al.* (2003)
		31	35	0.21-35.36	Li *et al.* (2012b)
	Chinese medicinal plants	57	44	1.2-158.7	Yang *et al.* (2010)
	fermented tea and plant perfume	95	-	2-40	Liu (2011)
	manufactured food products	110	12	0.01-0.39	Wu *et al.* (2012)
	raw and cooked food	287	35	0.01-2.09	HWFB (2006)
	wheat	61	39	0.23-14.25	Li *et al.* (2012b)
	wine	36	3	0.24	Kuang *et al.* (2012)
India	spice	126	36	>10-110	Thirumala-Devi *et al.* (2001)
Iran	bean	30	10	0.23-0.39	Fakoor Janati *et al.* (2011)
	malt beverage	70	100	0.0005-0.5245	Mahdavi *et al.* (2007)
	rice	182	6	0.002-0.048	Feizy *et al.* (2011)
Japan	barley	11	0	-	Aoyama *et al.* (2010)
	beer	81	56	0.01-0.445	Aoyama *et al.* (2010)
		20	70	0.01-0.054	Kumagai *et al.* (2008)
		20	60	0.01-0.05	Sugita-Konishi *et al.* (2006)
	bitter chocolate	41	66	0.1-0.94	Kumagai *et al.* (2008)
	buckwheat	142	52	0.1-1.79	Aoyama *et al.* (2010)
		2	100	0.12-0.45	Tabata *et al.* (2008)
	buckwheat flour	10	80	0.16-1.79	Kumagai *et al.* (2008)
		10	60	0.16-1.79	Sugita-Konishi *et al.* (2006)
	cacao	28	57	0.11-0.67	Tabata *et al.* (2008)
	cocoa	153	79	0.1-3.45	Aoyama *et al.* (2010)

Table 4. Continued.

Country	Commodity	Number of analysed samples	Frequency (%)	Level (μg/kg or μg/l)	References
Japan	coffee	177	55	0.1-4.23	Aoyama *et al.* (2010)
		20	25	0.11-0.76	Sugita-Konishi *et al.* (2006)
		45	22	0.16-0.81	Tabata *et al.* (2008)
	coriander	5	20	0.93	Aoyama *et al.* (2010)
	dried bonito	22	0	-	Aoyama *et al.* (2010)
	dried fig	5	0	-	Aoyama *et al.* (2010)
	fruits	47	21	0.11-4.0	Tabata *et al.* (2008)
	grape juice	34	0	-	Aoyama *et al.* (2010)
	green beans	11	27	0.14-0.76	Kumagai *et al.* (2008)
	maize	130	0	-	Aoyama *et al.* (2010)
	maize and maize products	60	0	-	Sugita-Konishi *et al.* (2006)
	millet	11	0	-	Aoyama *et al.* (2010)
	oatmeal	20	50	0.06-0.18	Kumagai *et al.* (2008)
		54	13	0.1-2.5	Aoyama *et al.* (2010)
		20	10	0.13-0.18	Sugita-Konishi *et al.* (2006)
	pasta	80	70	0.1-1.66	Aoyama *et al.* (2010)
	raisins	52	60	0.1-12.5	Aoyama *et al.* (2010)
		11	91	0.02-12.5	Kumagai *et al.* (2008)
		11	64	0.18-12.5	Sugita-Konishi *et al.* (2006)
	rice	121	0	-	Aoyama *et al.* (2010)
		50	0	-	Sugita-Konishi *et al.* (2006)
	roast coffee	9	33	0.11-0.33	Kumagai *et al.* (2008)
	rye	40	45	0.1-2.59	Aoyama *et al.* (2010)
		10	90	0.28-1.59	Kumagai *et al.* (2008)
		10	70	0.28-2.59	Sugita-Konishi *et al.* (2006)
	wheat and wheat products	12	50	0.12-0.3	Tabata *et al.* (2008)
		160	49	0.1-1.0	Aoyama *et al.* (2010)
		50	56	0.1-0.48	Kumagai *et al.* (2008)
		50	48	0.1-0.48	Sugita-Konishi *et al.* (2006)
	wine	83	18	0.05-1.29	Aoyama *et al.* (2010)
		10	80	0.02-0.72	Kumagai *et al.* (2008)
		10	60	0.07-0.72	Sugita-Konishi *et al.* (2006)
Korea	barley	22	23	0.6-0.9	Park *et al.* (2005a,b)
	barley products	32	12	8-11	Park *et al.* (2002a)
	beer	46	4	0.2-0.3	Park *et al.* (2005a,b)
	gochujang	20	15	1.77-8.3	Ahn *et al.* (2011)
	pepper powder	50	44	0.84-33.59	Ahn *et al.* (2011)
	red paprika	192	22	0.84-34.96	Ahn *et al.* (2010)
	rice	148	9	0.9-6	Park *et al.* (2005a,b)
Pakistan	maize	36	78	1.13-7.32	Shah *et al.* (2010)
Qatar	beverages	17	18	0.2-1.47	Abdulkadar *et al.* (2004)
	raisins	7	29	0.93-1.2	Abdulkadar *et al.* (2004)
	rice	9	33	1.23-1.95	Abdulkadar *et al.* (2004)
	spices	12	25	0.86-4.91	Abdulkadar *et al.* (2004)
Taiwan	coffee	10	10	16.5	Chen *et al.* (2011)
Thailand	coffee	64	94	0.6-27	Noonim *et al.* (2008)
Vietnam	coffee	-	-	0.4-1.8	Leong *et al.* (2007)
	rice	100	35	0.08-2.78	Nguyen *et al.* (2007)
		25	8	21.3-26.2	Trung *et al.* (2001)

Because of similar structure with sphingolipid and their bases, toxic mechanism of FUM is suggested to involve disruption of sphingolipid metabolism (Riley *et al.*, 1996). It is well know that FUM are associated with various adverse effects in animals including ELEM, porcine pulmonary oedema syndrome (PPE), hepatotoxicity and nephrotoxicity, and carcinogenicity (for a review see Segvic and Pepeljnjak, 2001). FB_1 is classified as a possible human carcinogen (Group 2B) by IARC (IARC, 1993). In humans, there has been only one suspected foodborne disease outbreak associated with FB_1 in India characterized by abdominal pain, borborygmus and diarrhea (Bhat *et al.*, 1997). A number of epidemiological studies were conducted to reveal the relationships between FUM occurrence and oesophageal cancer. The possible association between FB_1 level and oesophageal cancer incidence was evident from studies conducted in Transkei region of South Africa (Rheeder *et al.*, 1992; Sydenham *et al.*, 1990) and northern China (Sun *et al.*, 2007; Wang *et al.*, 2000). Besides oesophageal cancer, FUM have also been suspected to be the contributory risk factor for human primary liver cancer in China (Sun *et al.*, 2007; Ueno *et al.*, 1997).

Possible link between FUM exposure, folate deficiency and neural tube defect (NTD) has also been speculated for years (for a review see Marasas *et al.*, 2004). It has been hypothesized that FUM on maize products may have a role in the etiology of human NTD occurred in South Texas during 1990-1991 (Hendricks, 1999; Hendricks *et al.*, 1999). However, the suggestive link was not proven until recent findings using mouse model (Gelineau-van Waes *et al.*, 2005; Sadler *et al.*, 2002). A recent population-based case-control study (Missmer *et al.*, 2006) as well as findings of high FUM levels in regions with high NTD incidence (Moore *et al.*, 1997; Ncayiyana, 1986; Rheeder *et al.*, 1992; Venter *et al.*, 1995; Yoshizawa *et al.*, 1994) have further supported this association.

As *F. verticillioides and Fusarium proliferatum* are most commonly found in maize, FUM are detected predominantly in maize (Table 5). Apart from maize, FUM are also detected in other commodities such as sorghum, barley, wheat, and peanut in Asia. The group PMTDI established by JECFA for FB_1, B_2 and B_3 alone or in combination is 2 μg/kg body weight (JECFA, 2011b).

6. Deoxynivalenol

Trichothecenes constitute a family of more than 200 structurally related sesquiterpenoid metabolites produced by a range of fungal genera (Grove, 1996). They have been suspected to be the etiology of 'taumelge treide' (staggering grains), a human illness, that was first observed in Siberia in the 1890s (Pestka and Smolinski, 2005). Alimentary toxic aleukia in Orenburg (West Siberia), stachybotryotoxicosis in Europe and akakaby byo disease (red mould disease) in Japan are the three most important fusariotoxicosis related to trichothecenes in humans (Parent-Massin, 2004). Trichothecenes were also associated with the well-known yellow rain controversy in mid 1970s (Tucker, 2001). They were asserted as bioweapons in Laos (1975-1981), Cambodia (1979-1981), Afghanistan (1979-1981) and the Gulf War (1990-1991) (Ingle *et al.*, 2010). Trichothecenes are classified into four categories, A, B, C and D according to chemical properties and producers. Of the trichothecenes, only those are significant to human health are of concern such as T2-toxin, DON, nivalenol and diacetoxyscirpenol. Although T2-toxin is highly toxic and well know, DON is always of greater concern in the field of food safety because of its strong association with human food supply (Murphy *et al.*, 2006).

DON is also known as vomitoxin due to its strong emetic effects in pigs (Vesonder *et al.*, 1973). It belongs to type B non-macrocyclic trichothecenes. It was first isolated and characterised from *Fusarium*-infected barley in Japan (Yoshizawa and Morooka, 1973). Apart from its emetic effects, DON is also associated with immunological suppression, reproductive and developmental toxicity in laboratory animals (for a review see Pestka, 2010). In Asia, several outbreaks related to human DON intoxication have been documented in China (Luo, 1988), India (Bhat *et al.*, 1989), and Japan (Yoshizawa, 1983) characterised by nausea, vomiting, gastrointestinal upset, dizziness, diarrhoea and headache. Although DON may not constitute significant threat to human health (Sobrova *et al.*, 2010), there is a perceived concern relating to its potential subtle toxicity of chronic low dose exposure as well as its causation of gastroenteritis in humans (Pestka, 2010).

DON is primarily produced by *Fusarium graminearum* and *Fusarium culmorum*, which have been associated with epidemics of *Fusarium* head blight (scab disease) and maize ear rot in Asian cereal-growing areas (Bhat and Miller, 1991). It has been predominantly detected in grains such as barley, maize and wheat (Zinedine *et al.*, 2007). Of the trichothecenes, DON is the most commonly detected with the highest levels in cereal grains (Canady *et al.*, 2001). The widespread and prevalent occurrence of DON in cereals in South America, Canada, China as well as many European countries have shown more than 50% barley, oats and wheat are contaminated by DON with mean concentrations as high as 9 mg/kg in barley (Moss, 2002). In Asia, a number of studies have reported the presence of DON in different food commodities (Table 6). PMTDI of 1 μg/kg body weight was proposed by JECFA based on potential effects of DON on the growth, immune function, and reproduction (JECFA, 2011a).

Table 5. Examples of fumonisins (FUM) contamination in Asian food in the 21st century.

Country	Commodity	Toxins	Number of analysed samples	Frequency (%)	Level (μg/kg or μg/l)	References
China	barley	FUM	25	56	100-1,100	Haubruge *et al.* (2003)
		FUM	40	95	20,100-<40,000	Li (2001)
	fermented tea and plant perfume	FUM	95	-	1->20	Liu (2011)
	barley, maize, wheat	FB_1	73	73	2,470-143,070	Wang *et al.* (2001b)
	kidneys (pig, chicken, duck)	FUM	72	0	-	Liu *et al.* (2008)
	maize	FUM	25	32	150-4,480	Feng *et al.* (2011)
		FB_1	78	32	740[a]	Gong *et al.* (2008)
		FUM	50	26	20,100->40,000	Li (2001)
		FUM	20	75	58-3,251	Li *et al.* (2001)
		FUM	20	75	72-468	Li *et al.* (2001)
		FUM	310	72	0.2-9.06	Li *et al.* (2012a)
		FUM	36	-	500-15,200	Liu *et al.* (2008)
		FB_1	50	38	10,090-31,360	Lu *et al.* (2005)
		FB_1	108	93	16-3,700	Sun *et al.* (2011)
		FB_1	259	89	100-5,700	Sun *et al.* (2007)
		FB_1	23	100	121-2,560	Wang and Zhu (2002)
		FB_1	21	95	200-145,810	Wang *et al.* (2000)
	maize products	FB_1	104	40	220-3,200	Wang *et al.* (2008)
	peanuts and products	FUM	132	-	500-15,200	Liu *et al.* (2008)
	rice	FB_1	49	33	10,360-13,640	Lu *et al.* (2005)
		FB_1	29	90	16-500	Sun *et al.* (2011)
	wheat	FUM	50	94	20,100->40,000	Li (2001)
		FB_1	52	56	7,680-20,120	Lu *et al.* (2005)
	wheat flour	FB_1	16	94	16-400	Sun *et al.* (2011)
Indonesia	maize	FUM	54	65	12.9-2,471	Nuryono *et al.* (2004)
	maize products	FUM	57	67	13-234	Nuryono *et al.* (2002)
Iran	maize	FUM	52	62	2,123-15,447	Ghiasian *et al.* (2006)
		FB_1	38	100	1.19-12.95	Yazdanpanah *et al.* (2005)
		FB_1	49	98	1,190-12,950	Yazdanpanah *et al.* (2006)
	wheat	FUM	82	68	30-235	Chehri *et al.* (2010)
Japan	asparagus	FB_1,B_2	20	10	2-2.8	Aoyama *et al.* (2010)
	barley	FUM	40	0	-	Aoyama *et al.* (2010)
	beer	FB_1	30	33	2-12.9	Aoyama *et al.* (2010)
	buckwheat	FUM	65	0	-	Aoyama *et al.* (2010)
	maize	FB_1	3	67	40-50	Tabata *et al.* (2008)
	maize and products	FUM	512	30	2-1670	Aoyama *et al.* (2010)
	millet	FB_1	30	20	2-6.5	Aoyama *et al.* (2010)
	rice	FUM	31	0	-	Aoyama *et al.* (2010)
		FUM	48	0	-	Kushiro *et al.* (2009)
	soybeans	FUM	82	16	2-8	Aoyama *et al.* (2010)
	wheat	FUM	47	2	>12	Kushiro *et al.* (2009)
Korea	barley food	FB_1	32	6	15-16	Park *et al.* (2002a)
	maize products	FB_1	76	50	13-1210	Kim *et al.* (2002)
		FB_1	47	19	29-122	Park *et al.* (2002a)
	rice	FB_1	88	2	48.2-60.6	Park *et al.* (2005a)
Nepal	maize	FB_1	46	40	>1000	Desjardins and Busman (2006)

[a] Values are expressed as mean.

Table 6. Examples of deoxynivalenol contamination in Asian food in the 21st century.

Country	Commodity	Number of analysed samples	Frequency (%)	Level (μg/kg or μg/l)	References
China	barley	25	12	100-200	Haubruge *et al.* (2003)
	fermented tea and plant perfume	95	-	250-5,000	Liu (2011)
	maize and maize products	7	100	38.286[a]	Cai *et al.* (2011)
		25	-	28-2,533	Feng *et al.* (2011)
		204	50	1.5-590.7	Li *et al.* (2011)
		215	85	0.1-2,511.7	Ma *et al.* (2011)
		338	103	0.3-2,802.8	Wang *et al.* (2010)
		42	100	188.14-6,281.93	Wang *et al.* (2011)
		99	42	-	Xiong *et al.* (2009)
	rice	18	44	0.1-2.1	Ma *et al.* (2011)
	wheat and wheat products	93	90	53-14,000	Li *et al.* (2002)
		192	88	1.6-4,374.4	Li *et al.* (2011)
		125	97	0.1-1,016.8	Ma *et al.* (2011)
		292	100	0.5-2,995.1	Wang *et al.* (2010)
		42	98	-	Xiong *et al.* (2009)
India	rice	50	24	20-500	Murthy *et al.* (2009)
Indonesia	maize and maize products	50	100	47.5-348	Setyabudi *et al.* (2012)
Iran	maize and maize products	60	80	54.4-518.4	Karami-Osboo *et al.* (2010)
Japan	cereals	6	17	170	Tabata *et al.* (2008)
	wheat and wheat products	638	37	50->2,000	Nakatani *et al.* (2011)
		12	25	150-1,100	Tabata *et al.* (2008)
Korea	barley	96	49	3.7-36.8	Ok *et al.* (2009a)
		84	58	22[a]	Ok *et al.* (2009b)
	beer	26	12	22[a]	Ok *et al.* (2009b)
	biscuits	8	38	25[a]	Ok *et al.* (2009b)
	bread	8	38	52[a]	Ok *et al.* (2009b)
	buckwheat	34	0	-	Ok *et al.* (2009b)
	cereals	25	24	24[a]	Ok *et al.* (2009b)
	maize and maize products	125	56	3.6-807.3	Ok *et al.* (2009a)
		136	63	-	Ok *et al.* (2009b)
	malt	33	76	42[a]	Ok *et al.* (2009b)
	minor cereal	50	38	16[a]	Ok *et al.* (2009b)
	rice	68	19	19.15[a]	Ok *et al.* (2009b)
		199	16	3.7-127.9	Ok *et al.* (2009a)
		127	15	26.32[a]	Ok *et al.* (2009b)
		88	3	105-159	Park *et al.* (2005a)
	rye	5	100	95[a]	Ok *et al.* (2009b)
	wheat and wheat products	94	43	3.1-353.6	Ok *et al.* (2009a)
		85	49	49.14[a]	Ok *et al.* (2009b)
Malaysia	noodle	135	81	0.652-1.243	Moazami and Jinap (2009)
Pakistan	maize and maize products	65	9	136-2,625	Khatoon *et al.* (2012)
Qatar	custard powder	6	17	86.43	Abdulkadar *et al.* (2004)
	rice	9	11	142.31	Abdulkadar *et al.* (2004)
	wheat and wheat products	6	33	148.22-182.94	Abdulkadar *et al.* (2004)
Thailand	bread	30	17	140-1,130	Poapolathep *et al.* (2008)
	cereals	30	33	130-390	Poapolathep *et al.* (2008)
	noodle	30	7	170-350	Poapolathep *et al.* (2008)

[a] Values are expressed as mean.

7. Zearalenone

ZEA, previously known as F-2 toxin, is a non-steroidal estrogenic mycotoxin produced by various *Fusarium* species, which are common soil fungi detected in both warm and temperate countries (Bennett and Klich, 2003). Remarkable toxic effect induced by ZEA are primarily associated with its strong oestrogenic activity resulting from the competition with 17β-estradiol (principal hormone produced by human ovary) in binding to cytosolic oestrogen receptors present in uterus, mammary gland, hypothalamus and pituitary gland (Kuiper-Goodman *et al.*, 1987; Takemura *et al.*, 2007), hence, mimicking the actions of endogenous estrogens and disrupting normal estrogenic signalling (Mueller *et al.*, 2004). ZEA is implicated in reproductive disorders in animals, in particular swine, and hyperoestrogenic syndromes in humans (for reviews see Pitt, 2000; Metzler *et al.*, 2010; Zinedine *et al.*, 2007). It has been implicated in several incidents of precocious pubertal changes in children (Kuiper-Goodman *et al.*, 1987; Saenz de Rodriguez, 1984; Schoental, 1983) and possible cervical cancer (Bhatnager *et al.*, 2002). A number of toxicities associated with ZEA have also been reported in laboratory animals including hepatotoxicity (Collins *et al.*, 2006; Conkova *et al.*, 2001; Maaroufi *et al.*, 1996), genotoxicity (Ayed-Boussema *et al.*, 2007, 2008; El-Makawy *et al.*, 2001; Hassen *et al.*, 2007), reproductive and developmental toxicity (Collins *et al.*, 2006), haematotoxicity (Maaroufi *et al.*, 1996; Ostry and Ruprich, 1998), immunotoxicity (Berek *et al.*, 2001; Murata *et al.*, 2003), and carcinogenicity (Ahamed *et al.*, 2001; Becci *et al.*, 1982; El-Makawy *et al.*, 2001; Tomaszewski *et al.*, 1998). Compare to those mycotoxins mentioned above, impact of ZEA is largely associated with animal health instead of human.

ZEA is produced mainly by *F. graminearum*, *Fusarium clumorum*, *Fusarium equiseti* and *Fusarium crookwellense*, which are regular contaminants in cereal crops worldwide (Maragos, 2010). In Asia, a number of studies have reported the detection of ZEA in corn, barley, oats, wheat, sorghum, millet and rice (Table 7). The PMTDI established by JECFA is 0.5 μg/kg body weight (JECFA, 2000).

8. Situation in China

China is the most populous country in the world with a population of over 1.3 billion. This country located between latitudes 18° and 54°N of the equator (Figure 1). The extensive and complex topography in this nation constitute to wide variation of climate and environmental conditions from region to region. It is not surprising that there are more than one climate zones in China ranging from alpine-cold zone in the north to tropical zone in the south. Different climate zones provide various optimal environments for the growth of mycotoxins-producing fungi. In China, mycotoxins contamination have been monitored and investigated for more than 20 years. Mycotoxin levels vary among provinces in different climate zones. Generally, southern China exhibits a more serious mycotoxins problem because of warm temperature and heavy rain, which favour the growth of fungi. Due to the increasing evidence regarding health risk of mycotoxins exposure, mycotoxins contamination in food and feedstuffs, in particular AFLs, OTA, FUM, DON and ZEA, have been continuously monitored in various provinces in China.

AFLs have been extensively studied and monitored in China because of its potential etiological role in liver cancer, which is one of the most common cancers in this developing country. In China, the first cohort study was initiated in 1982 reporting a positive linear correlation between AFB_1 levels in food and mortality rates of primary hepatocellular carcinoma in Guangxi province (Yeh *et al.*, 1989). A prospective study monitoring more than 18,200 participants over 3.5 years in Shanghai further provided the most direct evidence for an etiological role of AFLs exposure as well as a confounding factor for hepatitis B in liver cancer (Ross *et al.*, 1992). Consistent findings were also reported in recent years supporting the etiological role of AFB_1 in liver cancer in China (Li *et al.*, 2001; Wang *et al.*, 2001a). According to a number of investigations on AFLs contamination in the 21st century, AFLs contamination occurs mainly in cereal, maize and peanut in almost every province with levels above the Chinese maximum limit (20 μg/kg) for some samples (Table 3). In 2012, there was an aflatoxin-tainted milk scandal reporting AFM_1 level 1.4 times higher than the Chinese national maximum limit (He, 2012). A batch of cow milk was contaminated by AFM_1 as a result of the consumption of contaminated feed by dairy cattle. Two weeks later, a recall of cooking oil contaminated with AFLs was ordered in Guangdong province (Lu, 2011). Although the whole batch of contaminated milk was destroyed before being released to the market and the cooking oil was recalled, these have already raised the alarm on current mycotoxins problem linked with human food supply in China. Continuous detection of AFLs in foodstuffs during the last ten years indicates AFLs exposure remains a severe problem in this country, in particular Guangxi province, where high incidence of liver cancer is reported.

Comparing to AFLs, contamination associated with another common storage mycotoxin OTA is less severe. OTA contamination is mainly reported for cereal products in China ranging from 0.01 to 158.7 μg/kg (Table 4). Although the overall incidence rate of OTA contamination (~50%) is lower than that of AFLs, OTA levels of a number of analysed samples exceeded the Chinese maximum limit. However, due to limited studies on OTA contamination in China, it is not sufficient to reveal the actual situation of OTA contamination in foodstuffs and its potential impact on public health in this country.

Table 7. Examples of zearalenone contamination in Asian food in the 21st century.

Country	Commodity	Number of analysed samples	Frequency (%)	Level (µg/kg or µg/l)	References
China	barley	25	96	25-270	Haubruge *et al.* (2003)
	cereals	46	63	0.42-220.7	Meng *et al.* (2010)
	Chinese medicinal plants	103	9	18.7-211.4	Zhang *et al.* (2011)
	fermented tea and plant perfume	95	-	40-1000	Liu (2011)
	functional food	175	5	11.09-26.54	Wu *et al.* (2011)
	maize and maize products	7	100	1.1[a]	Cai *et al.* (2011)
		25	60	60-1,239	Feng *et al.* (2011)
		48	100	18-730	Li *et al.* (2004)
		204	42	1.6-4,808.7	Li *et al.* (2011)
		215	69.3	0.1-1,151.4	Ma *et al.* (2011)
		347	88	0.3-942.6	Wang *et al.* (2010)
		41	100	4.79-1,219.9	Wang *et al.* (2011)
		42	62	-	Xiong *et al.* (2009)
	rice	18	39	0.1-0.3	Ma *et al.* (2011)
	wheat and wheat products	93	52	5-1,400	Li *et al.* (2002)
		33	100	14-470	Li *et al.* (2004)
		192	23	1.7-3,425.1	Li *et al.* (2011)
		41	68	-	Xiong *et al.* (2009)
		125	73	0.1-52	Ma *et al.* (2011)
		292	53	0.3-55.01	Wang *et al.* (2010)
India	rice	50	12	20-300	Murthy *et al.* (2009)
Indonesia	maize and maize products	89	36	5.5-526	Nuryono *et al.* (2005)
Iran	barley	20	20	136[a]	Rashedi *et al.* (2011)
	bread	18	0	-	Yazdanpanah *et al.* (2012)
	cheese snacks	19	100	371-1,471	Oveisi *et al.* (2005)
	maize and maize products	8	25	150[a]	Rashedi *et al.* (2011)
		19	100	36-889	Oveisi *et al.* (2005)
		40	8	100-212	Hadiani *et al.* (2003)
		18	0	-	Yazdanpanah *et al.* (2012)
	rice	18	0	-	Yazdanpanah *et al.* (2012)
		20	10	89[a]	Rashedi *et al.* (2012)
	silage	12	17	140[a]	Rashedi *et al.* (2011)
	wheat and wheat products	175	9	39-104	Karami-Osboo and Mirabolfathy (2008) as cited in Yazdanpanah *et al.* (2012)
		15	0	-	Rashedi *et al.* (2012)
		14	0	-	Rashedi *et al.* (2011)
		18	0	-	Yazdanpanah *et al.* (2012)
Korea	barley	30	33	14-171	Park *et al.* (2002b)
		50	16	<16	Thongnrussamee *et al.* (2008)
	barley and barley products	32	38	3.4-120	Park *et al.* (2002b)
	maize and maize products	18	22	3.4-5.8	Park *et al.* (2002b)
		38	24	41-909	Thongnrussamee *et al.* (2008)
		47	19	3.6-84	Park *et al.* (2002b)
	dried fruits and veggie	37	0	-	Park *et al.* (2002b)
	rice	88	3	21.7-47	Park *et al.* (2005a)
		80	9	<16	Thongnrussamee *et al.* (2008)
Pakistan	maize and maize products	65	1	1,250	Khatoon *et al.* (2012)
Qatar	maize and maize products	5	60	3.8-6.81	Abdulkadar *et al.* (2004)
	oats	5	20	1.18	Abdulkadar *et al.* (2004)
	rice	9	33	0.18-1.41	Abdulkadar *et al.* (2004)
	wheat and wheat products	4	100	0.21-2.1	Abdulkadar *et al.* (2004)
Taiwan	maize and maize products	7	57	7.9-9	Liao *et al.* (2009)

[a] Values are expressed as mean.

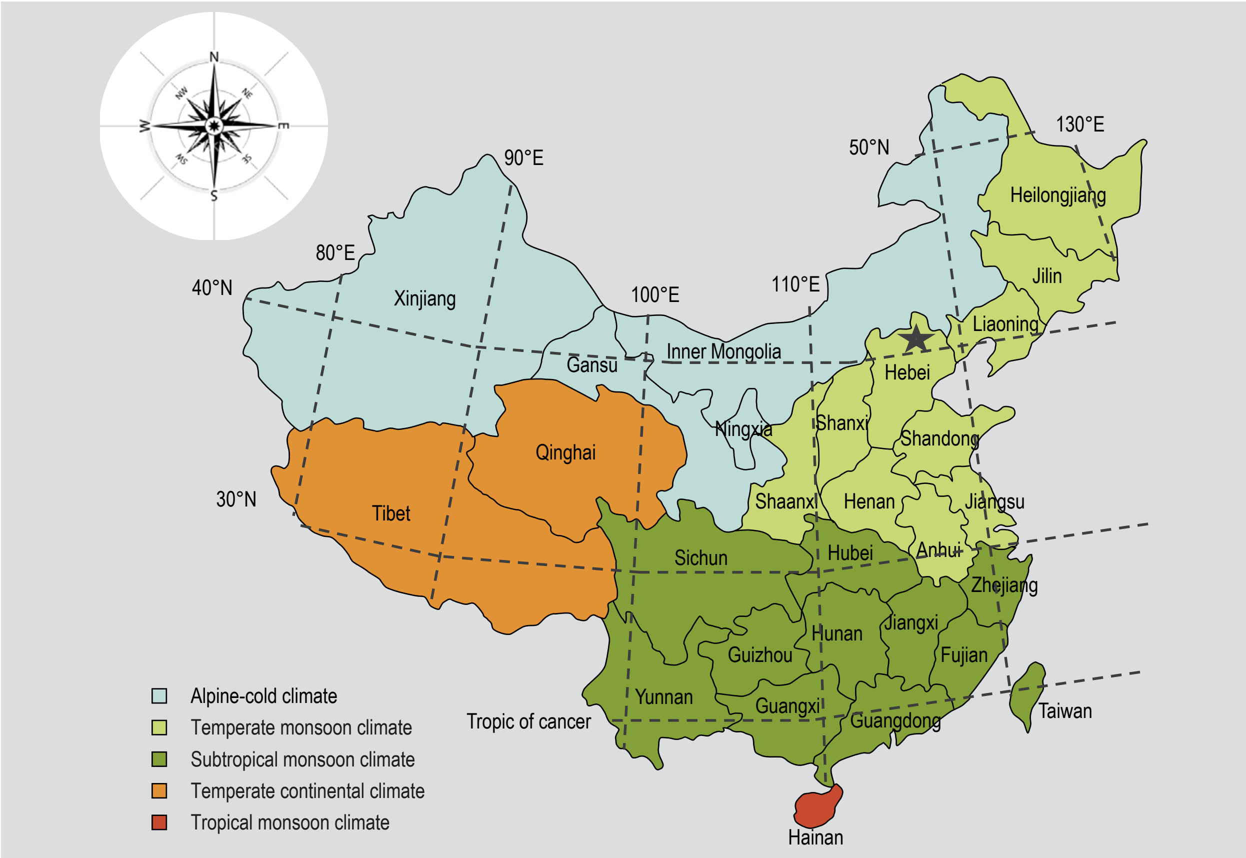

Figure 1. Geographical and climate map of China.

Similar to AFLs, FUM have received extensive concern among *Fusarium* toxins. A number of studies have reported high incidence of FUM contamination in foodstuffs in regions with high oesophageal cancer incidence in China (Chu and Li, 1994; Sun *et al.*, 2007; Wang *et al.*, 2000, 2008; Yoshizawa *et al.*, 1994). These findings indicate a possible contributing role of FUM in human oesophageal cancer in this country. In recent years, FUM have been detected extensively in maize and cereals with incidence rate more than 90% with levels up to 140 mg/kg surpassing the maximum limits set by the European Union (4 mg/kg) or USFDA (2 mg/kg) (Table 5). In addition, simultaneous contaminations of AFLs and FUM in foodstuffs have also been reported in high-incidence area for human liver cancer and oesophageal cancer in China suggesting the contribution of the co-exposure of AFLs and FUM to the etiology of human chronic diseases (Li *et al.*, 2001; Sun *et al.*, 2011). Despite the frequent occurrence of FUM in human foodstuffs with levels exceeding the foreign maximum limits together with its potential etiological role in oesophageal cancer in China, currently there is no Chinese maximum limits for the presence of FUM in human foods. Effort on further investigation and monitoring as well as implementation of maximum limit with regard to FUM will be necessitated for the sake of public health in this populous country.

Apart from FUM, other *Fusarium* toxins, DON and ZEA, have also been monitored but to a lesser extent. In China, epidemic of *Fusarium* head blight occurs frequently in wheat and barley growing regions in the middle and downstream valleys of the Yangtze River as well as in the Heilongjiang province in northeast areas (Zhang *et al.*, 2007). People in the northern region are frequently exposed to DON mainly via consumption of contaminated wheat and barley, which are the major food staples in northern China. DON has been implicated in acute gastrointestinal illness (red mould intoxication) involving tens of thousands of victims in a number of provinces in China during the past decades (Li *et al.*, 1999; Luo, 1994; Luo *et al.*, 1987; Yang, 1992). A comparative study also suggested the association between the level of DON in contaminated cereals and the incidence of oesophageal cancer in China (Luo *et al.*, 1990). During the last 10 years, DON has been detected widely in barley, maize and wheat throughout the country. The latest multi-cities survey on the occurrence of DON in cereal-based products showed that more than 80% analysed samples were DON positive with levels ranging between 0.1 and 2,511.7 μg/kg (Ma *et al.*, 2011). The contamination levels of DON in a number of samples even exceeded the Chinese maximum limit (1000 μg/kg). In general, there is a more severe DON contamination of maize and cereal products from the central region of China with temperate and subtropical monsoon climates.

Due to the estrogenic properties, ZEA has attracted recent attention. As both DON and ZEA are mainly produced by *F. graminearum* and *F. culmorum*, ZEA has been detected simultaneously with DON in maize and cereal products in China (Haubruge *et al.*, 2003; Li *et al.*, 2002, 2011; Ma *et al.*, 2011; Wang *et al.*, 2010). Based on recent surveys on the occurrence of ZEA in foodstuffs, there is a high incidence of ZEA contamination particularly in maize and wheat products (Table 7). ZEA was detected in 40-100% of analysed samples collected from different provinces with overall level exceeded the Chinese maximum limit (60 μg/kg). Similar to DON, provinces locating in the north-eastern and central China are the most severe regions.

It is evident that residents in this populous nation have been exposed to various mycotoxins simultaneously in a frequent and chronic manner. Due to the serious impact of mycotoxins contamination on human health, the Chinese government has already imposed the Food Hygiene Law of the People's Republic of China and guidances such as the 'National food safety standard on maximum levels of mycotoxins in foods GB2761-2011' (Table 8) and the 'Code of practice for the prevention and reduction of mycotoxin contamination in cereals GB/T22508-2008' (SAC, 2008). Currently, control measures including good agricultural practices and good manufacturing practices for preventive strategies from pre-harvest to post-harvest level have been implemented (SAC, 2008). The hazard analysis critical control point, which is a complementary management system, has also been recommended for mycotoxin control in different levels ranging from agriculture, processing, storage and distribution (SAC, 2008). To minimize the risk of mycotoxins contamination, apart from preventive measures, further effort should also be devoted to the development of decontamination process. Extensive survey on mycotoxin contamination in foodstuffs as well as human biomarker monitoring should also be conducted for risk management in China. In 2011, the Chinese Academy of Agricultural Science has participated in the international MycoRed project so as to strengthen the cooperation in Asian region tackling mycotoxin problems (http://www.mycored.eu/page/news/66/whate).

9. Conclusions

Recent investigations on the occurrence of mycotoxins in human foodstuffs have evidenced the seriousness of mycotoxins problem among Asian countries nowadays. In China, due to extensive and complex topography, diverse climate zones have provided various optimal environments for the growth of mycotoxins-producing fungi. AFLs and

Table 8. Chinese maximum levels of mycotoxins in foods (MOH, 2011).

Mycotoxins	Food type	Chinese maximum level (μg/kg or μg/l)
Aflatoxin B_1	maize and maize products	20
	paddy, brown rice and rice	10
	wheat, barley, and other grains	5
	wheat noodle, oatmeal, other shelled grains	5
	fermented bean products	5
	peanut and products	20
	other cooked nuts and seeds	5
	vegetable fat (except peanut oil, corn oil)	10
	peanut oil, corn oil	20
	condiments (grains are the main ingredients)	5
	elder and infant formulas (mainly for soybean and soybean protein products)	0.5 (by powdery product)
Aflatoxin M_1	milk and dairy products	0.5
	elder and infant formulas (mainly for soybean and soybean protein products)	0.5 (by powdery product)
Deoxynivalenol	maize and maize products	1000
	barley, wheat, oatmeal, wheatmeal	1000
Patulin	fruit products (based on apple and haw)	50
	fruit and vegetable juice	50
	wines	50
Ochratoxin A	cereals and products	5
	legumes	5
Zearalenone	wheat and flour	60
	maize and flour	60

OTA have been predominantly detected in southern part of China with Guangxi as the most severe province, while *Fusarium* toxins in northern and central part of China. Although the Chinese government has implemented laws and guidances in respond to mycotoxins contamination, continuous effort is necessitated to minimise the mycotoxin levels and safeguarding the health of general public in this continent.

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