Current research and prevention of aflatoxins in China

E. Tumukunde, G. Ma, D. Li, J. Yuan, L. Qin and S. Wang*

Key Laboratory of Pathogenic Fungi and Mycotoxins of Fujian Province and School of Life Sciences, Fujian Agriculture and Forestry University, Fuzhou 350002, China P.R.; wshmail@m.fafu.edu.cn

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Abstract

Since their discovery in the 1960s, aflatoxins were found to have a considerable impact on the health of humans and animals as well as the country's economy and international trade. Aflatoxins are often found in nuts, cereals and animal feeds, which has a significant danger to the food industry. Over the years, several steps have been undertaken worldwide to minimise their contamination in crops and their exposure to humans and animals. China is one of the largest exporters and importers of food and animal feed. As a result, many studies have been carried out in China related to aflatoxins, including their distribution, pollution, detection methods, monitoring, testing and managing. Chinese scientists studied aflatoxins in microbiological, toxicological, ecological effects as well as policies relating to their controlling. China has thus put into practice a number of strategies aiming at the prevention and control of aflatoxins in order to protect consumers and ensure a safe trade of food and feed, and the status and enlargement of these strategies are very important and useful for many consumers and stakeholders in China. Therefore, this article aims at the detriment assessments, regulations, distribution, detection methods, prevention and control of aflatoxins in China. It equally provides useful information about the recent safety management systems in place to fight the contamination of aflatoxins in food and feed in China.

Keywords: aflatoxins, *Aspergillus species*, region, distribution, prevention and control

1. Introduction

Aflatoxins are among the major mycotoxins (Sun *et al.*, 2017) and they are widely known as a group of cancer-causing chemicals and highly toxic secondary metabolites produced by members of fungal *Aspergillus genus* (Wild and Turner, 2002; Williams *et al.*, 2004), such as *Aspergillus parasiticus*, *Aspergillus flavus* and *Aspergillus nominus* (Al-Gabr *et al.*, 2013; Rawal *et al.*, 2010). A research conducted by Ma *et al.* (2014) reported that food safety issues caused by mycotoxins have caught a large attention worldwide and aflatoxins are known as the main representative toxins. It was also indicated that these aflatoxins can cause serious health issues to both humans and animals. However, the toxic properties of aflatoxins manifest themselves in a diverse way based on the dose, test system and duration of exposure (Dhanasekaran *et al.*, 2011; Khlangwiset *et al.*, 2011). Recent studies indicate that the aflatoxin-producing fungus *A. flavus* is one of the main causes of invasive and non-invasive aspergillosis (Amaiike and Keller, 2011;

Gonçalves *et al.*, 2012; Hedayati *et al.*, 2007; Yu *et al.*, 2005) and aflatoxicosis (Cardwell and Henry, 2004; Farombi, 2006). The former is an infection caused by inhalation of spores of the aflatoxin-producing fungus *A. flavus* through the respiratory tract, while the latter is caused by the ingestion of aflatoxins (Fouad *et al.*, 2019; Liu *et al.*, 2016). Aflatoxin contamination can occur either in the field or during storage or during transit of crops (Santos Pereira *et al.*, 2019; Zhang *et al.*, 2015). However, the pathogenicity of aflatoxin-producing fungi in agricultural commodities increases with the presence of insects and stress on the host (Agrios, 2005; Diao *et al.*, 2015). It has also been reported that high temperatures and extreme moisture conditions of storage for legumes and grains increase the amount of aflatoxins produced by the fungal species (Amaiike and Keller, 2011; Li *et al.*, 2014).

Another study reported the aflatoxins as a highly contaminating toxin in food crops, such as groundnuts and their products, dried fruit, tree nuts, spices, rice, cottonseed,

wheat and maize under particular temperature and moisture conditions (Barrett, 2005; Li *et al.*, 2009a). When these foods are contaminated, it may result in a significant economic loss. Annual destruction of contaminated food crops was anticipated to be 25% worldwide (WHO, 2018). However, these mycotoxins are especially dominant in some parts of the world, such as Sub-Saharan Africa and Southeast Asia where large amounts of the aforementioned food crops are consumed. In these areas, there is also a high humidity which favours proliferation of aflatoxins-producing fungi (Khlanguis *et al.*, 2011; Liu and Wu, 2010; McGlynn and London, 2005). In recent years, aflatoxin contamination has become quite a daunting problem for the agricultural industry in China. As a result, many cases of exposure to aflatoxins with a higher incidence of human liver cancer has been reported in different parts of the country (Liao *et al.*, 2009; Wang and Liu, 2007b). In China, various universities and institutions have conducted studies on aflatoxins. Thus, this research reviews the current progress on aflatoxin prevention and management addressing the safety of both living organisms and food in China.

2. Geographical location and climate of China

To address the present situation of aflatoxin contamination and prevention in China, the geography, economy, and population of China must be understood (Al-Tamimi, 2017; CIA, 2019; Liu and Diamond, 2005; Stadler, 2015). China is located between the 18° and 54° N latitudes of the equator (Goss *et al.*, 2014). Given the vast and complex topography of the country, both the environmental and climate conditions differ from one region to the other (Lin *et al.*, 2015; Zheng *et al.*, 2010). Therefore, the dissimilarity of climate in the regions provides different favourable environments for aflatoxin production and the growth of aflatoxin-producing fungi. In the 21st century, aflatoxin contamination is mostly observed in peanuts, maize and cereals in nearly every province of China (Woo and El-Nezami, 2014). In general, serious problems caused by aflatoxins are observed in the southern region of China, due to heavy rain and warm temperatures that allow the growth of aflatoxin-producing fungi (Li *et al.*, 2001; Wu *et al.*, 2016b). A high rate of liver cancer, which is caused by aflatoxin exposure, was particularly reported in Guangxi province (Li *et al.*, 2001; Woo and El-Nezami, 2014). However, due to the increase of aflatoxin contamination in food crops or feedstuffs and the escalating health risk of exposure to these toxins, several strategies to investigate and monitor aflatoxins have been initiated in China. These were implemented to protect consumers from exposure and to ensure food safety (Zhang *et al.*, 2013). In the light of the above information, it is clear that the optimal conditions for aflatoxins production differ from one location to another, owing to China's huge landscape with different climate zones.

3. Aflatoxin regulation in China

The International Agency for Research on Cancer (IARC) recently highlighted aflatoxins carcinogenicity and classified them as group 1 carcinogenic – being able to influence the DNA structure of exposed organisms (Hell *et al.*, 2008). Aflatoxins were initially identified in the 1960s in the UK after more than 100,000 turkey poultts died of toxins from mould-contaminated peanut meal (Monson *et al.*, 2014; Wannop, 1961; Wogan and Goldblatt, 1969). The toxin was then named 'aflatoxin' after its fungal producer *A. flavus* (Negash, 2018). To date, about 18 types of aflatoxins have been discovered, but only 4 – aflatoxin B₁, B₂, G₁ and G₂ (AFB₁, AFB₂, AFG₁, and AFG₂) – are studied extensively and are well-known for their toxicological effects (Bakirdere *et al.*, 2012; Mzungu *et al.*, 2018; Xie *et al.*, 2016). The letters B and G refer to their fluorescence colour under ultraviolet light (B for Blue, G for Green) and the numbers represent their relative migration distance on a thin layer chromatographic plate (Kew, 2013; Liu *et al.*, 2013; Ventura *et al.*, 2004). These toxins are highly toxic and are usually found in all the main food crops such as grains, nuts, and their derived products. Thus, once humans or animals are more exposed to contaminated foods, it may lead to severe health issues (WHO, 2018). AFM₁ and AFM₂ are other known aflatoxins which are the metabolites of AFB₁ and AFB₂ respectively, and they are found in the milk of animal exposed to contaminated food. Consequently, humans can also be exposed to these aflatoxins through intake of milk and their derived products initially collected from the infected animal (Bianco *et al.*, 2012; Goldblatt, 2012). Among all these toxins aflatoxin B₁ is the most abundant toxin and the most intoxicating substance (Li *et al.*, 2018).

Due to potent carcinogenic and toxic properties of aflatoxins, many of the developed countries established very strict regulations that limit the highest allowable aflatoxin concentration in feed and food. Some of the developing countries, such as Mexico and China, have also set up rules consistent with those in the United States for both trading and human consumption (Table 1). In Asia and the Pacific, China has been reported as the country with the most detailed and extensive regulations for mycotoxins (Zhao *et al.*, 2013). The limits in AFB₁ contents in some foodstuff in China are outlined in Table 1. Typical examples include but are not limited to maize, peanuts and their derived products (≤ 20 $\mu\text{g/kg}$), edible vegetable oil, rice, and irradiated rice (≤ 10 $\mu\text{g/kg}$) as well as vinegar, beans, fermented foods, starch products, fermented wine, pastry biscuit (≤ 5 $\mu\text{g/kg}$). Furthermore, the limit of AFM₁ in dairy products and milk is ≤ 5 $\mu\text{g/kg}$. These regulations were set in order to protect the consumer against the detrimental effects of aflatoxins (Liu *et al.*, 2006b). In 2003, more than 99 countries had established regulations relating to mycotoxins in food and feed. Most of these countries have at least set up regulatory limits for AFB₁ content, while some of them

have established limits for the total of the 4 main aflatoxins (AFT = AFB₁ + AFB₂ + AFG₁ + AFG₂) (Guzmán-de-Peña and Peña-Cabriaes, 2005). Hence, the current worldwide allowed levels of both AFB₁ and AFT are in the range of 1~20 µg/kg and 0~35 µg/kg, respectively, consistent with the aforementioned Chinese regulations (Ding *et al.*, 2012; Van Egmond and Jonker, 2004).

In summary, it is believed that by imposing certain regulations aiming at the limitation of the total amount of aflatoxins allowed in feed and foodstuffs in China, the efforts could significantly reduce potential exposure to aflatoxins and improve the safety of consumers in the country.

4. The main fungal species producing aflatoxins in China

A. flavus, *A. parasiticus* and *A. nomius* are the known fungal species that are able to produce aflatoxins. However, it was also discovered that about 20 different types of aspergilli, such as *Aspergillus nidulans*, and some other species of *Bipolaris*, *Chaetomium*, *Monocillium*, and *Farrowia* can also produce sterigmatocystin (ST) which was subsequently identified as a highly toxic intermediate in the AFB₁ biosynthetic pathway (Heidtmann-Bemvenuti *et al.*, 2011; Zheng *et al.*, 2012). It was also uncovered that the aflatoxin cluster is conserved to variable levels in several types of fungi such as *Aspergillus oryzae* (Tominaga *et al.*, 2006), *Emericella astellata*, *Aspergillus ochraceoroseus* (Cary *et al.*, 2005), *Aspergillus versicolor* (Viegas *et al.*,

Table 1. Maximum aflatoxin concentration allowed in foodstuffs by regulations some countries.

Countries	Foodstuffs	Aflatoxins ¹	Limit levels of AFs (µg/kg)	References
China	Peanut and maize (their derivatives/products), irradiated peanut, peanuts oil,	AFB ₁	≤20	Moss, 2002; Van Egmond and Jonker, 2004
	Edible vegetable oil, rice, and irradiated rice	AFB ₁	≤10	
	Vinegar, beans fermented foods, starch products,	AFB ₁	≤5	
	fermented wine, pastry biscuit, salad oil, soya bean sauce, bread, fermented bean products, butter cake, grain paste, other grains, both food additives alpha-amylase and glucoamylase			
	Dairy product and milk	AFM ₁	≤0.5	
New Zealand/ Australia	Tree nuts and peanuts	AFT	≤15	Wu <i>et al.</i> , 2016a
European Union	Dried fruit, groundnuts, cereals, nuts and all with their products	AFB ₁	≤2	Juan <i>et al.</i> , 2008; Moss, 2002
		AFT	≤4	
Singapore	Nuts, corn, cereal and their products	AFT	≤5	Wu <i>et al.</i> , 2016a
Brazil	Maize, peanuts and their product	AFT	≤20	Bakirdere <i>et al.</i> , 2012
Canada	Nuts and their products	AFT	≤15	Van Egmond and Jonker, 2004
South Africa	All foods	AFB ₁	≤5	Wu <i>et al.</i> , 2016a
		AFT	≤10	
USA	All kinds of food	AFT	≤20	Liu <i>et al.</i> , 2006b
Japan	All kinds of food	AFB ₁	≤10	Ding <i>et al.</i> , 2012
Turkey	Peanut and other nuts, hazelnut, spices, dried fruits oily seed and their products	AFB ₁	≤5	Set and Erkmen, 2010; Van Egmond and Jonker, 2004
		AFT	≤10	
		AFB ₁	≤2	
Mexico	Cereals and their product	AFT	≤4	Van Egmond and Jonker, 2004
		AFT	≤20	
		AFT	≤12	
Malaysia	Corn flour for tortilla	AFT	≤12	Liu <i>et al.</i> , 2006b
India	All types of food	AFT	≤35	
	All types of food	AFT, AFM ₁	≤30	Moss, 2002

¹ AFT = aflatoxins B₁ + G₁ + B₂ + G₂; AFB₁ = aflatoxin B₁; AFM₁ = aflatoxin M₁.

2013), and other vaguely related fungi, such as *Dothistroma* (Zhang *et al.*, 2007). Although all these fungi have high levels of similarities in terms of conservation of their gene cluster, it was revealed that only *Aspergilli* can produce both aflatoxin and its allied sterigmatocystin (Amaike and Keller, 2011). Some of the aforementioned species have also been identified in China. For example, a study by Sun *et al.* (2017) indicated that *A. versicolor* and *A. nidulans* are the major mycotoxigenic fungi contaminating rice in Henan and Hubei provinces of China. The study by Zhang *et al.* (2017) isolated aflatoxin-producing *Aspergillus* species from 600 soil samples obtained from the 4 agro-ecological areas in China. From these soil samples, 344 *Aspergillus* strains were isolated. Among these strains, 20 (5.8%) were found to be *A. parasiticus* and the remaining 324 strains (94.2%) were found to be *A. flavus*. Thus, *A. flavus* was the most predominant species among the aflatoxigenic fungal samples collected from all the districts. A previous study by Gao *et al.* (2007) suggests that *A. flavus* is the primary source of the fungal infection in maize, and responsible for more than 99% of all the contamination cases that have been recorded so far in the northeast region of the country.

A recent study examined and quantified several types of fungal species present in drinking water. Samples were collected from 15 different sites and water systems in the city of Xiamen, China. The authors showed that the predominant fungi were *Aspergillus* spp., *Phialophora* spp., *Fusarium* spp., *Trichoderma* spp., *Penicillium* spp., and included *A. flavus* and *A. parasiticus*, the last two being the major aflatoxigenic fungi identified in their study (Al-Gabr *et al.*, 2014). The recent study by Su *et al.* (2018) investigated the occurrence of fungi in root herbs focusing on fungi that are capable to produce aflatoxins. They collected 48 samples of eight root herbs from Yulin and Anguo medicinal products markets and found that all these samples were contaminated with fungi, whereby a total of 1,844 isolates were detected. All these fungi belonged to 24 different genera including *Aspergillus*, *Arthrinium*, *Alternaria*, *Chaetomium*, *Coprinellus*, *Mycocladius*, *Cladosporium*, *Fusarium*, *Lichtheimia*, *Wallemia*, *Hyphopichia*, *Myceliophthora*, *Paecilomyces*, *Eurotium*, *Penicillium*, *Pichia*, *Phanerochaete*, *Pestalotiopsis*, *Phoma*, *Rhizopus*, *Trichoderma*, *Syncephalastrum*, *Mucor* and *Trichosporon*. The study further revealed that both the *Penicillium* and *Aspergillus* genera included potential toxigenic species with an occurrence of 25 and 10%, respectively. From all tested samples of eight root herbs (48 samples), the occurrence of aflatoxins was found to be 37.50%, whereby the species with great potential of aflatoxin production were *A. flavus* and *A. parasiticus*. AFB₁ and AFB₂ are normally produced by *A. flavus* toxigenic strains, while most of *A. parasiticus* strains produce all four aflatoxin types (Kew, 2013). The two other aflatoxins AFM₁ and AFM₂ are produced by hydroxylation of AFB₁ and AFB₂, respectively, and they

are linked to casein proteins (Bianco *et al.*, 2012; Motawee and McMahon, 2009; Prandini *et al.*, 2009).

In general, different aflatoxins and aflatoxin producing fungal species occur in several regions of China, and most of them can easily be isolated and identified from samples. Table 2 lists the major aflatoxigenic *Aspergillus* species and the types of aflatoxins they produce as well as properties of aflatoxins.

5. Conditions for aflatoxins production in China

Aflatoxin production is influenced by several factors, including chemical, biological and physical ones. The criticality of the chemical factors is mostly based on the nature of the substrate being involved as well as the composition of the air. The physical factors, however, consist of moisture and temperature, whereas the biological factors include those relating to the host species (Al-Gabr *et al.*, 2013; Liu *et al.*, 2017; Yin *et al.*, 2008). Some of the factors that influence aflatoxin production in China were studied by Lu *et al.* (2010). They found that numerous enzymes, such as peroxidases, dehydrogenases, cyclases, oxidoreductase and methyltransferases have a key function in aflatoxin biosynthesis. The action of these enzymes could directly affect the aflatoxin yield. Alternatively, Yu (2012) indicated that the most essential environmental factors are the plant metabolites, water activity, temperature, nitrogen and carbon source. It was also confirmed that the environmental conditions play an important role in aflatoxin contamination during, before and after harvest of crops (Ding *et al.*, 2012). A study conducted by Liu *et al.* (2016) analysed the effects of several nutrients on AFB₁ production by fungi. The authors found that some nutrients, i.e. vitamins, amino acids, minerals (such as zinc), energy source (especially in the form of starch) and fatty acids are also essential for aflatoxin production. These findings were supported by those from an earlier study conducted by Ma *et al.* (2015) who already indicated that substrate content and the composition of nutrients could be the key factor affecting AFB₁ production. Another research added that aflatoxin production in water can also be affected by different environmental factors, such as nitrogen, micronutrients, macronutrients, carbon, pH and temperature (Al-Gabr *et al.*, 2013).

The temperature range for aflatoxin production by the highly aflatoxin-producing fungi *A. parasiticus* and *A. flavus* species is between 12 to 41 °C, whereby the optimum production occurs in the range between 25 and 32 °C. Thus, production of aflatoxins decreases when the temperatures approach 37 °C (Dwivedi *et al.*, 2013; O'Brian *et al.*, 2007; Yu, 2012). However, the rate of aflatoxins biosynthesis is higher when the temperature is greater than 27 °C and when moisture and humidity levels are above 14 and 62%, respectively (Royes and Yanong, 2002). It has also been

Table 2. *Aspergillus* species and aflatoxins properties.¹

Type of aflatoxin	Major producing species/metabolites	Mol. Formula	Mol. Wt (g/mol)	Melting point (°C)	Optical rotation [α] _D	Description	UV absorption		Fluorescence emission (mμ)	References
							λ _{max} (nm)	ε (l/molCm)		
AFB ₁	<i>A. flavus</i> ; <i>A. parasiticus</i> ; <i>A. nomius</i>	C ₁₆ H ₁₂ O ₆	312.3	268-269 decomposed	-558° in chloroform	Change from colourless to pale-yellow crystals. Emits strong blue fluorescence under UV light.	265; 223; 362	13,400; 25,600; 21,800	425	Andersen <i>et al.</i> , 2012; Cole <i>et al.</i> , 2003; Humans <i>et al.</i> , 2002; Iqbal <i>et al.</i> , 2017; Kumar, 2018; O'Neil <i>et al.</i> , 2001
AFB ₂	<i>A. flavus</i> ; <i>A. parasiticus</i> ; <i>A. nomius</i>	C ₁₇ H ₁₄ O ₆	314.3	286-289 decomposed	-492° in chloroform	Colourless to pale-yellow crystals. Emits blue fluorescence under UV light.	265; 363;	11,700; 23,400	425	Andersen <i>et al.</i> , 2012; Cole <i>et al.</i> , 2003; Iqbal <i>et al.</i> , 2017; Kumar, 2018
AFG ₁	<i>A. parasiticus</i> ; <i>A. flavus</i> ; <i>A. nomius</i> ; <i>A. niger</i>	C ₁₇ H ₁₂ O ₇	328.3	244-246 decomposed	-556° in chloroform	Colourless to pale-yellow crystals. Emits strong green fluorescent under UV light.	264; 257; 362; 243	10,000; 9,900; 16,100; 11,500	450	Andersen <i>et al.</i> , 2012; Cole <i>et al.</i> , 2003; Iqbal <i>et al.</i> , 2017; Kumar, 2018; O'Neil <i>et al.</i> , 2001
AFG ₂	<i>A. parasiticus</i> ; <i>A. flavus</i> ; <i>A. nomius</i> ; <i>A. niger</i>	C ₁₇ H ₁₄ O ₇	330.3	237-240 decomposed	-473° in chloroform	Colourless to pale-yellow crystals. Strong green-blue fluorescence under UV light.	265; 363	9,700; 21,000	450	Andersen <i>et al.</i> , 2012; Cole <i>et al.</i> , 2003; Iqbal <i>et al.</i> , 2017; Kumar, 2018; O'Neil <i>et al.</i> , 2001
AFM ₁ (metabolite of AFB ₁)	<i>A. flavus</i> ; <i>A. parasiticus</i> ; <i>A. nomius</i>	C ₁₇ H ₁₂ O ₇	328.3	299 decomposed	-280° in dimethylformamide	Colourless to pale-yellow crystals. Emits strong blue-violet fluorescence under UV light.	357; 267; 244	19,950; 12,950; 9,100	430	Andersen <i>et al.</i> , 2012; Cole <i>et al.</i> , 2003; Holzapfel <i>et al.</i> , 1966; Iqbal <i>et al.</i> , 2017; Stubblefield <i>et al.</i> , 1972
AFM ₂ (metabolite of AFB ₂)	<i>A. flavus</i> ; <i>A. parasiticus</i> ; <i>A. nomius</i>	C ₁₇ H ₁₄ O ₇	330.3	293 decomposed	N/A	Colourless to pale-yellow crystals. Emits strong violet fluorescence under UV light.	357; 264; 244	21,250; 11,650; 10,100	N/A	Andersen <i>et al.</i> , 2012; Holzapfel <i>et al.</i> , 1966; Stubblefield <i>et al.</i> , 1972

¹ ε = extinct coefficient; Mol. wt = molecular weight; λ_{max} = maximum wavelength; N/A = not available.

shown that different levels of water activity (0.99 and 0.93 a_w) can affect both growth and aflatoxin production in *A. flavus* at 37 °C (Zhang *et al.*, 2014). Previous studies on *A. parasiticus* revealed that the combination of water activity (0.90~0.99 a_w) and temperature (17~42 °C) affects aflatoxin biosynthesis (Schmidt-Heydt *et al.*, 2010). A study conducted by Liu *et al.* (2017) on *A. flavus* showed that fungal growth in shelled peanuts and its aflatoxin production were also affected by the combination of temperature and water activity within a similar range of 15~42 °C and 0.85~0.99 a_w , respectively. However, the optimal growth conditions for *A. flavus* were found to be at 37 °C with 0.98 a_w , while those for AFB₁ production were found to be at 25~28°C with 0.96 a_w , and 33~37 °C with 0.92 a_w .

All these studies together show that environmental conditions, substrates, hosts and fungal species interact with each other, creating different conditions for aflatoxin production in different countries, including China (Figure 1).

6. Distribution of aflatoxin contamination in China

Spores of aflatoxigenic fungi are mainly found and/or distributed in the dust, air, water and soil, whereby higher concentrations of aflatoxins have been particularly reported in contaminated grain maize, peanuts, wheat and decomposing organic substances (Guan *et al.*, 2011a). The

aforementioned problems have recently been verified in studies by Sun *et al.* (2011), Tumukunde *et al.* (2019), and Wang and Liu (2007b) who indicated that aflatoxins were found contaminating Chinese seed crops, such as peanuts, rice, cotton, beans, wheat and maize. These authors further reiterated that the massive infections caused by aflatoxins are the most important cause for the immense losses in agricultural commodities suffered by numerous farmers in China. The aforesaid crop seeds contamination has been identified in several regions of China. However, the levels of aflatoxin distribution vary dramatically in different areas because agricultural systems and environmental conditions differ from one location to another (Table 3).

Aflatoxin contamination has been a great issue in different counties in southern China. For example, in Chongzuo county situated in the southern region of Guangxi province, aflatoxins have been found at high levels and the people are highly exposed to AFB₁. In this county, the relative humidity, average annual temperature, rainy days and precipitation are 79%, 21.9 °C, 148 days, and 1,311 mm, respectively. Based on the analysis of climatic conditions conducted for over a 10-year period in Chongzuo county, more than 150 days/year have temperatures greater than 30 °C and a relative humidity over 80%, which are the optimum conditions supporting the growth of *Aspergillus* species and production of related mycotoxins, respectively. Therefore, the high level of aflatoxin production is due to environmental conditions in this region (Li *et al.*, 2001). The study (Liao *et al.*, 2009) indicates that peanuts produced in the southern regions

Figure 1. Environmental conditions vis-a-vis aflatoxins production.

Table 3. Aflatoxin contamination in foodstuffs in China.¹

Food type	Location	Origin	Aflatoxin detected	No. of examined samples	Occurrence %	Level range of + ve sample (µg/kg)	Average no. of +ve samples µg/kg	Methods	Mean estimated intakes		References
									children	adults	
Peanut	12 provinces: Shandong, Liaoning, Henan, Hebei, Jiangsu, Anhui, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Fujian	agro-ecological zones	AFB ₁	1,040	25	0.01-720	2.13	HPLC and immunoaffinity columns	0.218-0.222 ng/kg (BW)/day	0.106-0.108 ng/kg (BW)/day	Ding <i>et al.</i> , 2012
Peanut	1 Province: Nanjing	markets	AFB ₁	20	80	0-58.25	0.72	ELISA	N/A	N/A	Xu <i>et al.</i> , 2006
Maize	8 provinces: Chongqing, Fujian, Guangxi, Zhejiang, Hubei, Shanghai, Guangdong, Jiangsu	markets	AFB ₁	74	62.16	0.14-970.32	29.05	HPLC	N/A	N/A	Wang and Liu, 2007b
			AFB ₂		55.41	0.02-128.04	2.00				
			AFG ₁		12.16	0.36-4.76	0.97				
Yogurt	31 provinces	retail store and supermarkets	AFM ₁	178	4.49	N/A	27.10	ELISA	0.327-0.353 ng/kg (BW)/day	0.023-0.382 ng/kg (BW)/day	Guo <i>et al.</i> , 2013
Milk				233	48.07		21.49				
Maize	Shandong	feed companies	AFB ₁	87	99	0.0-183	8.8	ELISA	N/A	N/A	Fu <i>et al.</i> , 2014
	6 provinces: Hainan, Guangxi, Guangdong, Liaoning, Heilongjiang, Jilin	granaries, farmer stores and markets	AFT	370	63.5	0.030-21.0	0.65				
			AFB ₁		63.5	0.030-20.0	0.60				
			AFB ₂		17.6	0.0-1.6	0.15				
Rice								DLLME-HPLC	N/A	N/A	Lai <i>et al.</i> , 2015a
Peanut	6 provinces: Sichuan, Hubei, Anhui, Hunan, Jiangxi, Jiangsu	fields in Yangtze River ecological region	AFB ₁	2,983	31	0-92.467	7.101	HPLC-FLD	0.777-0.790 ng/(kg·d)	0.343-0.349 ng/(kg·d)	Ding <i>et al.</i> , 2015
Maize	Beijing	animal farms	AFB ₁	22	50	59	6.0	HPLB	N/A	N/A	Fan <i>et al.</i> , 2012
			AFB ₂		9.1	12	0.6				
			AFG ₁		4.5	0.5	0.0				
			AFG ₂		9.1	0.5	0.0				
Rice	Liaoning	barns	AFG ₁	36	91.7	N/A	0.88	HPLC-FLD	N/A	N/A	Liu <i>et al.</i> , 2006b
Maize			AFT	73	2.8	N/A	0.99				
Maize	Guangxi	farmers	AFB ₁	40	85	9-2,496	460	HPLC	N/A	3.68 µg/kg (BW)/day	Li <i>et al.</i> , 2001
			AFB ₂		65	11-320	82				
			AFG ₁		45	12-21	15				

¹ N/A = not available; BW = body weight; HPLC-FLD = high-performance liquid chromatography with fluorescence detection; DLLME-HPLC = dispersive liquid-liquid microextraction with high performance liquid chromatography; HPLC = high-pressure liquid chromatography; ELISA = enzyme-linked immunosorbent assay; AFB₁ = aflatoxin B₁; AFB₂ = aflatoxin B₂; AFG₁ = aflatoxin G₁; AFG₂ = aflatoxin G₂; AFT = total aflatoxins (AFB₁ + AFB₂ + AFG₁ + AFG₂).

of China are usually more contaminated by aflatoxins than those in the northern parts. This was also confirmed in a series of studies that were conducted between 2002 and 2008 on aflatoxin contamination in 20 provinces around the country. More than 1000 study cases were conducted, and results showed that aflatoxins were present in many provinces and in most of the tested samples, whereby the overall level of aflatoxins contamination in the southern region of China was greater than that in the northern part. The most severe contamination cases were found in Guangxi province and the humid and hot southern climate might have been the main reasons for these higher rates of contaminations (Wu *et al.*, 2016a; Zhang *et al.*, 2011b). Some studies correlate the incidence of hepatocellular carcinoma (HCC) cancer occurring in China, Southeast Asia and sub-Saharan Africa regions, where populations experience high hepatitis B virus (HBV) incidence, to the largely unmanageable aflatoxin exposure in foodstuff (Liu and Wu, 2010; Yu *et al.*, 2013). Dietetic aflatoxin exposure and HBV are known to be the leading etiological causes of HCC (Wang *et al.*, 2001).

Several studies revealed that the incidence and conditions of aflatoxin production in the northern part of China are lower than those in the southern part of China (Gao *et al.*, 2011; Gong *et al.*, 2017; Ma *et al.*, 2011). A research conducted in Beijing, located in northern part, to evaluate and analyse aflatoxin contamination demonstrated that AFB₁ is distributed in Beijing's feeds and feedstuffs (Fan *et al.*, 2012). A conducted survey by Liu *et al.* (2012) revealed that the amount of aflatoxin contamination in different samples was low in Hebei province, whereby the identified level of aflatoxins in most samples was less than 0.5 µg/kg. These results were recently corroborated by Gong *et al.* (2016) who compared, investigated and indicated that the maximum positive value, average content and incidence of mycotoxins in the northern part of China are lower in contrast to those in the southern part. Although many studies indicated that the levels of aflatoxins in the northern region of the country are below the maximum levels, the risk of exposure should not be ignored in this region due to frequent contamination. Several cases of aflatoxins have been also identified in central area of China (Gao *et al.*, 2011; Wu *et al.*, 2016b). Rainfall and temperature are among the important climatic factors that affect the production of aflatoxins in China (Diao *et al.*, 2015; Li *et al.*, 2014). Consequently, the study by Wu *et al.* (2016b) reported that aflatoxin contaminated feeds in Henan province located in the centre of China were found to be a great issue in this region. This province exhibits plentiful rainfall and long periods of increased temperature simultaneously. Gao *et al.* (2011) collected maize samples in order to analyse the levels of aflatoxin production in 6 provinces of China (central, southern and northern parts) and noted that the contamination levels were significantly different within these provinces. They found that the contamination

levels in the southern area were more prevalent than in the northern and central areas. This clearly indicates that aflatoxin contaminated feed and food are found in different provinces of China, which might result in several problems including food shortage, health issues and economic losses among others.

7. Commodities contaminated by aflatoxins in China

Aflatoxin contaminated food often leads to serious health issues when ingested by humans and animals in significantly low-level doses on a daily basis (Sun *et al.*, 2013; Wang *et al.*, 2009). Specifically, long-term aflatoxin exposure leads to a decreased efficiency of immunisation and stunted growth in children, whereas cytochrome p450 enzymes activating AFB₁ in the liver will result in AFB₁-8,9-epoxide, leading to carcinogenic effects in the kidney (Chen *et al.*, 2006). These findings are supported by Yu (2012) and Wang *et al.* (2015) who reported that AFB₁ is a potent carcinogen in both animals and humans, whereby chronic exposure of these living beings could result in proliferation of the bile duct, suppressed the immune response, hepatomas, centrilobular necrosis, malnutrition, fatty infiltration of the liver, and hepatic lesions. Due to these health risks, grain storage conditions and agriculture practices have been improved in the country. This has contributed to a great reduction in the occurrence of aflatoxins. A brief description of the present levels of aflatoxins in different crops and the estimated exposure of humans to this mycotoxin is discussed in this section and summarised in Table 3.

Aflatoxin contaminations are commonly found in Chinese maize. For example, studies performed in Guangxi province assessed the risk of AFB₁ contamination on human primary HCC based on the concentration level (9~2,496 µg/kg) from maize samples in high incidence areas in this province (Ding *et al.*, 2012; Li *et al.*, 2001). They realised that residents in this province eat maize and its derivatives as their staple food (400 g/day/person). The estimated exposure to AFB₁ per individual ranged from 0.07-19.96 µg/kg BW/day, indicating that maize and its derivatives are a major contributor to AFB₁ exposure in this province. These results corroborate with those reported by Wang and Liu (2007a). The authors further indicated that peanuts, peanut oil and rice were other major contributors to aflatoxin exposure. The occurrence of aflatoxins in maize collected from farmers in Guangxi province in the low and high incidence regions for human cancer was examined, and they found that AFB₁ was the main toxin in terms of frequency and quantity. The incidence of AFB₁ was 85% and its contamination levels were in the range of 9~2,496 µg/kg. Differences in concentration of AFB₁, AFB₂ and AFG₁ in maize were also found (Table 3). Also, the average estimated daily intake of AFB₁ from maize for adults was 3.68 µg/kg (BW)/day (Li *et al.*, 2001). In another research conducted

by Gao *et al.* (2011), the authors examined AFB₁, AFB₂, AFG₁ and AFG₂ contamination in maize obtained from different provinces of China. They collected 279 samples in total and found that 76% of them were positive for aflatoxin contamination.

Peanuts are an important food crop and oil in China, and they are extensively grown in most provinces of the country. Currently, China is the largest country in the world in terms of annual peanut consumption, international trade and production (Liao *et al.*, 2009). However, aflatoxin contamination of Chinese peanuts has been found in different parts of the country. AFB₁ was detected in 80% of peanut samples collected from different markets in Nanjing with an average concentration of 0.72 µg/kg (range 0–58.25 µg/kg) (Liao *et al.*, 2009). To examine AFB₁ distribution in various areas, contamination levels in crops and its effect on human health, Ding *et al.* (2012) collected 1,040 peanuts samples from different agro-economic zones in 12 provinces of China between 2009 and 2010. In their study, the authors analysed AFB₁ using both immunoaffinity columns and HPLC methods, and found that 25% (0.01–720 µg/kg) of the samples were contaminated. A recent study investigated the potential AFB₁ and AFB₂ production in rice grain by 127 strains of *A. flavus* isolated from rice grains collected throughout China. Rice grains were inoculated with these strains and incubated for 21 days at 28 °C, and the results showed that 37% produced AFB₁ and AFB₂. The average yields of these isolates were 5,884 and 1,968 µg/kg for AFB₁ and AFB₂, respectively. Overall, most of the aflatoxigenic strains produced higher levels of AFB₁ than AFB₂ in rice (Lai *et al.*, 2015b).

The occurrence of aflatoxin M (AFM) in both milk and milk powder has also been analysed. During the study by Qian *et al.* (1994), a total of 15 milk powder and 57 milk samples was examined, and the results showed that 27 and 74% were contaminated, respectively. The range of AFM was found to be 0.1–0.35 and 0.025–0.95 pg/l in milk powder and milk, respectively (Qian *et al.*, 1994). However, a current study on AFM₁ mentioned that the risk associated with AFM₁ in milk is quite low in China (Guo *et al.*, 2013). In this study, AFM₁ was detected in 4.49% of the yogurt and 48.07% of the milk samples, however, none of the samples were found to contain AFM₁ above the recent regulation limit in China.

In the next sections, aflatoxin detection, prevention and control methods in China will be discussed, as well as the management strategies to prevent aflatoxicosis and aflatoxin-related diseases to consumers.

8. Common methods to detect aflatoxins in China

The identification and quantification of aflatoxin content in food and feed has been crucially important to ensure the safety of food in recent years (Krska *et al.*, 2008; Xie *et al.*, 2016). Studies indicate that both detection and identification of aflatoxins are achieved based on their light absorption and emission spectra (Wang, 2015). Several techniques have been developed to detect aflatoxins; the most common methods are thin layer chromatography (TLC), high-pressure liquid chromatography (HPLC), liquid chromatography coupled to mass spectrometry (LC/MS), enzyme-linked immunosorbent assay (ELISA), electrochemical immunosensors, and immunochromatography (ICG) techniques (Wacoo *et al.*, 2014; Zhang *et al.*, 2018a). A brief description of these methods is given below.

TLC is one of the oldest and popular separation methods used to detect aflatoxins in several food products. TLC was used for the first time by Iongh *et al.* in 1964. The method is capable of economically screening a significant number of samples (Fallah *et al.*, 2011; Stroka *et al.*, 2000). The level of aflatoxins present in the samples can be directly measured using TLC specimens under the UV-light radiation 365 nm (Lan *et al.*, 2019). Since the aflatoxin discovery in 1961, the TLC method has been widely utilised for mycotoxin analysis and is currently still used in China (Ahmad *et al.*, 2019; Ren *et al.*, 2018; Yuan *et al.*, 2019). However, due to the high demand for accurate data, both the quantification procedures and separation of this method have been gradually enhanced from TLC to the HPLC method (Zhang *et al.*, 2018b). HPLC has been developed since the 1960s and is known as a method that provides a quick, accurate and repeatable platform to analyse aflatoxin levels in different agricultural commodities (Wang, 2015). Therefore, this method has been frequently used because of its advantages, such as suitability for automation, easy to use, reproducibility, ability to couple with various detectors, high sensitivity and high separation power (Bakirdere *et al.*, 2012). Different detectors, which can be programmed, like the UV-visible absorption detector (Herzallah, 2009), diode array detector (Palmisano *et al.*, 1989) and fluorescence detector (Jaimez *et al.*, 2000) can be applied in HPLC during the identification and detection of aflatoxin based on the nature of analyte (Wacoo *et al.*, 2014). Once chemical derivatization is carried out, small amounts of aflatoxin (as little as 0.1 µg/kg) can be detected by HPLC fluorescence detector (HPLC-FLD) (Herzallah, 2009; Wang, 2015). Studies reported that the use of post-column derivatization technique in HPLC-FLD is an official and a frequently used technique in several countries (Ghali *et al.*, 2009; Zhang *et al.*, 2011b). Therefore, HPLC is the most frequently used method in China (Zhang *et al.*, 2013) and, for instance, applied to determine aflatoxin levels in

traditional Chinese medicines (Han *et al.*, 2010; Ip and Che, 2006; Zhang *et al.*, 2005).

ELISA is also a widely used technique for aflatoxin detection in agricultural commodities in China. The method is commonly used in the food and feed industries in order to identify aflatoxins content in food products (Li *et al.*, 2009b; Pei *et al.*, 2009; Wang *et al.*, 2011). For this method, numerous ELISA kits are commercially available and based on the competitive immunoassay format (Sun *et al.*, 2015; Zhang *et al.*, 2018b). ELISA is a reproducible method and can be used to analyse numerous samples simultaneously (Wacoo *et al.*, 2014; Zhang *et al.*, 2018b). However, this method sometimes gives either false negative or false positive results due to the instability of enzymes and/or reaction conditions. As a result, the application of this method to analyse aflatoxin should be improved (Beltrán *et al.*, 2011; Xie *et al.*, 2016).

As stated before, HPLC combined with fluorescence detection is a commonly used technique. It gives accurate and fast detection for aflatoxins, but a tedious derivatization procedure for fluorescence improvement must be carried out in traditional HPLC methods. This problem could be successfully solved by coupling HPLC to mass spectrometry (LC-MS). The ionisation source is utilised as interface between mass spectrometer and liquid chromatography. Because the structural information of the involved analytes can be directly examined by mass spectrometer, the chemical derivatization of aflatoxins could be eliminated. Moreover, LC-MS methods exhibit high sensitivity. Therefore, the LC-MS method also allows multiple analysis of aflatoxins and is suitable for detection of aflatoxins in cereals and feed (Zheng *et al.*, 2014; Zhu *et al.*, 2010).

Immunochromatography is also among the methods which are used to detect aflatoxins in food in China (Xiulan *et al.*, 2006; Zhang *et al.*, 2011a). This technique is a type of immunoassay method which was developed in recent years for quick detection of an analyte. Thus, it is rapid and simple, and appropriate for both prescreening and analysis of more samples (Shim *et al.*, 2007). Another method that has also been applied in China for aflatoxin quantification uses an electrochemical immunosensor (Linting *et al.*, 2012; Liu *et al.*, 2006a).

Additional methods are those that examine the pre-occurrence of aflatoxins. This includes the development of an orbitrap Fusion Mass Spectrometry method for monitoring metabolites through the aflatoxin biosynthesis pathway. In this method, ultra-high-performance liquid chromatography combined with high-resolution mass spectroscopy (UHPLC–HRMS) technique is developed for aflatoxins identification. A reverse-phase chromatography column is subsequently used to separate metabolites in the

aflatoxin pathway. For the analysis of these metabolites both high-energy collision-induced dissociation (HCD) and electrospray ionization (ESI) should be carried out with an Orbitrap Fusion mass spectrometer (Xie *et al.*, 2018). Another technique is the development of a specific nanobody-polyclonal antibody sandwich ELISA for detection of the aflatoxin-producing fungi *A. flavus* and *A. parasiticus* in agricultural products (Wang *et al.*, 2017). The comparison of all the above methods, with their advantages and disadvantages is summarised in Table 4.

9. Control and management strategies for aflatoxins in China

In China, several strategies have been developed to manage and control aflatoxins, which are grouped into different categories. Most methods used to prevent/control aflatoxin production include, but are not limited to: breeding for resistance, the use of genetic engineering, the use of biological control agents, control of environmental factors, field management practices, proper storage, chemo-prevention, adsorption as well as detoxification techniques, and dietary change among others (Hamid *et al.*, 2013; Liao *et al.*, 2009). Moreover, the application of post-harvesting techniques for aflatoxin reduction, such as sorting, cleaning, fast and proper drying, post-harvest insect control, spraying and smoking of synthetic pesticides or botanicals were used as storage protectants (Guan *et al.*, 2011b; Hell *et al.*, 2010; Liao *et al.*, 2009). A summary of these techniques/methods is described in this section.

Biological control of fungal development in the field is the potential technique to control toxins in China. Different species have been analysed for biological control of infection by aflatoxigenic fungi, including yeasts (*Pichia anomala* and *Candida krusei*), non-toxigenic *Aspergillus* strains and bacteria (*Lactobacillus* spp., *Burkholderia* spp., *Ralstonia* spp., *Pseudomonas* spp. and *Bacillus subtilis*) (Yin *et al.*, 2008, 2009). Further studies highlighted the potential use of the bacterial strains for biological control of AFB₁ in agriculture and food industries. *Pseudomonas qingdaonensis* strain JJ3^T as well as *Myroides odoratimimus* strain 3J2MO were found to have the ability to degrade AFB₁ (Mwakinyali *et al.*, 2019; Wang *et al.*, 2019b). An earlier study found that *Pseudomonas fluorescens* strain 3JW1 had numerous effects, such as inhibition of *A. flavus* growth and AFB₁ biosynthesis, but it is also able to degrade AFB₁ (Yang *et al.*, 2017).

Breeding for resistance and genetic engineering techniques are also used for aflatoxin control. These methods help crop breeding in the development of germplasm that is able to resist fungal growth or/and aflatoxin contamination (Guo *et al.*, 2009; Liao *et al.*, 2009). Field management practices for aflatoxin control are carried out using effective weed control mechanisms, fertilisers, diversity of resistant

Table 4. Comparison between the main methods used to detect aflatoxins in China.¹

Method	Advantages	Disadvantages	References
TLC	Economical and fast Detect several mycotoxins in one sample More accurate compared to HPLC	Requires prior preparation of sample Need a trained/skilled operator Not automatic and high chance to be harmful to the operator	Bakirdere <i>et al.</i> , 2012; Turner <i>et al.</i> , 2009; Wang <i>et al.</i> , 2015
HPLC	Automatic Easy to use, reproducibility Able to couple with various detectors High sensitive High separation power	High operating costs Time-consuming Pretreatment of the sample	Bakirdere <i>et al.</i> , 2012; Xie <i>et al.</i> , 2016
LC-MS	Suitable for multiple analysis Simultaneous quantification and qualification	Requires a skilled operator Difficult High cost	Zheng <i>et al.</i> , 2014
ELISA	Fast and sensitive analysis Requires a small volume of sample for analysis Many samples can be analysed simultaneously ELISA kits are cheap and easy to use No intrinsic health hazards associated with enzyme labels	Requires multiple washing steps that can at times prove lengthy and time-consuming Sometimes gives false negative or false positive results	Pei <i>et al.</i> , 2009; Zhang <i>et al.</i> , 2018b
ICG	Offers good sensitivity User-friendly format Short assay time/rapid Durable stability to a broad range of climates Cost-effectiveness Can screen large numbers of samples Does not require skilled analysts	Single analyte analysis can pose a huge potential problem from grave false positive results Lack of selectivity	Shim <i>et al.</i> , 2007; Xiulan <i>et al.</i> , 2006; Zhang <i>et al.</i> , 2011a
Electrochemical immunosensor	Stability Good sensitivity Repeatable Simple Necessity of a sample pre-treatment can be avoided	Requires multiple washing steps that can at times prove it lengthy and time-consuming Need a skilled operator	Evtugyn and Hianik <i>et al.</i> , 2019

¹ TLC = thin layer chromatography; LC/MS = liquid chromatography coupled to mass spectrometry; ICG = immunochromatography.

crops, bird or insect control by pesticides, as well as by avoiding nutritional and drought stress (Choudhary and Kumari, 2010; Diao *et al.*, 2015). In addition, timely planting and harvesting crops, as well as decrease of deep tillage practices, and in some cases elimination of the amount of inoculum that might be present in the topmost layer of the soil (Diao *et al.*, 2015). Contamination can also be controlled by the construction of appropriate humidity proof storage facilities to shield the grains from infection and maintain favourable storage temperature (Hell *et al.*, 2010; Liao *et al.*, 2009; Zhang *et al.*, 2011b).

Adsorption is another method to decrease aflatoxin contamination. Studies have shown that the harmful effect of aflatoxins on animals can be minimised by the addition of different types of nutrition adsorbent to the animal feed. The combination of some bacteria can lower the adsorption capacity of toxins in the intestinal tract

of chickens, thereby reducing their biological activity *in vivo* and prevent liver cancer (Gratz *et al.*, 2005; Wang *et al.*, 2018). Specific changes in animal and human diets, for instance by eating chlorophyllin-rich foods, reduces the effects of aflatoxin exposure and minimises the risks of liver cancer, as well as the absorption of AFB₁ (Egner *et al.*, 2001; Fahey *et al.*, 2005; Versantvoort *et al.*, 2005). Also, the frequent consumption of high-risk foods, like maize and groundnut, should be minimised by intake of a more varied diet, and use of a less risky staple food, such as sorghum and millet (Hell *et al.*, 2008). The use of chemoprevention, i.e. daily ingestion of oltipraz or chlorophyllin and hydrated sodium calcium aluminosilicate anticaking agent into the diet, can help to decrease the effects of aflatoxins. The hydrated sodium calcium aluminosilicates reduce aflatoxin absorption by binding to the β -carbonyl portion of the aflatoxin molecules and hence prevent the aflatoxicosis (Chen *et al.*, 2014; Ledoux

et al., 1999). Regular decontamination of commodities from aflatoxins can be achieved either physically (through physical segregation, sorting, and/or flotation), chemically (with ammonia or calcium hydroxide), or microbiologically by including pro-biotics or lactic acid bacteria into the diet (Shu *et al.*, 2018; Wang *et al.*, 2018). Another strategy to control and prevent the aflatoxins risks in China is a vaccination against hepatitis B. This vaccination plays an important role in the reduction and prevention of cancer that might be caused by dietary exposure to aflatoxins in China (Chen *et al.*, 2013).

Photocatalytic degradation is a recently developed technique to remove and/or degrade pollutants, including aflatoxins, from environment in gentle or mild conditions (Bai *et al.*, 2017; Sun *et al.*, 2019; Wang *et al.*, 2019a). A recent study, Mao *et al.* (2018a) revealed that the nanosized graphitic carbon nitride sheets (g-C₃N₄) presents a significantly higher photocatalytic activity for degradation of AFB₁ in aqueous solutions. The enhanced photocatalytic mechanisms were a result of better photogenerated charges separation and larger surface area of nanosized g-C₃N₄ sheets. Although this technique provided good results, a later study (Mao *et al.*, 2018b) suggested that it was a good idea to explore more convenient and expedient strategies to improve the performance of pristine g-C₃N₄. To this end, they designed a geometric architecture of ternary Z-scheme composites consisting of bulk g-C₃N₄, WO₃ nanowires and RGO (WO₃/RGO/g-C₃N₄) for enhanced visible-light-driven activity of refractory AFB₁ degradation. Their results indicate that the use of the above-mentioned composites as an electron mediator could markedly increase the photocatalytic activity of pristine g-C₃N₄ for AFB₁ degradation under visible-light irradiation (Mao *et al.*, 2018b). In a similar fashion, a kind of all-solid-state Z-scheme composite obtained by depositing CdS on the surface of clew-like WO₃ was able to sharply reduce the toxicity of AFB₁ in aqueous solution under visible light radiation (Mao *et al.*, 2019).

In summary, all the above-mentioned control and prevention strategies can greatly help in reducing diseases caused by aflatoxins. These control and prevention strategies would equally increase both positive economic impact for farmers and the production of seed crops.

10. Conclusions and future outlook of aflatoxins in China

The current level of research relating to the incidence of aflatoxins in human, animals and foodstuff in Asian countries have demonstrated the seriousness of the aflatoxin problem these days. In China, the topographic complexity and extensiveness, as well as the distinctly different climate zones have provided diverse favourable environmental conditions for the growth of aflatoxin-producing fungi.

Generally, the level of aflatoxin contamination detected in the southern area of China is greater than that in the northern part. However, the diminution of aflatoxins risk could rely on the feed and food safety management by the production companies and government. In recent years, Chinese feed and food companies have tried to improve their standardised running protocols for aflatoxin control/management, which has made China to be classified among the countries in Asia that have the most detailed and extensive process of regulation for mycotoxins including aflatoxins (Van Egmond and Jonker, 2004). The Chinese government has equally been improving these regulations to avoid these toxins reach consumers all over the country. Also, the management and supervision of production, consumption and distribution chains by the liable agencies have been gradually improved.

Although the Chinese government has established some regulations and laws in response to aflatoxin contamination, additional efforts are still needed to minimise the aflatoxin levels in food and their risks to the human and animal health in the country. Therefore, the future outlook with regard to aflatoxin prevention in China can be anticipated. Firstly, the stakeholders in the manufacturing chain, especially farmers, should be made conscious of the value of measures to decrease aflatoxin contamination to guarantee their safety and protect consumers. Secondly, people at all levels, such as technicians, scientists and extension agents should be trained timely and rightly. Thirdly, we should use the most accurate techniques to detect aflatoxins that are recently documented. Fourthly, we should carry out periodically and extensively surveys about the incidence of aflatoxins and their metabolites in human's breast milk, since severe health risks to the infant, foetus, and mother can occur.

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Conflict of interest

The authors declare no conflict of interest.

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