Food Research International 113 (2018) 74–85

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

Aflatoxin in foodstuffs: Occurrence and recent advances in decontamination

Amir Ismail[a], Bruna L. Gonçalves[b], Diane V. de Neeff[b], Bárbara Ponzilacqua[b], Carolina F.S.C. Coppa[b], Henning Hintzsche[c,d], Muhammad Sajid[e], Adriano G. Cruz[f], Carlos H. Corassin[b], Carlos A.F. Oliveira[b,*]

[a] Institute of Food Science and Nutrition, Bahauddin Zakariya University, Multan, Pakistan
[b] Department of Food Engineering, School of Animal Science and Food Engineering, University of São Paulo, Av. Duque de Caxias Norte, 225, CEP, Pirassununga, SP 13635-900, Brazil
[c] Institute of Pharmacology and Toxicology, University of Würzburg, Germany
[d] Bavarian Health and Food Safety Authority, Eggenreuther Weg 43, Erlangen 91058, Germany
[e] Institute of Chemical Sciences, Bahauddin Zakariya University, Multan, Pakistan
[f] Science and Technology of Rio de Janeiro, Department of Food Science, Federal Institute of Education, Rio de Janeiro, RJ, Brazil

ARTICLE INFO

Keywords:
Aflatoxins
Food safety
Incidence
Removal
Degradation
Decontamination
Detoxification

ABSTRACT

Aflatoxins are highly toxic compounds produced as secondary metabolites by some *Aspergillus* species, whose occurrence have been reported predominantly in several types of foods of low moisture content, while aflatoxin biotransformation products have been reported mainly in milk and milk products. This review deals with the occurrence of aflatoxins in some of the major food products in the last 5 years including regulatory aspects, and recent advances in detoxification strategies for contaminated foods. Aflatoxin contamination in cereals including corn and peanut is still a public health problem for some populations, especially in African countries. Despite that most of physical and chemical methods for aflatoxin detoxification may affect the nutritional properties of food, or are not safe for human consumption, gamma-radiation and ozone applications have demonstrated great potential for detoxification of aflatoxins in some food matrices. Biological methods based on removal or degradation of aflatoxins by bacterial and yeast have good perspectives, although further studies are needed to clarify the detoxification mechanisms by microorganisms and determine practical aspects of the use of these methods in food products, especially their potential effects on sensory characteristics of foods.

1. Introduction

Aflatoxins are secondary metabolites produced by fungi species from the genus *Aspergillus*, notably *A. flavus*, *A. parasiticus* and *A. nomius*, which develop naturally in food products and cause a wide array of toxic effects in several animal species, including humans (Abbas, 2005). There are > 20 types of aflatoxin molecules, although the most prominent are aflatoxins B_1 (AFB_1), B_2 (AFB_2), G_1 (AFG_1), G_2 (AFG_2), M_1 (AFM_1), and M_2 (AFM_2). Aflatoxins are typically reported in dry food commodities (cereals, spices, and dry fruits), while the metabolic products of aflatoxins, such as AFM_1 and AFM_2, are reported in milk (Akhtar, Shahzad, Yoo, & Ismail, 2017; Udomkun et al., 2017).

AFB_1 and the mixture of aflatoxins B, G and M are classified by the International Agency for Research on Cancer (2012) as group 1 carcinogens. In fact, the most notable human health impact of aflatoxins is hepatocellular carcinoma (HCC), which is recognized worldwide as the 9th and 7th leading type of cancer in women and men, respectively. Every year, > 320,000 new cases of HCC are reported, hence contributing with > 4% of the total cases of reported malignant tumors in the world. Despite the relative low incidences, HCC is a highly deteriorating form of cancer, also showing a much higher death rate (0.31 million death/year) when compared with other types of cancer (Wang et al., 2001). Additional health impacts of aflatoxins include teratogenicity, hepatotoxicity, cytotoxicity, and genotoxicity. Aflatoxins are also strongly linked with growth impairment, including stunting and wasting, and these health impacts are frequently reported in African countries where aflatoxin occurrence is much higher (Reddy et al., 2009). Fetuses and infants are exposed to aflatoxins through their mothers at much lower rates compared with the rate of exposure after weaning (Khlangwiset, Shephard, & Wu, 2011).

Aflatoxins exhibit great resistance to conventional treatments usually applied to food or feed processing, including pasteurization, sterilization and other thermal applications (Rustom, 1997). Therefore measures aiming to prevent the contamination of grains, especially with

* Corresponding author.
E-mail address: carlosaf@usp.br (C.A.F. Oliveira).

https://doi.org/10.1016/j.foodres.2018.06.067
Received 18 October 2017; Received in revised form 26 June 2018; Accepted 28 June 2018
Available online 30 June 2018
0963-9969/

Table 1
Occurrence of aflatoxins in food products from countries in different continents, reported in the last 5 years (2013 to date).

Country	Year	Food product	Aflatoxin	Total/positive samples	Range/mean (μg/kg)	Analytical method	Reference
Americas:							
Brazil	2014	Cashew nuts	Total AFs	70/24	0.60–31.5/NI	ELISA	Milhome et al. (2014)
Brazil	2013	Cow milk	AFM_1	129/18	0.05/0.58	HPLC	Picinin et al. (2013)
Costa Rica	2017	Corn	Total AFs	453/175	24/420	ELISA and HPLC	Granados-Chinchilla et al. (2017)
Costa Rica	2017	Peanut	Total AFs	572/125	18/400	ELISA and HPLC	Granados-Chinchilla et al. (2017)
USA	2017	Chilies	AFB_1	169/108	< 2/94.9	ELISA and TLC	Singh and Cotty (2017)
Africa:							
Congo	2016	Corn (pre-harvest)	Total AFs	50/16	3.1–103.89/20.64[a]	HPLC	Kamika, Ngbolua, and Tekere (2016)
		Corn (post harvest)		150/78	1.5–2806.5/NI		
Egypt	2015	Meat products	Total AFs	50/50	0.47–2.1/1.12	Fluorimeter	Abd-Elghany and Sallam (2015)
Ethiopia	2013	Groundnuts	Total AFs	120/93	15–11,900/1992	HPLC	Chala, Mohammed, Ayalew, and Skinnes (2013)
Malawi	2014	Nut-based foods	AFB_1	55/43	0.1–40.6/6.28	HPLC	Matumba et al. (2014)
Nigeria	2017	Ginger	Total AFs	120/66	0.11–9.52/0.54[a]	HPLC	Lippolis et al. (2017)
			AFB_1	120/66	0.11–8.76/0.46[a]		
			AFB_2	120/44	0.13–1.01/0.09[a]		
Zambia	2016	Peanuts	AFB_1	92/41	0.015–46.60/0.45	HPLC	Bumbangi et al. (2016)
			Total AFs	92/51	0.014–48.67/0.43		
Zimbabwe	2017	Corn	AFB_1	388/80	0.75–26.6/3.21[a]	HPLC	Murashiki et al. (2017)
Asia:							
China	2015	Rice	AFB_1	370/235	0.03–20/0.6[a]	HPLC	Lai, Liu, Ruan, Zhang, and Liu (2015)
China	2013	Cow milk	AFM_1	233/112	0.05/0.95	HPLC	Guo, Yuan, and Yue (2013)
China	2013	Yoghurt	AFM_1	178/8	0.05/0.85	HPLC	Guo et al. (2013)
China	2017	Cow milk	AFM_1	5650/267	0.05/0.41	ELISA	Li et al. (2017)
India	2014	Corn	AFB_1	150/150	48–383/NI	HPLC	Mudili et al. (2014)
Iran	2016	Cow milk	AFM_1	64/54	0.006–0.188/0.059[a]	HPLC	Bahrami, Shahbazi, and Nikousefat (2016)
		Yoghurt	AFM_1	42/10	0.006–0.021/0.015[a]		
Korea	2015	Functional foods	AFB_1	185/0	NI	HPLC	Lee, Lyu, and Lee (2015)
Malaysia	2014	Spaghetti	Total AFs	25/7	0.05/51.4	HPLC	Iqbal, Asi, and Jinap (2014)
Malaysia	2017	Cow milk	AFM_1	102	0.020–0.142/0.092[a]	HPLC	Shuib, Makahleh, Salhimi, and Saad (2017)
Pakistan	2014	Cereals	AFB_1	237/98	0.04–6.90/1.32	HPLC	Iqbal et al. (2014)
Pakistan	2016	Milk	AFM_1	520/484	0.001–0.26/0.103	ELISA	Ismail et al. (2016)
Pakistan	2017	Chilies	Total AFs	312/176	15.16/2.22	HPLC	Iqbal, Asi, Hanif, Zuber, and Jinap (2017)
Saudi Arabia	2013	Nuts	Total AFs	264/70	1.0–110/8.1	HPLC	El Tawila, Neamatallah, and Serdar (2013)
Taiwan	2013	Peanut products	Total AFs	1827/597	0.2–513.4/16.5	HPLC	Chen, Liao, Lin, Chiueh, and Shih (2013)
Turkey	2014	Cow milk	AFM_1	176/53	0.03/0.55	HPLC	Golze (2014)
Turkey	2016	Figs	Total AFs	130/16	0.1–28.2/3.8[a]	HPLC	Kabak (2016)
Turkey	2015	Wheat flour	AFB_1	60/0	NI	HPLC	Kara, Ozbey, and Kabak (2015)
		Maize flour	AFB_1	24/16	0.041–1.12/0.19		
Vietnam	2017	Corn	AFB_1	2370	1.0–34.8/13.1	ELISA	Lee et al. (2017)
Europe:							
Greece	2013	Milk	AFM_1	196/91	< 0.005–0.016/0.01[a]	ELISA	Tsakiris et al. (2013)
Italy	2014	Spices	AFB_1	130/20	0.59–5.38/0.31	HPLC	Prelle, Spadaro, Garibaldi, and Gullino (2014)
Italy	2017	Buffalo and cow milk	AFM_1	804/79	0.004/0.05	HPLC	De Roma, Rossini, Ritieni, Gallo, and Esposito (2017)
Portugal	2013	Cow milk	AFM_1	40/11	0.005–0.069/0.024[a]	ELISA	Duarte et al. (2013)
Serbia	2013	Corn	Total AFs	380/137	1.01–86.1/36.3[a]	ELISA	Kos, Mastilović, Hajnal, and Šarić (2013)
Serbia	2014	Different types of milk	AFM_1	176/165	0.01/1.20	ELISA	Kos, Levi, Đuragi, Koki, and Miladinovi (2014)
Serbia	2015	Milk	AFM_1	80/74	< 0.003–0.319/0.026	HPLC	Torović (2015)
		Infant formula		21/1	< 0.03–0.020/0.020[a]		
Spain	2013	Cereals	Total AFs	67/0	NI	HPLC	Vidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)
Spain	2016	Toasted cereal flour (gofio)	AFB_1	94/24	< 0.025–0.17/NI	LC-MS	Luzardo et al. (2016)
			AFB_2	94/23	< 0.025–0.07/NI		
			AFG_1	94/9	< 0.025–0.12/NI		
			AFG_2	94/8	< 0.025–0.17/NI		

ELISA: Enzyme-linked immunosorbent assay. HPLC: High performance liquid chromatography. NI: Not informed.
[a] Indicate the mean of positive samples only.

the most toxic compound AFB_1, are essential throughout the production chain, mainly during pre- and post-harvest operations. However, several environmental factors, as well as failure in the application of good agricultural practices may favor contamination, leading to the need for detoxification methods of contaminated products (Bovo, Corassin, Rosim, & Oliveira, 2013). Different approaches have been tested to remove or degrade the aflatoxins in foods, and the most prominent of these can be categorized into physical, chemical, and biological methods. This review deals with the occurrence of aflatoxins in some of the major food products in the last 5 years including regulatory aspects of the mycotoxin, and recent advances in detoxification strategies for contaminated foods.

2. Occurrence and regulations of aflatoxins in food commodities

Since their discovery in 1960s, aflatoxins are reported consistently from different parts of world. Food items that have shown maximum aflatoxin levels are cereals, spices, and milk. The occurrence of aflatoxins in the major food products in different countries worldwide reported from 2013 until present date is presented in Table 1, along with