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Aflatoxin in foodstuffs: Occurrence and recent advances in decontamination

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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 B₁ (AFB₁), B₂ (AFB₂), G₁ (AFG₁), G₂ (AFG₂), M₁ (AFM₁), and M₂ (AFM₂). Aflatoxins are typically reported in dry food commodities (cereals, spices, and dry fruits), while the metabolic products of aflatoxins, such as AFM₁ and AFM₂, 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

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Table 1

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

NetworkVersion<	Country	Year	Food product	Aflatoxin	Total/positive samples	Range/mean (µg/kg)	Analytical method	Reference
Brazil Brazil Brazil Brazil 	Americas:							
Brazil Costa Rice Costa Rice Costa Rice Costa Rice Costa Rice Costa RiceAPM Costa Rice Costa RiceAPM Costa Rice Costa RiceAPM Costa Rice Costa RiceAPM Costa Rice Costa RicePichula Rat Costa Rice Costa RicePichula Rat Costa Rice Costa RicePichula Rat Costa Rice Costa Rice Costa Rice Costa RicePichula Rat Costa Rice Costa Rice Rice Rice Costa Rice Costa Rice <b< td=""><td>Brazil</td><td>2014</td><td>Cashew nuts</td><td>Total AFs</td><td>70/24</td><td>0.60-31.5/NI</td><td>ELISA</td><td>Milhome et al. (2014)</td></b<>	Brazil	2014	Cashew nuts	Total AFs	70/24	0.60-31.5/NI	ELISA	Milhome et al. (2014)
Cash Rice 2017 Coron Total AFs 5/21/25 18/400 ELSA and HPLC Granados-Chinchilla et al. (2017) USA 2017 Colinies APB, 169/108 < 2/94.9	Brazil	2013	Cow milk	AFM_1	129/18	0.05/0.58	HPLC	Picinin et al. (2013)
Costa Res 2017 Pentut Total AFs 572/125 18/400 ELISA and TLC Simulable Construction of the set of th	Costa Rica	2017	Corn	Total AFs	453/175	24/420	ELISA and HPLC	Granados-Chinchilla et al. (2017)
USA 2017 Chilis AFB, 169/108 < 2/94.9 ELSA and TC Singh and Coty (2017) Arriaz: Comgoon 2015 More (pro-barvest) Total AFS 50/16 3.1-103.89/20.64 ⁴ HPLC Kamila, Nglobia, and Tekere (2016) Egypt 2013 Groundnuts Total AFS 50/50 0.47-2.1/1.12 Floorimetr Abd-Egipany and Sillam (2015) Bahopia 2013 Groundnuts Total AFS 20/93 0.47-6.67.28 HPLC Murahus et al. (2014) Nigeria 2017 Ginger Total AFS 20/96 0.11-876.0.46 ⁹ HPLC Lippolis et al. (2017) Ambiav 2017 Genger Total AFS 20/44 0.014-48.67/0.43 HPLC Lippolis et al. (2016) Zambia 2017 Corn AFB, 20/44 0.014-48.67/0.43 HPLC Lippolis et al. (2017) Zambia 2015 Kice AFB, 20/25C 0.05-0.05C HPLC Lippolis (Lippolis et al. (2017) China 2015 Corn milk AFB, <td< td=""><td>Costa Rica</td><td>2017</td><td>Peanut</td><td>Total AFs</td><td>572/125</td><td>18/400</td><td>ELISA and HPLC</td><td>Granados-Chinchilla et al. (2017)</td></td<>	Costa Rica	2017	Peanut	Total AFs	572/125	18/400	ELISA and HPLC	Granados-Chinchilla et al. (2017)
Africe:VietnomTotal AFSourceSourceNatureKamila, Ngholan and Kater (2016)Cong post harves()Total AFSource1.5-2806.5/mlFinorimeterAbd-Fighany and Sallan (2015)Ethiopia2013GroundmutsTotal AFSource15-11,900/1992HPLCAbd-Fighany and Sallan (2015)Malawi2014Nuchased foodsAFBSourceHPLCMuturable et al. (2017)Migeria2017GroundmutsAFB200/640.11-8.760.464HPLCMuturable et al. (2017)Zambia2016PennutsAFB200/640.11-8.760.464HPLCMuturable et al. (2017)Zambia2017GronAFB200/640.11-8.760.464HPLCMuturable et al. (2017)AnishesTotal AFB200/640.11-8.760.465HPLCLai, Liu, Ruan, Zhang, and Liu (2015)China2017Gron milkAFB70/2350.05-20.676HPLCLai, Liu, Ruan, Zhang, and Liu (2015)China2013VoghurtAFB70/2350.05-0.055HPLCGuo, Yuan, and Yue (2013)China2013VoghurtAFB32/1120.05/0.55HPLCGuo, Yuan, and Yue (2013)China2014Gron milkAFB10/2120.05/0.41ELISALia Li, Ruan, Zhang, and Liu (2015)China2018Gron milkAFB10/2120.05/0.41ELISAHELCMuturable et al. (2014)China2014Gron milkAFB10/2120.05/0.41ELI	USA	2017	Chilies	AFB_1	169/108	< 2/94.9	ELISA and TLC	Singh and Cotty (2017)
CongProof Array and Proof Array and	Africa:							
Egypt Dis Marge modelss Total AFS Disord Disord Marge modelss Total AFS Disord Disord Pluc Ald-Playm and Sallam (2015) Ethiopia 2013 Groundnuts Total AFS 120,93 15–11,900/1992 HPLC Ald-Playm and Sallam (2015) Malawi 2014 Nit-based foods AFB, 55/43 0.1–40.6/6.28 HPLC Matumba et al. (2017) Nigeria 2017 Ginger AFB, 120/66 0.11–8.76.0/4.6' HPLC Matumba et al. (2017) Zambia 2016 Peanuts AFB, 320/41 0.015–46.60/0.45 HPLC Murashik et al. (2017) Asia 2017 Corn AFB, 370/235 0.03–20/0.6' HPLC Guo et al. (2013) China 2013 Yoghur AFM, 378,9 0.05/0.95 HPLC Guo et al. (2013) China 2013 Yoghur AFM, 550/267 0.05/0.45 HPLC Guo et al. (2014) Inai 104 Corn milk AFM,	Congo	2016	Corn (pre-harvest)	Total AFs	50/16	3.1-103.89/20.64 ^a	HPLC	Kamika, Ngbolua, and Tekere (2016)
Exployie Exployie2015Near produces total AFs70tal AFs90/500.47-2.1.1.2 1.1900.1902HPLC HPLC 1.010.000Add-Efghany and Sallam (2015) Chala, Mohammed, Ayalew, and Skinnes (2013)Malawi Nigeria2017Niesed foods (3017)AFFs120.45101-05.65.26HPLC 1.18-76.04.67Matumbe et al. (2014) 1.18-76.04.67Nigeria2017Garger (3018)AFFs120.460.11-9.52.05.47HPLC 1.18-76.04.67HPLC 1.18-76.04.67Hender 1.18-76.04.67Zamba2017Foral AFs20.740.014-86.70.03HPLCHumashi et al. (2017)Zamba2017Foral AFs20.750.014-86.70.03HPLCHumashi et al. (2017)Zamba2015RenausAFFs20.7250.03-20.06.5HPLCHumashi et al. (2017)China2013GorumitaAFFs20.7250.05-0.05HPLCHumashi et al. (2017)China2013GorumitaAFFs20.7250.05-0.05HPLCHumashi et al. (2014)China2013GorumitaAFFs20.7260.05-0.05HPLCHumashi et al. (2014)China2014GorumitaAFFs20.7260.06-0.018.00HPLCHumashi et al. (2014)China2015GorumitaAFFs20.7260.06-0.018.00HPLCHumashi et al. (2014)China2014GorumitaAFFs20.7260.06-0.018.00HPLCHumashi et al. (2014)China2015GorumitaAFFs <td>0</td> <td></td> <td>Corn (post harvest)</td> <td></td> <td>150/78</td> <td>1.5-2806.5/NI</td> <td></td> <td></td>	0		Corn (post harvest)		150/78	1.5-2806.5/NI		
Ethopia2013GroundnutsTotal AR120/9315-11.900/1992HPLCChain, Mohammed, Ayalew, and Skinne (2013)Malawi2014Nut-based foodsAFB,55/430.1-40.6/6.28.HPLCMatumba et al. (2014)Migeria2017GingerAFB,120/660.11-8.27.0/46'HPLCLippolis et al. (2017)Zambia2016FeanutsAFB,92/410.015-4.660/0.45HPLCMurashik et al. (2017)Zimbabwe2017CornAFB,388/800.75-26.6/3.21*HPLCMurashik et al. (2017)Asia:	Egypt	2015	Meat products	Total AFs	50/50	0.47-2.1/1.12	Fluorimeter	Abd-Elghany and Sallam (2015)
Nalawi Nalawi NigeriaUt based foods (nigerAFB, (101 AFB, (101 AFB, (10	Ethiopia	2013	Groundnuts	Total AFs	120/93	15-11,900/1992	HPLC	Chala, Mohammed, Ayalew, and Skinnes
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AFE 120/65 0.13+01.0.09" Zambia 0.0 Peanuts AFE 0.044 0.015+46.60/0.45 HPLC Bumbangi et al. (2016) Zimbabwe 2017 Corn AFE 0.014-48.67/0.43 US Zimbabwe 2017 Corn AFE 388/80 0.75-26.6/3.21" HPLC Marashiki et al. (2017) Asia:	Nigeria	2017	Ginger	Total AFs	120/66	0.11-9.52/0.54 ^a	HPLC	Lippolis et al. (2017)
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Zimbalwe 2017 Corn AFB ₁ 388/80 $0.75-26.6/3.21^{10}$ HPLC Murashiki et al. (2017) Asia:				Total AFs	92/51	0.014-48.67/0.43		
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China 2013 Yoghurt APM 178/8 0.05/0.85 HD.C Guo et al. (2017) China 2017 Cow milk APM 5650/267 0.05/0.41 ELISA Li et al. (2017) India 2016 Cow milk APM 150/150 48-383.NI HPLC Mudil et al. (2014) Iran 2016 Cow milk APM 42/10 0.006-0.021/0.015' HEC Babrami, Shabbazi, and Nikousefat (2016) Malaysia 2014 Spaghetti Total AFS 25.77 0.05/51.4 HPLC Lee, Lyu, and Lee (2015) Malaysia 2017 Com milk APM 102 0.02-0.142/0.092 HPLC Shabi.hasiah5.3145.3162 Pakistan 2017 Com milk APM 520/78 0.04-6.90/1.32 HPLC Igbal.Asi, Ianif. Zuber, and Jinap (2017) Pakistan 2016 Milk AFM 520/787 0.2513.47/16.5 HPLC Igbal.Asi, Ianif. Zuber, and Jinap (2017) Pakistan 2013 Nuts Total AFS 132/7597 0.2513.47/16.5	China	2013	Cow milk	AFM ₁	233/112	0.05/0.95	HPLC	Guo, Yuan, and Yue (2013)
China2017Cow milkAFM1 AFB15650/2670.05/0.41ELISALisALi et al. (2017)India2014Com milkAFB1150/15048-383/NIHPLCMudili et al. (2014)Iran2016Cow milkAFM164/540.006-0.021/0.015'Baltrami, Shabhasi, and Nikousefat (2016)Korea2015Functional foodsAFB1185/0NIHPLCLee, Lyu, and Lee (2015)Malaysia2014SpaghettiTotal AF825/70.05/51.4HPLCShuib, Makahleh, Salhimi, and Saad (2017)Pakistan2014CorealsAFB123/980.024-0.42/0.092'HPLCShuib, Makahleh, Salhimi, and Saad (2017)Pakistan2014CorealsAFB123/7980.046-50/1.32HPLCLipdal, Asi, Hanff, Zuber, and Jinap (2017)Pakistan2014MilkAFM152/4840.001-0.26/0.103ELISAIsmail et al. (2016)Pakistan2013NutsTotal AF812/17615.16/2.22HPLCLipdal, Asi, Hanff, Zuber, and Jinap (2017)Staudi Arabia2013NutsTotal AF812/17615.16/2.22HPLCLipdal, Asi, Hanff, Zuber, and Jinap (2017)Turkey2014Cow milkAFM1176/530.2-513.4/16.5HPLCGolze (2014)Turkey2016FigsTotal AF812/1760.1-28.2/3.8"HPLCKabak (2016)Turkey2016FigsTotal AF812/1760.1-28.2/3.8"HPLCKabak (2016)Turkey<	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)
Voghurt AFM ₁ 42/10 0.006-0.021/0.015 ⁴ Korea 2015 Functional foods AFB ₁ 185/0 NI HPLC Lec.Ly, and Lec (2015) Malaysia 2014 Spaghetti Total AFS 25/7 0.05/51.4 HPLC Iqbal, Asi, and Jinap (2014) Malaysia 2017 Cow milk AFB ₁ 237/98 0.046-69/01.32 HPLC Iqbal, Asi, and Jinap (2014) Pakistan 2016 Milk AFB ₁ 237/98 0.046-69/01.32 HPLC Iqbal, Asi, Hanif, Zuber, and Jinap (2017) Pakistan 2016 Milk AFM ₁ 520/484 0.001-0.26/0.103 ELISA Ismail et al. (2016) Pakistan 2017 Chilies Total AFS 1827/597 0.2-513.4/16.5 HPLC Iqbal, Asi, Hanif, Zuber, and Jinap (2017) Turkey 2016 Figs Total AFS 130/16 0.328/2.38" HPLC Kabak (2016) Turkey 2015 Wheat flour AFB ₁ 24/16 0.041-1.12/0.19 Europe Europe Figs	Iran	2016	Cow milk	AFM_1	64/54	0.006-0.188/0.059 ^a	HPLC	Bahrami, Shahbazi, and Nikousefat (2016)
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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 Iqbal, Asi, and Jinap (2014) Pakistan 2014 Cereals AFB ₁ 337/98 0.046-6.90/1.32 HPLC Iqbal, Asi, and Jinap (2014) Pakistan 2016 Milk AFM ₁ 520/484 0.001-0.26/0.103 ELISA Ismail et al. (2016) Pakistan 2017 Chiles Total AFs 520/484 0.001-0.26/0.103 ELISA Ismail et al. (2016) Saudi Arabia 2013 Nuts Total AFs 526/470 1.0-110/8.1 HPLC EliSA Igbal, Asi, Hanif, Zuber, and Jinap (2017) Turkey 2014 Cow milk AFM ₁ 176/53 0.02-513.4/16.5 HPLC Chen, Liao, Lin, Chiueh, and Shih (2013) Turkey 2016 Figs Total AFs 130/16 0.1-28.2/3.8" HPLC Kara, Ozbey, and Kabak (2016) Turkey 2016 Keat flour AFB ₁ 2370 0.291.4 Kara, Ozbey, and Kabak (2015) ELI	Korea	2015	Functional foods	AFB_1	185/0	NI	HPLC	Lee, Lyu, and Lee (2015)
Malaysia 2017 Cow milk AFM ₁ 102 $0.020-0.142/0.092^{\circ}$ HPLC Shuib, Makahleh, Salhimi, and Saad (2017) Pakistan 2016 Kerals AFB ₁ 237/98 $0.04-6.90/1.32$ HPLC Iqbal et al. (2014) 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) 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° HPLC Kabak (2016) Turkey 2016 Figs Total AFS 130/16 0.1-28.2/3.8° HPLC Kabak (2015) Maize flour AFB ₁ 237/9 0.03-0.55 HPLC Kabak (2016) Turkey 2017 Corn AFB ₁ 24/16 0.041-1.12/0.19 Kabak (2016) Vietnam 2017 Corn AFB ₁ 237/9 0.005-0.016/0.0	Malaysia	2014	Spaghetti	Total AFs	25/7	0.05/51.4	HPLC	Iqbal, Asi, and Jinap (2014)
Pakistan 2014 Cereals AFB ₁ 237/98 $0.04-6.90/1.32$ HPLC liphal 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 1827/597 $0.2-513.4/16.5$ HPLC Chen, Liao, Lin, Chiueh, and Shih (2013) Turkey 2014 Cow milk AFM ₁ 176/53 $0.037.05.5$ 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 2370 $1.0-34.8/13.1$ ELISA Lee et al. (2017) Europe:	Malaysia	2017	Cow milk	AFM_1	102	$0.020 - 0.142 / 0.092^{a}$	HPLC	Shuib, Makahleh, Salhimi, and Saad (2017)
Pakistan 2016 Milk AFM1 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 Golze (2014) Turkey 2016 Figs Total AFs 1827/597 0.32/0.55 HPLC Golze (2014) Turkey 2016 Figs Total AFs 130/16 0.1-28.2/3.8 ^a HPLC Kabak (2016) Turkey 2015 Wheat flour AFB1 60/0 NI HPLC Kabak (2015) Maize flour AFB1 2370 1.0-34.8/13.1 ELISA Lee et al. (2017) Europe:	Pakistan	2014	Cereals	AFB ₁	237/98	0.04-6.90/1.32	HPLC	Iqbal et al. (2014)
Pakistan2017ChilesTotal AFs $312/176$ $15.16/2.22$ HPLCIqbal, Asi, Hanf, Zuber, and Jinap (2017)Saudi Arabia2013NutsTotal AFs 26470 $1.0-110/8.1$ HPLCEl Tawila, Neamatallah, and Serdar (2013)Taiwan2013Peanut productsTotal AFs $1827/597$ $0.2-513.4/16.5$ HPLCChen, Liao, Lin, Chiueh, and Shih (2013)Turkey2016FigsTotal AFs $130/16$ $0.1-28.2/3.8^a$ HPLCKabak (2016)Turkey2015Wheat flourAFB ₁ $60/0$ NIHPLCKabak (2016)Maize flourAFB ₁ $24/16$ $0.041-1.12/0.19$ Kabak (2017)Vietnam2017CornAFB ₁ 2370 $1.0-34.8/13.1$ ELISALee et al. (2017)Europe:Greece2013MilkAFM ₁ $196/91$ $< 0.005-0.016/0.01^a$ ELISATsakiris et al. (2013)Italy2014SpicesAFB ₁ $130/20$ $0.59-5.38/0.31$ HPLCPrelle, Spadaro, Garibaldi, and Gullino (2014)Italy2013Cow milkAFM ₁ $496/79$ $0.004/0.05$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013CornTotal AFS $380/137$ $1.01-86.1/36.3^a$ ELISAKos, Mastilović, Hajnal, and Šarić (2013)Serbia2014Different types of milkAFM ₁ $176/165$ $0.01/1.20$ ELISAKos, Levi, Duragi, Koki, and Miladinovi (2014)Serbia2015MilkAFM ₁ $80/74$ <td>Pakistan</td> <td>2016</td> <td>Milk</td> <td>AFM₁</td> <td>520/484</td> <td>0.001-0.26/0.103</td> <td>ELISA</td> <td>Ismail et al. (2016)</td>	Pakistan	2016	Milk	AFM ₁	520/484	0.001-0.26/0.103	ELISA	Ismail et al. (2016)
Sauda Arabia2013NutsTotal AFs264/701.0-110/8.1HPLCEl Tawila, Neamataliah, and Serdar (2013)Taiwan2013Peanut productsTotal AFs1827/597 $0.2-513.4/16.5$ HPLCGolze (2014)Turkey2016FigsTotal AFs130/16 $0.370.55$ HPLCGolze (2014)Turkey2015Wheat flourAFB60/0NIHPLCKabak (2016)Turkey2017CornAFB60/0NIHPLCKara, Ozbey, and Kabak (2015)Maize flourAFB2370 $1.0-34.8/13.1$ ELISALee et al. (2017)Vietnam2017CornAFB130/20 $0.59-5.38/0.31$ HPLCPrelle, Spadaro, Garibaldi, and Gulino (2014)Italy2014SpicesAFB130/20 $0.59-5.38/0.31$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013Cow milkAFM804/79 $0.004/0.05$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013Cow milkAFM40/11 $0.005-0.069/0.024^a$ ELISADuarte et al. (2013)Serbia2014Different types of milkAFM176/165 $0.01/1.20$ ELISAKos, Levi, Duragi, Koki, and Miladinovi (2014)Serbia2015MilkAFM80/74 $< 0.003-0.020/0.020^a$ Torović (2015)Spain2013CornTotal AFS380/137 $1.01-86.1/36.3^a$ ELISAKos, Levi, Duragi, Koki, and Miladinovi (2014)Serbia	Pakistan	2017	Chilies	Total AFs	312/176	15.16/2.22	HPLC	Iqbal, Asi, Hanif, Zuber, and Jinap (2017)
Tarkey2013Peanut productsTotal AFs182/797 $0.2-513.4716.5$ HPLCChen, Liao, Lin, Chulen, and Shin (2013)Turkey2014Cow milkAFM1176/53 $0.03/0.55$ HPLCGolze (2014)Turkey2015FigsTotal AFs130/16 $0.1-28.2/3.8^a$ HPLCKabak (2016)Turkey2015Wheat flourAFB1 $60/0$ NIHPLCKara, Ozbey, and Kabak (2015)Vietnam2017CornAFB1 $24/16$ $0.041-1.12/0.19$ Lee et al. (2017)Europe:	Saudi Arabia	2013	Nuts	Total AFs	264/70	1.0-110/8.1	HPLC	El Tawila, Neamatallan, and Serdar (2013)
Intreey2014Cow minkAFM1176/53 $0.03/0.55$ HPLCGolze (2014)Turkey2016FigsTotal AFs130/16 $0.1-28.2/3.8^{a}$ HPLCKabak (2016)Turkey2015Wheat flourAFB1 $60/0$ NIHPLCKabak (2016)Maize flourAFB1 $24/16$ $0.041-1.12/0.19$ Kara, Ozbey, and Kabak (2015)Vietnam2017CornAFB1 2370 $1.0-34.8/13.1$ ELISALee et al. (2017)Europe:	Taiwan	2013	Peanut products	I OTAL AFS	182//59/	0.2-513.4/10.5	HPLC	Coleo (2014)
Integ2010Figs10d AF130/10 $0.1-20.2/3.5$ HFLRadak (2010)Turkey2015Wheat flourAFB160/0NIHPLCKara, Ozbey, and Kabak (2015)Maize flourAFB124/16 $0.041-1.12/0.19$ Kara, Ozbey, and Kabak (2015)Vietnam2017CornAFB12370 $1.0-34.8/13.1$ ELISALee et al. (2017)Europe:Greece2013MilkAFM1196/91< $0.005-0.016/0.01^a$ ELISATsakiris et al. (2013)Italy2014SpicesAFB1130/20 $0.59-5.38/0.31$ HPLCPrelle, Spadaro, Garibaldi, and Gullino (2014)Italy2017Buffalo and cow milkAFM1804/79 $0.004/0.05$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013CornTotal AFS380/137 $1.01-86.1/36.3^a$ ELISADuarte et al. (2013)Serbia2014Different types of milkAFM1176/165 $0.01/1.20$ ELISAKos, Levi, Duragi, Koki, and Miladinovi (2014)Serbia2015MilkAFM180/74< $0.003-0.319/0.026$ HPLCTorović (2015)Spain2013CerealsTotal AFs67/0NIHPLCVidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)	Turkey	2014	COW IIIIIK	Arivi ₁ Totol AFo	1/0/33	0.03/0.35 0.1. 20.2 /2.0 ²	HPLC	G012e (2014) Kabak (2016)
Indice2013Writer hour Maize flourAFB1 AFB124/16 24/160.041-1.12/0.19IFFCRata, Obely, and Radak (2013)Vietnam2017CornAFB1 Corn2370 $1.0-34.8/13.1$ ELISALee et al. (2017)Europe: Greece2013MilkAFM1 Spices196/91< $0.005-0.016/0.01^a$ ELISATsakiris et al. (2013)Italy2014SpicesAFB1 Spices130/20 $0.59-5.38/0.31$ HPLCPrelle, Spadaro, Garibaldi, and Gullino (2014)Italy2017Buffalo and cow milkAFM1 AFM1804/79 $0.004/0.05$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013Cow milkAFM1 	Turkey	2010	Wheat flour	AER.	130/10 60/0	0.1-20.2/ 5.0 NI	HPLC	Kabak (2010)
Vietnam2017CornAFB123701.0-34.8/13.1ELISALee et al. (2017)Europe: Greece2013MilkAFM1196/91< 0.005-0.016/0.01a	Turkey	2015	Maize flour	AFB.	24/16	0.041-1.12/0.19	III LC	Kara, Ozbey, and Kabak (2013)
Europe: Greece2013MilkAFM1196/91< 0.005-0.016/0.01aELISATsakiris et al. (2013)Italy2014SpicesAFB1130/20 $0.59-5.38/0.31$ HPLCPrelle, Spadaro, Garibaldi, and Gullino (2014)Italy2017Buffalo and cow milkAFM1804/79 $0.004/0.05$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013CornTotal AFs380/137 $1.01-86.1/36.3^{a}$ ELISADuarte et al. (2013)Serbia2014Different types of milkAFM1176/165 $0.01/1.20$ ELISAKos, Mastilović, Hajnal, and Šarić (2013)Serbia2015MilkAFM180/74< $0.003-0.319/0.026$ HPLCTorović (2015)Spain2013CerealsTotal AFs67/0NIHPLCVidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)	Vietnam	2017	Corn	AFB ₁	2370	1.0-34.8/13.1	ELISA	Lee et al. (2017)
Europe:Greece2013MilkAFM1196/91< 0.005-0.016/0.01a				1				
Greece 2013 Milk AFM ₁ 196/91 $< 0.005 - 0.016/0.01^a$ ELISA Tsakins 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 $< 0.03-0.020/0.020^a$ HPLC Torović (2015) Infant formula 21/1 $< 0.03-0.020/0.020^a$ HPLC Vidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)	Europe:				4.0.4 (0.4			
Italy2014Spices AFB_1 $130/20$ $0.59-5.38/0.31$ HPLCPrelie, Spadaro, Garibaidi, and Gullino (2014)Italy2017Buffalo and cow milk AFM_1 $804/79$ $0.004/0.05$ HPLCDe Roma, Rossini, Ritieni, Gallo, and Esposito (2017)Portugal2013Cow milk AFM_1 $40/11$ $0.005-0.069/0.024^a$ ELISADuarte et al. (2013)Serbia2013CornTotal AFs $380/137$ $1.01-86.1/36.3^a$ ELISAKos, Mastilović, Hajnal, and Šarić (2013)Serbia2014Different types of milk AFM_1 $176/165$ $0.01/1.20$ ELISAKos, Levi, Đuragi, Koki, and Miladinovi (2014)Serbia2015Milk AFM_1 $80/74$ $< 0.003-0.319/0.026$ HPLCTorović (2015)Spain2013CerealsTotal AFs $67/0$ NIHPLCVidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)	Greece	2013	Milk	AFM ₁	196/91	< 0.005-0.016/0.01	ELISA	Tsakiris et al. (2013)
Italy2017Buffalo and cow milk AFM_1 $8047/9$ $0.004/0.05$ HPLCDe Roma, Rossini, Riteri, Galio, and Esposito (2017)Portugal2013Cow milk AFM_1 $40/11$ $0.005-0.069/0.024^a$ ELISADuarte et al. (2013)Serbia2013CornTotal AFs $380/137$ $1.01-86.1/36.3^a$ ELISAKos, Mastilović, Hajnal, and Šarić (2013)Serbia2014Different types of milk AFM_1 $176/165$ $0.01/1.20$ ELISAKos, Levi, Đuragi, Koki, and Miladinovi (2014)Serbia2015Milk AFM_1 $80/74$ < $0.003-0.319/0.026$ HPLCTorović (2015)Spain2013CerealsTotal AFs $67/0$ NIHPLCVidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)	Italy	2014	Spices	AFB ₁	130/20	0.59-5.38/0.31	HPLC	Prelle, Spadaro, Garibaldi, and Gullino (2014)
Portugal 2013 Cow milk AFM1 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 AFM1 176/165 0.01/1.20 ELISA Kos, Levi, Đuragi, Koki, and Miladinovi (2014) Serbia 2015 Milk AFM1 80/74 < 0.03-0.319/0.026	Italy	2017	Buffalo and cow milk	AFM ₁	804/79	0.004/0.05	HPLC	(2017) (2017) (2017) (2017) (2017)
Serbia2013CornTotal AFs380/1371.01–86.1/36.3ªELISAKos, Mastilović, Hajnal, and Šarić (2013)Serbia2014Different types of milkAFM1176/1650.01/1.20ELISAKos, Levi, Đuragi, Koki, and Miladinovi (2014)Serbia2015MilkAFM180/74< 0.003–0.319/0.026	Portugal	2013	Cow milk	AFM_1	40/11	0.005-0.069/0.024 ^a	ELISA	Duarte et al. (2013)
Serbia 2014 Different types of milk AFM1 176/165 0.01/1.20 ELISA Kos, Levi, Đuragi, Koki, and Miladinovi (2014) Serbia 2015 Milk AFM1 80/74 < 0.003-0.319/0.026	Serbia	2013	Corn	Total AFs	380/137	1.01-86.1/36.3 ^a	ELISA	Kos, Mastilović, Hajnal, and Šarić (2013)
Serbia 2015 Milk AFM1 80/74 < 0.003-0.319/0.026 HPLC Torović (2015) Infant formula 21/1 < 0.03-0.020/0.020 ^a Vidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)	Serbia	2014	Different types of milk	AFM_1	176/165	0.01/1.20	ELISA	Kos, Levi, Đuragi, Koki, and Miladinovi (2014)
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)	Serbia	2015	Milk	AFM_1	80/74	< 0.003-0.319/0.026	HPLC	Torović (2015)
Spain 2013 Cereals Total AFs 67/0 NI HPLC Vidal, Marín, Ramos, Cano-Sancho, and Sanchis (2013)			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 AFB ₁ 94/24 < 0.025–0.17/NI LC-MS Luzardo et al. (2016)	Spain	2016	Toasted cereal flour	AFB_1	94/24	< 0.025-0.17/NI	LC-MS	Luzardo et al. (2016)
(gofio) AFB ₂ 94/23 < 0.025–0.07/NI	•		(gofio)	AFB ₂	94/23	< 0.025-0.07/NI		
AFG_1 94/9 < 0.025–0.12/NI				AFG_1	94/9	< 0.025-0.12/NI		
AFG_2 94/8 < 0.025–0.17/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 AFB₁, 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 Download English Version:

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