Chapter 3
Worldwide Prevalence of Aflatoxins in Food and Feed

Yusuf Opeyemi Oyebamiji, Kamoldeen Abiodun Ajijolakewu, and Ismail Abiola Adebayo

Abstract Aflatoxins are poisonous toxins produced by *Aspergillus* spp. They are groups of highly toxic and carcinogenic secondary metabolic products, which contaminate food and feeds consumed by humans and animals. These adverse properties of aflatoxins cause economic loss and health-related problems such as chronic and acute effects and sometimes lead to death when severe. Aflatoxin contamination of crops is common and usually found in dietary staple foods such as maize, groundnut, rice, and milk due to fungal infection before and after harvest. This makes aflatoxins a real threat to food security, safety, as well as population growth. Identification, detection, and elimination of aflatoxins and the use of strategic management approaches have become necessities in order to guarantee food safety. This book chapter focuses on the occurrence of aflatoxin contamination in crops around the world.

Keywords Aflatoxins · Contaminate · Food · Feed · Threat · Population · Management

3.1 Introduction

Recently, the entire universe has encountered a major challenge of food security and protection as part of the major difficulties affecting the entire population of the world. Food safety and security are primarily defined by (i) adequate availability of

Y. O. Oyebamiji
Department of Biological Sciences and Biotechnology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

K. A. Ajijolakewu
Department of Microbiology, Faculty of Life Sciences, University of Ilorin, Ilorin, Kwara State, Nigeria

I. A. Adebayo (✉)
Microbiology and Immunology Department, Faculty of Biomedical Sciences, Kampala International University, Ishaka-Bushenyi, Uganda
e-mail: ismail.abiola@kiu.ac.ug

K. R. Hakeem et al. (eds.), *Aflatoxins in Food*, https://doi.org/10.1007/978-3-030-85762-2_3

food; (ii) quality, nutritional, and cultural use of food for healthy life, and (iii) access to safe food (Nazhand et al. 2020). Factors connected to food scarcity, insecurity, and nutritional imbalance not only affect human health and well-being but also play key roles in the economic, political, and social outlook of a society. In respect to the foremost point, pre-harvest and post-harvest losses due to the contamination of mycotoxin are reported as one of the main factors causing insecurity of food since these substances occur along most food chains from farm to fork (Udomkun et al. 2017).

In the 1960s, more than hundreds of deaths were reported in Turkey due to the consumption of groundnut meal which was infected by mold, which brought about the advent and discovery of aflatoxins. A toxin secreted by two fungi, which are *Aspergillus flavus* and *Aspergillus parasiticus*, in several cultivars of agricultural crops is known as aflatoxin (Khlangwiset et al. 2011). Aflatoxins are groups of highly toxic secondary metabolic products of some *Aspergillus* spp. such as *Aspergillus flavus*, *Aspergillus parasiticus*, *Aspergillus nomius*, *Aspergillus fumigatus*, and *Aspergillus tamari*, though they are also produced by species such as *Emericella* spp. Aflatoxins are reported in feeds and foods during germination, cultivation, and storage stage. Both fungus (*Aspergillus flavus* and *Aspergillus parasiticus*) are predominant in crops, especially in groundnut, tree nuts, oil seeds, and maize, and in subtropical and tropical areas throughout the world (Khlangwiset et al. 2011). A study has shown that groundnuts are vulnerable and susceptible agricultural crops to aflatoxin contamination due to their relatively high moisture content, cultivation methods, and storage process which favored mold attack (Wu 2006). Furthermore, due to conducive social and environmental conditions, most countries which are developing and underdeveloped experience more cases of aflatoxin contamination in foods on a frequent basis (Ismail et al. 2015; Wu 2006).

More than 5 billion individuals are at risk of chronic exposure to aflatoxins, mostly in the developing countries. The tolerance level of the plant varieties to change in climate, rainfall pattern and drought, framing practices, and insect damage are factors that influence aflatoxin production by fungi. As earlier stated, the fungal contamination can occur during post-cultivation activities and crops such as groundnut and maize are highly vulnerable to *Aspergillus* attack due to the high level of consumption (Khlangwiset et al. 2011; Strosnider et al. 2006). Aflatoxins are of several types, but the popular ones are aflatoxin B_1 (AFB_1), aflatoxin B_2 (AFB), aflatoxin G_1 (AFG_1), and aflatoxin G_2. AFG_2, are capable of poisoning the body through respiratory, mucous, or cutaneous pathways, which prompt excess activation of inflammatory response, while aflatoxin M_1 (AFM_1) and aflatoxin M_2 (AFM_2) are found in milk and are the hydroxylated metabolites of AFB_1 and AFB_2 (Kumar et al. 2017). The level of toxicity of the aflatoxins increases in the order G_2, B_2, G_1, and B_1. Aflatoxins are known to be cancerous, mutagenic, and teratogenous in nature to humans and animals (Galvano et al. 1996). The International Agency for Research on Cancer (IARC) has categorized aflatoxins B_1 (AFB_1) as a group 1 carcinogen ("carcinogenic to humans") (Wu et al. 2009). The chain of transmission of aflatoxins from fungi to humans is shown in Fig. 3.1.

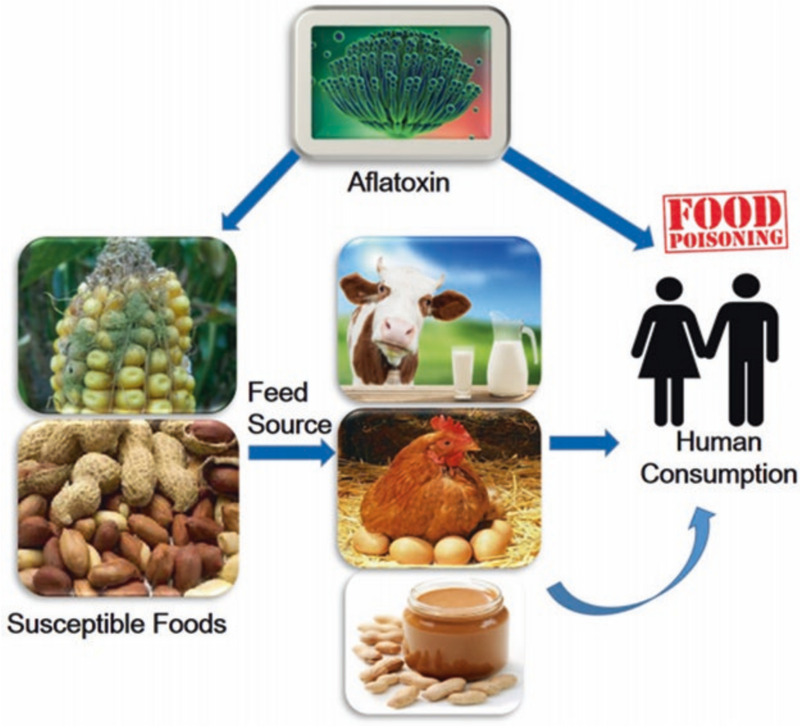

Fig. 3.1 Transmission chain of aflatoxin from fungi to humans. (Source: Kumar et al. 2017)

3.2 World Population Growth and Food Production Level

Figure 3.2 shows the increasing rate of population growth among the ten most populous countries around the world. These countries include China, India, The United States of America, Indonesia, Pakistan, Brazil, Nigeria, Bangladesh, Russia, and Mexico. China emerges as the most populous country in the world with 1,439,323,776 people followed by India and the United States of America with 1,380,004,385 and 331,002,651 people, respectively. As the world population increases, the demand, supply, and consumption rates of food produce such as cereals, legumes, oilseed, and vegetables increase which indicate that population growth is directly proportional to demand. Planting and cultivation of major cereal crops such as rice, maize, and wheat have also increased tremendously across the world. For example, the amount of cultivated rice, maize, and wheat has increased in multiple folds between 1968 and 2018 (Fig. 3.3). This increase is necessary in order to meet the frequent population growth and high consumption level of food worldwide. This continuous increase in the trend of all crops is essential in order to mitigate the threat to food security. Different factors such as *water use, pest infestation, efficiency of fertilizer use, production costs, government support, and change in farming systems have a*

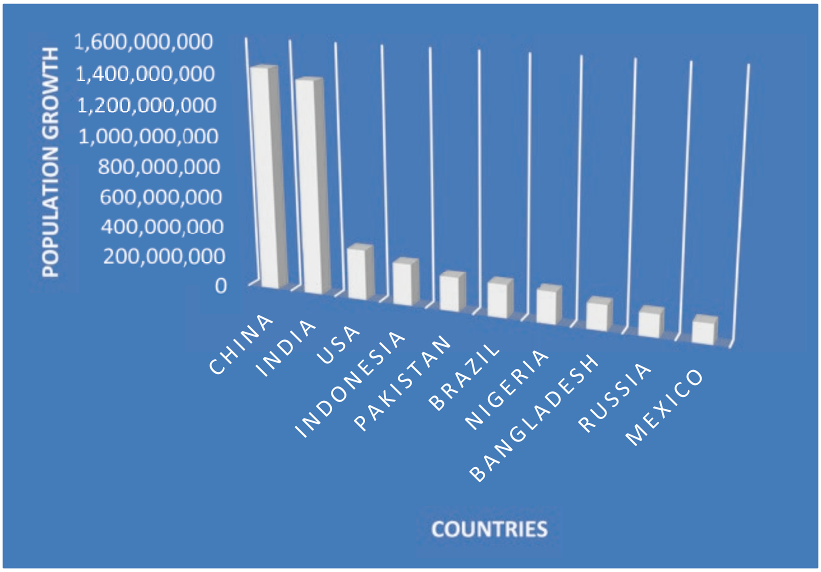

Fig. 3.2 Increasing population growth. (Source: Population by Country (2020) (Worldometers 2020))

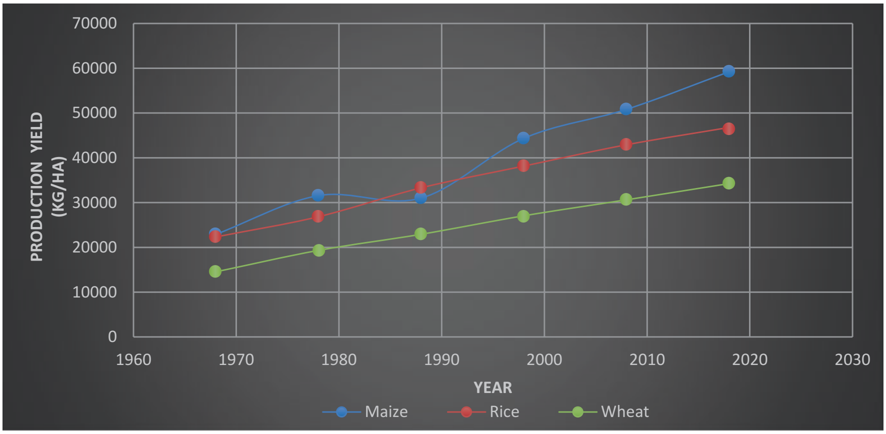

Fig. 3.3 World cereal production rate. (Source: FAOSTAT 2020)

major impact on crop production (Chang 1993). In 2016, the Food and Agriculture Organization (FAO) of the United Nations set the seventh sustainable developmental goal which is aimed to reduce hunger in different parts of the world by 2030. This may be difficult to achieve due to the advent of several threats which include environmental and abiotic stress such as drought and submergence and biotic stress such as pest, diseases, and fungi, especially aflatoxins that are having a massive effect on food production particularly cereals which are particularly vulnerable to the mycotoxins.

3.3 Occurrence of Aflatoxins in Feed and Food

The World Health Organization has declared aflatoxin as a threat to food security worldwide (Ali 2019). The presence of aflatoxin has been noticed in many food commodities and in animal feed. Certain crops and feeds which are predominately affected by aflatoxins include cereals (rice, corn, wheat, barley), oil seeds (groundnut, peanuts, almonds, pistachios, and other tree nuts), spices, fig, dried fruits, milk and dairy products, and other foods of animal origin (meat, offal, eggs).

3.3.1 Occurrence of Aflatoxins in Cereals

Cereals and their derivatives are the world's primary foodstuffs for human consumption. Grains of cereal crops such as barley, wheat, sorghum, and corn are prone to aflatoxin accretion, as a result of the presence of aflatoxigenic fungus. Aflatoxin complication which occurs in nature, especially in corn and rice, has become more severe due to frequent change in technological advancement in the agriculture sector. The problem of aflatoxin encountered in cereals is not confined to a particular climatic condition or geographical location of a place. Toxins occur in cereal crops at different stages such as on the field, in storage, on the seed, and in the entire plant (Filazi and Sireli 2013). It was reported that out of all the cereal crops tested for different types of aflatoxins, about 36.7% were infected. The degree of fungal growth and aflatoxin infection in cereals depends on multiple factors such as moisture content, temperature, types of soil, and mode of storage (Mahato et al. 2019). Table 3.1 highlights the occurrence of aflatoxin in cereal crops around the world.

Rice is the main cereal grain for half of the world's population followed by wheat, accounting for more than 19% of daily calories. Asia is considered the continent with the highest rice production and consumption. Rice is usually planted and harvested in a subtropical area under a hot and humid climatic condition which enhances the growth of fungus and the secretion of secondary metabolites. Rice may be infected with fungus-producing aflatoxins when the environment is conducive for their growth on the field, during cultivation, handling, and storage. Several studies have documented the occurrence of aflatoxins in rice which is highly predominant in many Asian countries (Ali 2019). Besides other mycotoxins, AFB_1 has been reported to have invaded rice in several countries such as China, the United Kingdom, the United States of America, India, Malaysia, Nepal, Iran, Pakistan, the Philippines, and Egypt (Mahato et al. 2019). The adverse consequences of this form of fungal attack include grain and/or husk discoloration, loss of viability, loss of quality, and contamination with toxins (Filazi and Sireli 2013). The high rate of invasion or occurrence of aflatoxins in rice and its derivatives has highlighted the significance of stringent control of this dietary staple food globally (Ali 2019).

Apart from rice, sorghum is a popular and staple food for most countries. Sorghum is planted in severe environmental conditions, whereby most other crops will not flourish or germinate well. Increasing and improving the

Table 3.1 The occurrence of aflatoxins in cereals

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
White rice	2016	Pakistan	34/14	AFB_1	Mean 7.74	HPLC	Iqbal et al. (2016)
Oat	2011	Malaysia	10/5	AFB_1	0.65–2.85	ELISA	Filazi and Sireli (2013)
Corn	2010	Brazil	214/82	AFB_1	0.2–129	–	Vargas et al. (2001)
Wheat	1999	Ethiopia	120/4.2	AFB_1	Mean 8.7	HPLC	Ayalew et al. (2006)
Rye	2018	Serbia	8/1	AFB_1	0.04	HPLC	Torović (2018)
Maize	2016	DRC	50/16	Total AFs	3.1–103.89	HPLC	Kamika et al. (2016)
Rice	2011	Canada	199/99	AFB_1	<0.002–7.1	HPLC	Filazi and Sireli (2013)
Rice	2018	Serbia	6/2	AFB_1	1.59–4.76	HPLC	Torović (2018)
Sorghum	2010	Tunisia	180	AFB_1	0.4–25.1	HPLC	Ghali et al. (2010); Mahato et al. (2019)
Sorghum	1990	India	150/4	Total AFs	0.02–0.06	TLC	Ramakrishna et al. (1990)
Cereal-based products	2013	Ghana	50/36	Total AFs	0.18–23.27	HPLC	Blankson et al. (2019)
Rice	2009	Iran	71/59	AFB_1	2.09	HPLC	Mazaheri (2009)
Rice	2015	China	370/235	Total AFs	Mean 0.65	HPLC	Lai et al. (2014)
Wheat	2008	Nigeria	–	AFB_1	17.01–20.53	TLC	Odoemelam and Osu (2009)
White corn	2019	Egypt	27/6	AFB_1	0.26–28.9	HPLC	El Sayed et al. (2019)
Maize	2016	DRC	50/16	AFB_1	1.5–51.23	HPLC	Kamika et al. (2016)
Sorghum	1999	Ethiopia	82/6.1	AFB_1	Mean 10.0	HPLC	Ayalew et al. (2006)
Breadfruit	2008	Nigeria	–	AFB_1	40.06–48.59	TLC	Odoemelam and Osu (2009)
Corn	2013	Serbia	10/8	AFB_1	3.88	HPLC	Torović (2018)
Maize	2014	India	150/28	AFB_1	48–58	HPLC/PCR	Mudili et al. (2014)
Rice		India	1511/581	AFB_1	5	HPTLC	Filazi and Sireli (2013)
Sorghum	2000	Brazil	140/18	AFB_1	Mean 7–33	–	Da Silva et al. (2000)
White yam	2011	Nigeria	100/21	AFB_1	<0.05–3.5	HPLC	Somorin et al. (2012)
Yellow corn	2019	Egypt	29/10	AFB_1	0.33–38.88	HPLC	El Sayed et al. (2019)

Rice flour	2016	Pakistan	30/11	AFB_1	Mean 3.51	HPLC	Iqbal et al. (2016)
Corn	2016	Serbia	600/30	Total AFs	1.3–6.9	ELISA	Kos et al. (2018)
White yam	2011	Nigeria	100/57	AFB_1	<0.02–3.2	HPLC	Somorin et al. (2012)
Corn	1990	India	102/45	Total AFs	0.02–74	TLC	Ramakrishna et al. (1990)
Wheat	20,020	Lebanon	25/3	AFB_1	1.05–2.20	HPLC	Joubrane et al. (2020)
Sorghum	2016	Ethiopia	30	Total AFs	11.44–344.26	HPLC	Weledesemayat et al. (2016)
Corn	2017	Vietnam	2370	AFB_1	1.0–34.8	ELISA	Ismail et al. (2018)
Maize	2017	Zimbabwe	388/80	AFB_1	0.56–26.6	HPLC	Murashiki et al. (2017)
Corn	2009	Italy	46/44	AFB_1	0.15–560	HPLC	Kos et al. (2018); Leggieri et al. (2015)
Maize	2006	China	73/71	Total AFs	Mean 0.99	–	Liu et al. (2006)
Rice	2019	Egypt	12/4	AFB_1	1.56–16.67	HPLC	El Sayed et al. (2019)
Brown rice	2016	Pakistan	28/15	AFB_1	Mean 8.91	HPLC	Iqbal et al. (2016)
Corn	2011	Italy	46/27	AFB_1	0.15–335	HPLC	Kos et al. (2018), Leggieri et al. (2015)
Rice	2009	India	1200/814	AFB_1	0.1–308	ELISA	Filazi and Sireli (2013)
Whole grain rice	2006	China	16/16	Total AFs	Mean 3.87	HPLC	Liu et al. (2006)
Corn	2015	Serbia	14/1	AFB_1	8.80	HPLC	Torović (2018)
Maize	2009	Mexico	41/36	AFG_1	1.59–57.1	HPLC	Espinosa et al. (2009)
Rice	2010	Nigeria	21/21	Total AFs	27.7–371.9	HPLC	Makun et al. (2011)
Corn	2012	Serbia	600/434	Total AFs	1.0–111.2	ELISA	Kos et al. (2018)
Wheat	2010	Tunisia	180	AFB_1	0.12–18	HPLC	Ghali et al. (2010); Mahato et al. (2019)
Wheat	2019	Egypt	11/4	AFB_1	1.59–8.13	HPLC	El Sayed et al. (2019)
Corn	2008	Nigeria	–	AFB_1	27.22–36.13	TLC	Odoemelam and Osu (2009)
Sorghum	2018	Tunisia	64/38	AFB_1	0.03–31.7	HPLC-FLD	Lahouar et al. (2018)
Barley	1999	Ethiopia	113/11.3	AFB_1	Mean 3.8	HPLC	Ayalew et al. (2006)
Rice	2009	Iran	71/59	AFB_1	1.89	HPLC	Mazaheri (2009)
Maize	2013	Pakistan	380/137	Total AFs	1.01–86.1	ELISA	Kos et al. (2014)

(continued)

Table 3.1 (continued)

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
Maize	2009	Mexico	41/–	AFB_1	5.03–465.3	HPLC	Espinosa et al. (2009)
Corn	2013	Serbia	600/148	Total AFs	1.2–65.2	ELISA	Kos et al. (2018)
Maize	1999	India	127/18	AFB_1	23–26.8	Indirect competitive ELISA	Janardhana et al. (1999)
Corn	2016	Serbia	32/18	AFB_1	4.20	HPLC	Torović (2018)
Corn	2019	Togo	55/21	AFB_1	Max. 256	HPLC-MS/MS	Hanvi et al. (2019)
Corn	2015	Serbia	600/220	Total AFs	1.1–76.2	ELISA	Kos et al. (2018)
Brown rice	2006	China	37/36	Total AFs	Mean 0.88	HPLC	Liu et al. (2006)
Millet	2008	Nigeria	–	AFB_1	34–40.30	TLC	Odoemelam and Osu (2009)
Sorghum	2019	Togo	12/3	AFB_1	6–16	HPLC-MS/MS	Hanvi et al. (2019)
Maize flour	2015	Turkey	100	AFB_1	0.041–1.12	HPLC	Kara et al. (2015); Mahato et al. (2019)
Corn	2006	Morocco	20/10	AFB_1	Mean 1930	HPLC	Zinedine et al. (2006)

DLLME-HPLC, Dispersive liquid-liquid micro-extraction coupled with high-performance liquid chromatography with fluorescence detection; IAC, immunoaffinity column; SPE, solid-phase extraction; nd, not detected; LOD, limit of detection; LOQ, limit of quantification; AfT, total aflatoxins (i.e., sum of AFB_1, AFB_2, AFG_1, and AFG_2); SK, super kernel production level, easy accessibility, adequate storage, and process of this crop will significantly reduce the threat to food security and increase the nutritional level of the crop. Usually, sorghum is cultivated as fast as possible in order to allow the germination of other crops on the same field. In some cases, the cultivation of sorghum is done when there is a change in climatic conditions such as flooding, high rainfall, and hurricanes, thereby increasing the moisture content of the harvested crop which stimulates the growth of mycotoxin-producing fungus (Filazi and Sireli 2013).

3.3.2 Occurrence of Aflatoxins in Oil Seeds

Oil seed crops mainly include seed of flowers, soybeans, canola, safflower, rapeseed, peanuts, flaxseed, mustard seeds, and cotton seeds, used for different purposes such as cooking oil production, protein feed for animals, and commercial applications. Castor beans and sesame are other forms of known oil seeds. Following the removal of oil from the seeds, the remnants are a good source of protein, particularly for livestock meal, which includes press or oil cake (Filazi and Sireli 2013). The crop and its derivatives are mostly eaten as snacks, and some of its ingredients are included in a normal human meal. Being aware of mycotoxin's existence has led to an increasing concern about their existence in edible materials. Oil seed crops are considered as a possible substrate for the secondary metabolites by a fungus, particularly the induction of aflatoxin by toxigenic strains of *Aspergillus flavus* and *Aspergillus parasiticus* (Kershaw 1982). Peanut's moisture content is one of the major factors which trigger the growth of fungus and production of aflatoxins. The presence of a suitable climatic condition enhances fungal growth, thereby promoting a high risk of liver cancer (Kamika and Takoy 2011).

Aspergillus parasiticus regularly attack young plants of peanuts in a systemic manner as a seedling from the seed, soil, and spread to the entire plant although the leaves and petioles are less affected compared to the stems and roots which experienced severe infection (Klich 2007). Aflatoxin infection are observed in tree nuts which include walnuts, pistachios, and almonds, although at a minimal rate as compared with cottonseed and corn, nevertheless the situation is worrisome to the producer due to (i) high unit value of the crop and (ii) the crop are mostly bought by the European markets which impose a significant limit as compared to other nations. The infection of peanuts by aflatoxins due to the attack of either *A. flavus* or *A. parasiticus* is a major concern in tropical semi-arid areas where plants are mainly rainfed, while the contamination of peanuts by aflatoxins does not in any way reduce the harvested yield. However, accumulation of a high amount of aflatoxins induced by the fungus in the nut could threaten the well-being of the mankind and animals' health (Filazi and Sireli 2013). Aflatoxin occurrence in oil seeds in different regions around the world is highlighted in Table 3.2.

Table 3.2 The occurrence of aflatoxins in oil seeds

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
Raw peanuts	2016	Zambia	92/51	Total AFs	0.015–46.60	HPLC	Bumbangi et al. (2016)
Peanuts	2006	Turkey	18/7	AFB_1	8–94	TLC	Gürses (2006)
Pistachio	2012	Iran	32/17	Total AFs	1–54	HPLC	Shadbad et al. (2012)
Musty peanuts	2010	China	5/5	Total AFs	1.2–1482.3	UHPLC–MS/MS	Huang et al. (2010)
Groundnut	2012	Ethiopia	120/93	Total AFs	15–11,900	ELISA	Gürses (2006)
Peanut butter	2007	Trinidad	32/0	AFB_1	ND	Charm II	Offiah and Adesiyun (2007)
Peanut butter	2008	Japan	21/10	AFB_1	Max. 2.59	LC/MS, HPLC, HPTLC	Kumagai et al. (2008)
Almond	2006	Turkey	13/3	AFB_1	1–13	TLC	Gürses (2006)
Cacao hazelnut cream	2005	Turkey	40/37	Total AFs	1–10	ELISA	Aycicek et al. (2005)
Nuts	2013	Iran	200/193	Total AFs	Mean 1.68	ELISA	Rezaei et al. (2014)
Cashew nuts	2013	Brazil	70/22	Total AFs	2–4	ELISA	Milhome et al. (2014)
Peanut products	1996	Brazil	80/41	Total AFs	43 to 1099	TLC	Freitas and Brigido (1998)
Peanuts	2003	Botswana	93/120	Total AFs	12.0–329	HPLC	Mphande et al. (2004)
Walnut	2012	Iran	26/20	Total AFs	1–54	HPLC	Shadbad et al. (2012)
Nuts	2013	Saudi Arabia	264/70	Total AFs	1–110	IAC/HPLC	El tawila et al. (2013)
Fresh peanuts	2010	China	35/14	Total AFs	Mean 2.5	UHPLC–MS/MS	Huang et al. (2010)
Nuts	2013	Iran	167/100	Total AFs	Mean 1.12	ELISA	Ali et al. (2013)

Peanuts	2001	Argentina	50/2	AFB_1	435–625	TLC	Fernandez Pinto et al. (2001)
Walnut	1993	Egypt	20/15	Total AFs	15–25	TLC	Abdel-Hafez and Saber (1993)
Peanut	2011	Malaysia	13/11	AFB_1	1.47–15.33	ELISA	Filazi and Sireli (2013)
Peanut	2012	Iran	6/2	AFB_1	<5	HPLC	Shadbad et al. (2012)
Walnut	2006	Turkey	24/6	AFB_1	3–28	TLC	Gürses (2006)
Dehulled hazelnut	2005	Turkey	51/20	Total AFs	1–10	ELISA	Aycicek et al. (2005)
Peanuts	2001	Argentina	50/2	AFG_1	83–625	TLC	Fernandez Pinto et al. (2001)
Pistachio	2010	Turkey	95/48	Total AFs	0.007–7.72	HPLC	Set and Erkmen (2010)
Peanuts		Taiwan	1827/597	Total AFs	0.2–513.4	HPLC	Chen et al. (2013)
Hazelnut	1993	Egypt	20/18	Total AFs	25–175	TLC	Abdel-Hafez and Saber (1993)
Peanut	2007	Trinidad	140/0	AFB_1	ND	Charm II	Offiah and Adesiyun (2007)
Hazelnut	2012	Iran	13/1	Total AFs	1–13	HPLC	Shadbad et al. (2012)
Peanut butters	2010	China	33/31	Total AFs	0.7–95.9	UHPLC–MS/MS	Huang et al. (2010)
Untreated nuts	2013	Iran	109/44	Total AFs	0–38.1	ELISA	Ostadrahimi et al. (2014)
Sunflower	2011	Malaysia	7/6	AFB_1	1.14–5.33	ELISA	Filazi and Sireli (2013)
Hazelnut	2006	Turkey	28/9	AFB_1	1–113	TLC	Gürses (2006)
Almond	2012	Iran	35/5	Total AFs	<5	HPLC	Shadbad et al. (2012)
Salt roasted nuts	2013	Iran	62/21	Total AFs	0–52.3	ELISA	Ostadrahimi et al. (2014)

(a) Total: $AFB_1 + AFB_2 + AFG_1 + AFG_2$
(b) ND: not detected

3.3.3 Occurrence of Aflatoxins in Spices

For many decades, spices have been utilized as fragrance, color, and preservatives for beverages, food, and flavor. In regard to the world commercial value, the most important spices include black pepper (*Piper nigrum* L.), chili (*Capsicum annuum* L.), nutmeg (*Myristica fragrans*), cumin (*Cuminum cyminum*), cinnamon (*Cinnamomum*), ginger (*Zingiber officinale*), turmeric (*Curcuma longa*), cloves (*Syzygium aromaticum*), and coriander (*Coriandrum sativum*) (Ozbey and Kabak 2012). Chili (*Capsicum annuum* L.) is among the spices which have gained popularity around the world, and it is mostly eaten as a food ingredient, especially in Southeast Asia and Latin America due to its taste, pungency, color, and flavor (Jalili and Jinap 2012). Due to its drying and processing method, climatic and environmental changes such as temperature, relative humidity, and insect and pest attack, spices tend to be highly infected by toxigenic and two mycotoxins which include aflatoxins (AFs) and ochratoxin A (OTA) (Ozbey and Kabak 2012**).** It was reported that several cultivars of spices such as black pepper, cardamom, cinnamon, clove, cumin, coriander, and ginger are contaminated with aflatoxins in various regions (Mahato et al. 2019). Contamination of spices with *Fusarium* and *Alternaria alternata* was observed in fresh and sun-dried pepper (Iqbal et al. 2011). Fungal infection such as mold infection in spices can be witnessed at different stages which include the time of crop production in the field, after harvest and during storage as well as when conditions are suitable for the growth (Filazi and Sireli 2013). After harvest, sun-drying is a popular practice in certain countries around the world, which requires the pepper being spread out on the soil in a single layer. Hot pepper is contaminated with *A. flavus* and *A. niger* during storage. During storage, infection of spices with *A. flavus* consequently producing aflatoxins is regarded as one of the most severe problems threatening food security globally (Iqbal et al. 2011). Previous aflatoxin occurrence in spices across the world is being highlighted in Table 3.3.

3.3.4 Occurrence of Aflatoxin in Milk and Dairy Products

Milk is a highly nutritious food consisting of several nutrients which are crucial for the development and maintenance of human well-being. The health status of people in a given population is often reflected in the condition of their food-producing ecosystems. In addition, enforcing food legislation may be directly connected to the amount and quality of foods available. Therefore, consumers in developing nations, in particular the rural inhabitants, are faced with food security and animal safety problems as they rely on foods grown locally (Iqbal et al. 2015). When breastfeeding mammals such as sheep, goats, and cows consumed foods which are contaminated with aflatoxin B_1 (AFB_1) and B_2 (AFB_2), these metabolites are transformed to aflatoxins M_1 (AFM_1) and M_2 (AFM_2) (Filazi et al. 2010**).** The quantity of AFM_1 in milk is directly proportional to the quantity of AFB_1 present in feed ingested by

Table 3.3 Occurrence of aflatoxins in spices

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
Red pepper	2010	Turkey	49/1	AFG_1	20	TLC	Demircioglu and Filazi (2010)
Red chili	2016	India	25/13	Total AFs	198.4	ELISA and TLC	Jeswal and Kumar (2016)
Red chili	2007	Turkey	100/100	AFB_1	<0.025–40.9	ELISA	Aydin et al. (2007)
Pepper	2011	Malaysia	4/4	AFB_1	0.65–2.1	ELISA	Filazi and Sireli (2013)
Turmeric	2016	India	25/9	Total AFs	65	ELISA and TLC	Jeswal and Kumar (2016)
Nutmeg	2001	Portugal	10/3	AFB_1	1–5	HPLC	Martins et al. (2001)
Paprika	2011	Spain	17	Total AFs	1.8–50.4	–	Santos et al. (2011)
Red chilies	2019	India	14/5	AFB_1	29.5–55.5	TLC	Nazir et al. (2019)
Ginger	2017	Nigeria	–	Total AFs	0.11–9.52	HPLC	Mahato et al. (2019)
Black chilies	2019	India	14/4	AFB_1	39.7–65.9	TLC	Nazir et al. (2019)
Paprika	2001	Portugal	12	AFB_1	1–20	HPLC	Martins et al. (2001)
Red chili	1996	Ethiopia	60/8	Total AFs	250–525	–	Fufa and Urga (1996)
Coriander	2016	India	25/12	Total AFs	116.5	ELISA and TLC	Jeswal and Kumar (2016)
Red chili	1995	Pakistan	176/116	AFB_1	–	TLC	Ahmad and Ahmed (1995)
Red pepper	2016	Iran	20/11	Total AFs	1.73–24.60	HPLC	Jalil (2016)
Black pepper	2006	Morocco	15/7	AFB_1	Mean 0.09	HPLC	Zinedine et al. (2006)
Smoked paprika	2011	Spain	4	Total AFs	22.3–83.7	–	Santos et al. (2011)
Cinnamon	2016	Iran	20/6	Total AFs	0.85–5.04	HPLC	Jalil (2016)
Ground red pepper	2004	Hungary	70/18	AFB_1	Max. 15.7	HPLC	Fazekas et al. (2005)
Red pepper	2010	Turkey	49/5	AFG_2	8–40	TLC	Demircioglu and Filazi (2010)
Cumin	2016	India	25/10	Total AFs	151	ELISA and TLC	Jeswal and Kumar (2016)

(continued)

Table 3.3 (continued)

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
Black pepper	2016	Iran	20/8	Total AFs	2.11–7.01	HPLC	Jalil (2016)
Dried ginger sliced	2017	India	10	Total AFs	3.64–7.52	HPLC	Bisht and Menon (2017)
Cayenne pepper	2007	Portugal	5/5	AFB_1	2–32	HPLC	Martins et al. (2001)
Paprika	2006	Morocco	14/14	AFB_1	Mean 2.88	HPLC	Zinedine et al. (2006)
Red pepper	2010	Turkey	49/11	AFB_2	3–60	TLC	Demircioglu and Filazi (2010)
Coriander	2019	India	14/6	AFB_1	33.4–67.9	TLC	Nazir et al. (2019)
Dried ginger powder	2017	India	10	Total AFs	2.99–5.25	HPLC	Bisht and Menon (2017)
Chillies	2017	USA	169/108	AFB_1	< 2	ELISA and TLC	Ismail et al. (2018)
Cumin	2006	Morocco	14/8	AFB_1	Mean 0.03	HPLC	Zinedine et al. (2006)
Ginger	2016	India	25/9	Total AFs	125	ELISA and TLC	Jeswal and Kumar (2016)
Black pepper	2016	Iran	40/5	Total AFs	1.44–3.21	HPLC	Barani et al. (2016)
Chili	2011	Spain	11	Total AFs	1.9–65.7	–	Santos et al. (2011)
Isot pepper	2004	Turkey	20/1	AFB + AFG	13.8	TLC	Erdogan (2004)
Turmeric	2016	Iran	20/7	Total AFs	1.48–5.68	HPLC	Jalil (2016)
Red-scaled pepper	2004	Turkey	44/8	AFB + AFG	1.1–97.5	TLC	Erdogan (2004)
Cumin	2011	Malaysia	3/2	AFB_1	1.89–4.64	ELISA	Filazi and Sireli (2013)
Red pepper	2016	Iran	36/36	Total AFs	4.26–30.2	HPLC	Barani et al. (2016)
Ginger	2006	Morocco	12/10	AFB_1	Mean 0.63	HPLC	Zinedine et al. (2006)
Powder pepper	2004	Turkey	26/3	AFB + AFG	1.8–16.4	TLC	Erdogan (2004)
Cumin	2019	India	14/4	AFB_1	24.9–63.9	TLC	Nazir et al. (2019)
Ginger	2016	India	25/2	Total AFs	25	ELISA and TLC	Jeswal and Kumar (2016)

AfT: $AFB_1 + AFB_2 + AFG_1 + AFG_2$

animals. AFM_1 infection of milk is posing a real threat to the human health, both in adults and infants, but it is more severe in infants due to high dependence on milk for their daily nutrition (Offiah and Adesiyun 2007).

Around 1–2% of AFB_1 present in animals' feed are converted to AFM_1 in milk although this varies from one animal to another, day to day, and depending on the type of milk consumed. When the consumption of AFB_1 has ceased, the concentration in milk reduces after 72 h to a level which cannot be detected (Filazi et al. 2010), but can be detected between 12 and 24 h of intake, and the bulk of AFB_1 and AFB_2 consumed by mammals are expelled from the body through feces and urine, but a few are bio-transformed in the liver and discharged simultaneously with milk in the form of AFM_1 and AFM_2, respectively (Filazi and Sireli 2013).

Occurrence of AFM_1 in milk and dairy products has been reported in many countries (Table 3.4). The existence of aflatoxin M_1 (AFM_1) in both dairy products and milk is a serious concern throughout the world, but it is more severe in developing nations (Iqbal et al. 2015), due to its carcinogenic, teratogenic, and mutagenic nature, which can lead to acute and chronic illness in humans and animals (Offiah and Adesiyun 2007). Contamination of milk with AFM_1 has been experienced in several countries**.** Different factors contribute to contamination of milk with AFM_1 such as change in climatic and environmental condition, change in feeding and agricultural practices, and the quality and safety control system of the food business operators in accordance with the different legislations. For instance, the Po valley (a province in Italy) which is the producer of almost all the milk consumed in the country, is regarded as the most susceptible region to AFM_1 due to its climatic conditions. AFM_1 can withstand heat deactivation process such as sterilization and pasteurization during food processing. So, cheese or any other products made from contaminated raw milk automatically contain AFM_1 (Serraino et al. 2019). To guard clients, mainly kids, from infected milk and dairy products, numerous nations have mounted regulation to adjust the levels of AFB_1 in feeds and AFM_1 in milk and cheese. The European Union limits for AFM_1 in milk and cheese are 50 ng/L and 250 ng/kg, respectively (Filazi et al. 2010).

3.4 Aflatoxin Safety Regulation

In order to control the level of aflatoxins intake in food, the European Union in 2007 set a safe limit for total aflatoxins and aflatoxins B_1 to be 4 μg/kg and 2 μg/kg accordingly for human consumption, where as in 2010 it was reviewed that the safe limit was set at 5 μg/kg and 10 μg/kg for aflatoxins B_1 and total aflatoxins, respectively. This has helped mitigate the level of aflatoxin in consumable agricultural commodities in Europe. Moreover, several other countries such as Taiwan, Canada, and the United States of America have set their safe limit at 10 μg/kg, 15 μg/kg, and 20 μg/kg, respectively (Ali 2019). The lowest safe limit for AFB_1 was at 1 μg/kg in Switzerland (Creppy 2002) and Bosnia and Herzegovina (Alessandra et al. 2011), while in Japan aflatoxins must be absent in crops for human consumption (Dadzie

Table 3.4 The Occurrence of aflatoxins in milk and dairy products

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
Yoghurt	2010	Iran	68/45	AFM_1	0.015–0.119	TLC	Fallah (2010)
Milk	2012	Pakistan	175/132	AFM_1	0.002–1.6	ELISA	Sadia et al. (2012)
Milk	2013	Brazil	129/111	AFM_1	<0.05	ELISA and HPLC	Picinin et al. (2013)
Yoghurt	2012	Iran	40/35	AFM_1	11.4–115.8	ELISA	Nilchian and Rahimi (2012)
Milk	2012	Pakistan	40/25	AFM_1	0.003–1.9	ELISA	Sadia et al. (2012)
Milk	2013	China	233/112	AFM_1	Mean 21.49	ELISA	Guo et al. (2013)
Yoghurt	2012	Iran	60/59	AFM_1	6.2–87	ELISA	Issazadeh et al. (2012)
Yoghurt	2013	China	178/8	AFM_1	Mean 27.10	ELISA	Guo et al. (2013)
UHT milk	2012	Saudi Arabia	96/79	AFM_1	0.01–0.19	ELISA	Abdallah et al. (2012)
Milk	2017	China	5650/267	AFM_1	0.05	ELISA	Ismail et al. (2018)
Milk	2012	Pakistan	17/15	AFM_1	0.002–0.794	ELISA	Sadia et al. (2012)
Feta cheese	2011	Egypt	15/10	AFM_1	7.14–122	ELISA	Ayoub et al. (2011)
Raw milk	2012	Palestine	40/34	AFM_1	3–80	ELISA	Zuheir and Omar (2012)
Cheese	2011	Lebanon	111/76	AFM_1	1.26–315	ELISA	Elkak et al. (2012)
White cheese	2009	Iran	116/93	AFM_1	52.1–744.5	ELISA	Fallah et al. (2009)
Raw milk	2012	India	45/45	AFM_1	0.1–3.8	HPLC	Siddappa et al. (2012)
UHT milk	2012	Turkey	40/8	AFM_1	<0.004–0.076	HPLC-FLD	Kabak and Ozbey (2012)
Sweets	2012	Pakistan	17/15	AFM_1	0.002–0.794	ELISA	Sadia et al. (2012)
White cheese	2010	Iran	72/59	AFM_1	0.030–1.200	TLC	Fallah (2010)
Cheese	2012	Iran	138/108	AFM_1	0.01–1.5	ELISA	Nilchian and Rahimi (2012)
Pasteurized milk	2012	India	7/3	AFM_1	1.8–3.8	HPLC	Siddappa et al. (2012)
Yoghurt	2020	Yemen	62/54	AFM_1	0.021–0.893	HPLC	Murshed (2020)
Milk	2009	Kuwait	309	AFM_1	BDL–80.8	ELISA	Dashti et al. (2009)
Fresh milk	2012	Nigeria	10/10	AFM_1	0.407–0.952	HPLC	Susan et al. (2012)
Cheese	2009	Kuwait	40/32	AFM_1	23.8–452	ELISA	Dashti et al. (2009)

Yoghurt	2010	Spain	72/2	AFM_1	13.22 ± 4.82	ELISA	Cano-Sancho et al. (2010)
Cheese	2020	Yemen	90/74	AFM_1	0.022–5.95	HPLC	Murshed (2020)
UHT milk	2009	Serbia	32/15	AFM_1	<0.01–0.05	TLC	Polovinski-Horvatovic et al. (2009)
Diary deserts	2011	Turkey	50/26	AFM_1	1.5–80	ELISA	Ertas et al. (2011)
Fresh milk	2013	Sudan	143/143	AFM_1	18–86	ELISA	Suliman and Abdalla (2013)
Milk	2010	Pakistan	84/81	AFM_1	0.69–100.04	HPLC	Muhammad et al. (2010)
Ice cream	2012	Iran	40/29	AFM_1	20.1–197.4	ELISA	Nilchian and Rahimi (2012)
Raw milk	2011	Egypt	48/37	AFM_1	3.41–137	ELISA	Ayoub et al. (2011)
Breast milk	2012	Iran	132/8	AFM_1	7.1–10.8	ELISA	Ghiasain and Maghsood (2012)
Pasteurized milk	2010	Iran	91/66	AFM_1	0.013–0.250	TLC	Fallah (2010)
Milk products	2012	Nigeria	10/10	AFM_1	0.248–2.510	HPLC	Susan et al. (2012)
UHT milk	2010	Spain	72/68	AFM_1	9.29 ± 2.61	ELISA	Cano-Sancho et al. (2010)
UHT milk	2012	India	45/29	AFM_1	0.06–2.1	HPLC	Siddappa et al. (2012)
Cream cheese	2009	Iran	94 /68	AFM_1	58.3–785.4	ELISA	Fallah et al. (2009)
Milk	2013	China	72/43	AFM_1	10–420	LC-MS/MS	Xiong et al. (2013)
Cow's milk	2014	Serbia	150/150	AFM_1	0.01–1.20	ELISA	Kos et al. (2014)
Milk	2009	Iran	196/196	AFM_1	Mean 77.92	ELISA	Sani et al. (2010)
Milk	2013	China	200/65	AFM_1	5.2–59.6	ELISA	Han et al. (2014)
Cow milk	2014	Croatia	194	AFM_1	3.65–162.3	ELISA	Bilandzic et al. (2014)
Ice cream	2010	Iran	36/25	AFM_1	0.015–0.132	TLC	Fallah (2009)
Milk	2016	Malaysia	53/19	AFM_1	3.5–100.5	ELISA	Nadira et al. (2016)
Butter	2010	Iran	31/8	AFM_1	0.013–0.026	TLC	Fallah (2009)
Cheese	2010	Spain	ND	AFM_1	<12.5	ELISA	Cano-Sancho et al. (2010)
Raw milk	2010	Sri Lanka	87/29	AFM_1	ND–0.085	–	Ismail et al. (2015)
Raw milk	2011	Turkey	50/43	AFM_1	1–30	ELISA	Ertas et al. (2011)

(continued)

Table 3.4 (continued)

Crops	Year	Country	Total/positive samples	Aflatoxin	Range	Detection techniques	References
Yogurt	2011	Egypt	22/17	AFM_1	9.70–89.3	ELISA	Ayoub et al. (2011)
Yoghurt	2011	Turkey	50/28	AFM_1	2.5–78	ELISA	Ertas et al. (2011)
Milk powder	2011	Egypt	19/5	AFM_1	2.15–16.5	ELISA	Ayoub et al. (2011)
Cheese	2011	Turkey	60/38	AFM_1	12–378	ELISA	Ertas et al. (2011)
Yoghurt	2011	Turkey	80/72	AFM_1	6–264	ELISA	Atasever et al. (2011)
Cow milk	2014	Croatia	143	AFM_1	2.69–44.9	ELISA	Bilandzic et al. (2014)
Milk	2006	Iran	72/72	AFM_1	230.2 ± 1.89	ELISA	Sefidgar et al. (2011)
Ice cream	2013	Iran	90/62	AFM_1	8.4–147.7	ELISA	Darsanaki et al. (2013)
Raw milk	2010	Thailand	240	AFM_1	0.014–0.197	HPLC	Ruangwises and Ruangwises (2010)
Lighvan cheese	2013	Iran	37/10	AFM_1	70.5–203	ELISA	Mohajeri et al. (2013)
Goat milk	2014	Croatia	32	AFM_1	2.78–40.8	ELISA	Bilandzic et al. (2014)
Yoghurt	2011	Turkey	80/70	AFM_1	10–475	ELISA	Atasever et al. (2011)
Milk products	2012	Nigeria	10/10	AFM_1	0.139–1.238	HPLC	Susan et al. (2012)
Powder milk	2020	Yemen	38/26	AFM_1	0.021–0.418	HPLC	Murshed (2020)
Raw milk	2011	Iran	122/122	AFM_1	4–112.4	ELISA	Kamkar et al. (2011)
Pasteurized milk	2011	Egypt	37/8	AFM_1	6.28–67.4	ELISA	Ayoub et al. (2011)
Liquid milk	2020	Yemen	60/40	AFM_1	0.021–2.89	HPLC	Murshed (2020)
Sheep milk	2014	Croatia	19	AFM_1	2.11–5.87	ELISA	Bilandzic et al. (2014)
Raw milk	2011	Iran	100/100	AFM_1	1.3–68	ELISA	Panahi et al. (2011)
Milk-based cereal weaning food	2007	Iran	80/72	AFM_1	3–35	ELISA	Oveisi et al. (2007)
Liquid milk	2007	Iran	128/128	AFM_1	31–113	ELISA	Oveisi et al. (2007)
Infant formula	2000	South Korea	26/18	AFM_1	0.032–0.132	HPLC	Filazi and Sireli (2013)
Infant formula	2007	Iran	120/116	AFM_1	1–14	ELISA	Oveisi et al. (2007)

ND: not determined

et al. 2019). Furthermore, in developed countries mentioned earlier, apart from the imposition of strict rules and regulation, other factors such as high rate of literacy and awareness among farmers and consumers, technological advancement both during processing and at storage stage has been associated with the low level of aflatoxins in such nations (Ismail et al. 2018).

However, in Africa and certain Asian countries, there are no strict safety regulations in place to curb the level of aflatoxins present in food commodities consumed by the population, which may be considered as one of the possible reasons for the presence of the high level of aflatoxins in food products. This has led to major health consequences among the people living in this part of the world. In addition, the presence of suitable environmental condition for aflatoxin development, technological hurdles, high rate of illiteracy among farmers and consumers and lack of awareness, poor storage condition and facilities, and overall high rate of poverty may also be considered as possible reasons for the high level of aflatoxins in Africa and certain Asia nations (Ismail et al. 2018).

3.5 Mycotoxins: Hidden Toxins

Mycotoxins are believed to be a part of the fungal chemical protection system that safeguards them from living creatures such as microorganisms, grazing animals, nematodes, insects, and humans. Mycotoxins can be found in food and several harvested crops and produce through many infection routes, at various phases of production, processing, transport, and storage. Mold and mycotoxin development are affected by numerous biotic and abiotic factors such as relative humidity, fungicides and fertilizers, temperature, insect infestation, kind of substrate and dietary factors, geographical place, genetic requirements, and interaction among the colonizing toxigenic fungal species (Rychlik et al. 2014). *Aspergillus*, *Fusarium*, *Alternaria*, and *Penicillium* are the most crucial fungal genera that produce mycotoxins which are found in foods and feeds. Mycotoxins which cannot be detected through traditional analytical methods due to modification of their form and structures inside the plants are referred to as masked mycotoxins (Berthiller et al. 2013). Nevertheless, the modified mycotoxins can be returned to their toxic nature during food processing and digestion through the process called hydrolysis. Parts of the altered toxins are found in various forms as complexes together with matrix compounds; for this reason, they can also be known as matrix-associated mycotoxins. Hidden fumonisin in its altered forms was returned to its toxic nature via hydrolysis and was eventually analyzed and determined via LC/MS/MS approach (Mahato et al. 2019). Several of the contemporary issues on the occurrence of masked mycotoxins are reported in different parts of the world including the United States of America, Africa, Europe, and some countries in Asia such as Japan and China. The highest prevalence rate of masked mycotoxins are reported in agricultural products, in particular cereal-based foods, which is threatening and detrimental to both humans and animals' health (Zhang et al. 2019). Therefore, the determination of masked mycotoxins is an essential part to ensure safety of feed, food, human lives, and animals.

3.6 Conclusion

Aflatoxins (AFs) are toxic secondary metabolites produced by *Aspergillus* species, which are found in susceptible agricultural products. Aflatoxins can cause substantial economic losses, and they have a detrimental effect on human and animal health. This book chapter summarizes the occurrence, effect, and implications of AF contamination in a wide range of agricultural crops around the world. Contamination of AFs can be found in both tropical and temperate regions of the world. Agricultural crops such as oil seeds, nuts, spices, dried fruit, beans, fruit, and cereals are the most important commodities affected by AFs. Maximum levels of aflatoxins were found in the food commodities of African and Asian countries. Due to the economic importance of AFs, regulations for major mycotoxins in agricultural commodities have been put in place in more than 100 nations, most of which are for aflatoxins, and maximum tolerated levels vary significantly across countries (Filazi and Sireli 2013). The inability to manage and at times even predict production of aflatoxin makes it a unique problem to food security. Although preventing aflatoxin contamination is the best control method, all forms of mycotoxin contamination cannot be avoided. Optimal conditions for post-harvest storage will reduce consumer exposure to most mycotoxins, but detoxification procedures may be needed in certain cases (Reddy et al. 2009).

References

Abdallah MIM, Bazalou MS, Al-Julaifi MZ (2012) Determination of aflatoxin M1 concentrations in full-fat cow's UHT milk sold for consumption in Najran-Saudi regarding its public health significance. Egypt J Appl Sci 27:40–54

Abdel-Hafez AI, Saber SM (1993) Mycoflora and mycotoxin of hazelnut (*Corylus avellana* L.) and walnut (*Juglans regia* L.) seeds in Egypt. Zentralblatt für Mikro- Biol 148(2):137–147

Ahmad IF, Ahmed SK (1995) Contamination of red chilli with aflatoxin B1 in Pakistan. Mycotoxin Res 11:21–24

Alessandra VJ, Carlos Augusto FO, Fernand SR, Leandra NZ (2011) Biomarkers of aflatoxin exposure and its relationship with the hepatocellular carcinoma. INTECH Open Access Publisher, pp 1–21

Ali N (2019) Aflatoxins in rice: worldwide occurrence and public health perspectives. Toxicology 6:1188–1197

Ali F, Mohammad R, Abdolatif M, Parisa F, Parisa M, Akbar AA, Mohammad R, Nasrin A (2013) Aflatoxin occurrence in nuts consumed in Arak, Iran. Int J Food Nutr Safety 4(2):91–97

Atasever MA, Atasever M, Ozturan K (2011) Aflatoxin M1 levels in retail yoghurt and Ayran in Erzurum in Turkey. Turk J Vet Anim Sci 35:59–62

Ayalew A, Fehrmann H, Lepschy J, Beck R, Abate D (2006) Natural occurrence of mycotoxins in staple cereals from Ethiopia. Mycopathologia 162:57–63

Aycicek H, Aksoy A, Saygi S (2005) Determination of aflatoxin levels in some dairy and food products which consumed in Ankara, Turkey. Food Control 16:263–266

Aydin A, Erkan ME, Baokaya R, Ciftcioglu G (2007) Determination of aflatoxin B1 levels in powdered red pepper. Food Control 18:1015–1018

Ayoub MM, Sobeih AMK, Raslan AA (2011) Evaluation of aflatoxin M1 in raw, processed milk and some milk products in Cairo with special reference to its recovery. Res 3:5–11

Barani A, Nasiri Z, Jarrah N (2016) Natural occurrence of aflatoxins in commercial pepper in Iran. Food Agric Immunol 27(4):570–576

Berthiller F, Crews C, Dall'Asta C, De Saeger S, Haesaert G, Karlovsky P, Oswald I, Seefelder W, Speijers G, Stroka J (2013) Masked mycotoxins: a review. Mol Nutr Food Res 57:165–186

Bilandzic N, Bozic D, Đokic M (2014) Assessment of aflatoxin M1 contamination in the milk of four dairy species in Croatia. Food Control 43:18–21

Bisht DS, Menon KRK (2017) Variation in the occurrence of aflatoxins in various processed forms of dried ginger. J Microbiol Biotech Food Sci 7(2):110–112

Blankson GK, Mills-Robertson FC, Ofosu IW (2019) Survey of aflatoxins in selected locally processed cereals-based food for human consumption in Ghana. Food Control,170–175

Bumbangi NF, Muma JB, Choongo K, Mukanga M, Velu MR, Veldman F, Hatloy A, Mapatano MA (2016) Occurrence and factors associated with aflatoxin contamination of raw peanuts from Lusaka district's markets, Zambia. Food Control 68:291–296

Cano-Sancho G, Marin S, Ramos AJ (2010) Occurrence of aflatoxin M1 and exposure assessment in Catalonia (Spain). Rev Iberoam Micol 27:130–135

Chang T (1993) Ch22. [online] Archive.unu.edu. Available at: http://archive.unu.edu/unupress/unupbooks/80815e/80815E0m.htm (Accessed 31 August 2020)

Chen Y, Liao C, Lin H, Chiueh L, Shih DY (2013) Survey of aflatoxin contamination in peanut products in Taiwan from 1997 to 2011. J Food Drug Anal 21:247–252

Creppy E (2002) Update of survey, regulation and toxic effects of mycotoxins in Europe. Toxicol Lett 127(1–3):19–28

Da Silva JB, Pozzi CR, Mallozzi MAB, Ortega EM, Correa B (2000) Mycoflora and occurrence of aflatoxin B1 and fumonisin B1 during storage of Brazilian sorghum. J Agric Food Chem 48:4352–4356

Dadzie M, Oppong A, Ofori K, Eleblu J, Ifie E, Blay E, Obeng Bio E, Appiah-Kubi Z, Warburton M (2019) Distribution of aspergillus flavus and aflatoxin accumulation in stored maize grains across three agro-ecologies in Ghana. Food Control 104:91–98

Darsanaki RK, Aliabadi MA, Chakoosari MMD (2013) Aflatoxin M1 contamination in ice-cream. J Chem Health Risks 3:43–46

Dashti B, Al-Hamli S, Alomirah H, Al-Zenki S, Bu Abbas A, Sawaya W (2009) Levels of aflatoxin M1 in milk, cheese consumed in Kuwait and occurrence of total aflatoxin in local and imported animal feed. Food Control 20:686–690

Demircioglu S, Filazi A (2010) Detection of aflatoxin levels in red pepper produced in Turkey. J Vet Med Assoc 81(2):63–66

El Sayed TI, El Desouky TA, Abd El Aziz AM (2019) Investigation of fungus associated within cooccurrence of aflatoxins and ochratoxin a in cereals from Egypt. MOJ Toxicol 5(3):1–9

El tawila MM, Neamatallah A, Serdar SA (2013) Incidence of aflatoxins in commercial nuts in the holy city of Makkah. Food Control 29:121–124

Elkak A, Atat OE, Habib J, Abbas M (2012) Occurrence of aflatoxin M1 in cheese processed and marketed in Lebanon. Food Control 25:140–143

Erdogan A (2004) The aflatoxin contamination of some pepper types sold in Turkey. Chemosphere 56:321–325

Ertas N, Gonulalan Z, Yildirim Y, Karadal F (2011) A survey of concentration of aflatoxin M1 in dairy products marketed in Turkey. Food Control 22:1956–1959

Espinosa ET, Askar KA, Torres LRN, Olvera RM, Santa Anna JPC (2009) Quantification of aflatoxins in corn distributed in city of Monterrey, Mexico. Food Addit Contam 12(3):383–386

Fallah AA (2010) Aflatoxin M1 contamination in dairy products marketed in Iran during winter and summer. Food Control 21:1478–1481

Fallah AA, Jafari T, Fallah A, Rahnama M (2009) Determination of aflatoxin M1 levels in Iranian white and cream cheese. Food Chem Toxicol 47:1872–1875

FAO org (2020) FAOSTAT. Available at: http://www.fao.org/faostat/en/#data/QC

Fazekas B, Tar A, Kovacs M (2005) Aflatoxin and ochratoxin a content of spices in Hungary. Food Addit Contam 22(9):856–863
Fernandez Pinto V, Patriarca A, Locani O, Vaamonde G (2001) Natural co-occurrence of aflatoxin and cyclopiazonic acid in peanuts grown in Argentina. Food Addit Contam 18(11):1017–1020
Filazi A, Sireli UT (2013) Occurrence of aflatoxins in food. Intech Open:143–169
Filazi A, Ince S, Temamoğulları F (2010) Survey of the occurrence of aflatoxin M1 in cheeses produced by dairy ewe's milk in Urfa city, Turkey. Ankara Üniversitesi Veteriner Fakültesi Dergisi 57(3):197–199
Freitas VPS, Brigido BM (1998) Occurrence of aflatoxins B1, B2, G1, and G2 in peanuts and their products marketed in the region of Campinas, Brazil in 1995 and 1996. Food Addit Contam 15(7):807–811
Fufa H, Urga K (1996) Screening of aflatoxins in Shiro and ground red pepper in Addis Ababa. EMJ 34:243–242
Galvano F, Galofaro V, Galvano G (1996) Occurrence and stability of aflatoxin M1 in milk and milk products: a worldwide review. J Food Prot 59(10):1079–1090
Ghali R, Khlifa KH, Ghorbel H, Maaroufi K, Hedilli A (2010) Aflatoxin determination in commonly consumed foods in Tunisia. J Sci Food Agric 90:2347–2351
Ghiasain SA, Maghsood AH (2012) Infants' exposure to aflatoxin M1 from mother's breast milk in Iran. Iranian J Public Health 41:119–126
Guo Y, Yuan Y, Yue T (2013) Aflatoxin M1 in milk products in China and dietary risk assessment. J Food Prot 76:849–853
Gürses M (2006) Mycoflora and aflatoxin content of hazelnuts, walnuts, peanuts, almonds and roasted chickpeas (LEBLEBI) sold in Turkey. Int J Food Prop 9:395–399
Han RW, Zheng N, Wang JQ (2014) Survey of aflatoxin in dairy cow feed and raw milk in China. Food Control 34:35–39
Hanvi DM, Lawson-Evi P, De Boevre M, Goto CE, De Saeger S, Eklu-Gadegbeku K (2019) Natural occurrence of mycotoxins in maize and sorghum in Togo. Mycotoxin Res 35:321–327
Huang B, Han Z, Cai Z, Wu Y, Ren Y (2010) Simultaneous determination of aflatoxins B1, B2, G1, G2, M1 and M2 in peanuts and their derivative products by ultra-high-performance liquid chromatography–tandem mass spectrometry. Anal Chim Acta 662:62–68
Iqbal Q, Amjad M, Asi M, Arino A (2011) Assessment of hot peppers for aflatoxin and mold proliferation during storage. J Food Prot 74:830–835
Iqbal SZ, Jinap S, Pirouz AA, Ahmad Faizal AR (2015) Aflatoxin M1 in milk and dairy products, occurrence and recent challenges: a review. Trends Food Sci Technol 46(1):110–119
Iqbal SZ, Asi MR, Hanif U, Zuber M, Jinap S (2016) The presence of aflatoxins and ochratoxin a in rice and rice products; and evaluation of dietary intake. Food Chem 210:135–140
Ismail A, Akhtar S, Levin RE, Ismail T, Riaz M, Ami M (2015) Aflatoxin M1: prevalence and decontamination strategies in milk and milk products. Crit Rev Microbiol:1–10
Ismail A, Gonçalves BL, de Neeff DV, Ponzilacqua B, Coppa CFSC, Hintzsche H, Sajide M, Cruzf AG, Corassin CH, Oliveira CAF (2018) Aflatoxin in foodstuffs: occurrence and recent advances in decontamination. Food Res Int 113:74–85
Issazadeh K, Darsanaki RK, Pahlaviani MRMK (2012) Occurrence of aflatoxin M1 levels in local yogurt samples in Gilan Province, Iran. Ann Biol Res 3:3853–3855
Jalil M (2016) Natural occurrence of aflatoxins contamination in commercial spices in Iran. IJHSE 3(2):513–517
Jalili M, Jinap S (2012) Natural occurrence of aflatoxins and ochratoxin a in commercial dried chili. Food Control 24(1–2):160–164
Janardhana GR, Raveesha KA, Shetty HS (1999) Mycotoxin contamination of maize grains grown in Karnataka (India). Food Chem Toxicol 37:863–868
Jeswal P, Kumar D (2016) Mycotoxins and their producing fungi from spices of Bihar (India). Int J Biotech Biomed Sci 2(2):174–177
Joubrane K, Mnayer D, EL Khoury A, EL Khoury A, Awad E (2020) Co-occurrence of aflatoxin B1 and Ochratoxin a in Lebanese stored wheat. J Food Prot 83(9):1547–1552
Kabak B, Ozbey F (2012) Aflatoxin M1 in UHT milk consumed in Turkey and first assessment of its bioaccessibility using an in vitro digestion model. Food Control 28:338–344

Kamika I, Takoy LL (2011) Natural occurrence of aflatoxin B1 in peanut collected from Kinshasa, Democratic Republic of Congo. Food Control 22(11):1760–1764

Kamika I, Ngbolua K, Tekere M (2016) Occurrence of aflatoxin contamination in maize throughout the supply chain in the 2 Democratic Republic of Congo. Food Control:1–24

Kamkar A, Khaniki GRJ, Alavi SA (2011) Occurrence of aflatoxin M1 in raw milk produced in Ardebil of Iran. Iran J Environ Health Sci Eng 8:123–128

Kara GN, Ozbey F, Kabak B (2015) Co-occurrence of aflatoxins and ochratoxin a in cereal flours commercialised in Turkey. Food Control 54:275–281

Kershaw S (1982) Occurrence of aflatoxins in oilseeds providing cocoa-butter substitutes. Appl Environ Microbiol 43(5):1210–1212

Khlangwiset P, Shephard G, Wu F (2011) Aflatoxins and growth impairment: a review. Crit Rev Toxicol 41(9):740–755

Klich M (2007) Aspergillus flavus: the major producer of aflatoxin. Mol Plant Pathol 8(6):713–722

Kos J, Levi J, Uragi O (2014) Occurrence and estimation of aflatoxin M1 exposure in milk in Serbia. Food Control 38:41–46

Kos J, Hajnal EJ, Šarić B, Jovanov P, Mandić A, Đuragić O, Kokić B (2018) Aflatoxins in maize harvested in the republic of Serbia over the period 2012–2016. Food Addit Contam 11(4):246–255

Kumagai S, Nakajima M, Tabata S, Ishikuro E, Tanaka T, Norizuki H (2008) Aflatoxin and ochratoxin a contamination of retail foods and intake of these mycotoxins in Japan. Food Addit Contam 25:1101–1106

Kumar P, Mahato D, Kamle M, Mohanta T, Kang S (2017) Aflatoxins: a global concern for food safety, human health and their management. Front Microbiol 07:1–10

Lahouar A, Jedidi I, Sanchis V, Said S (2018) Aflatoxin B1, ochratoxin a and Zearalenone in sorghum grains marketed in Tunisia. Food Addit Contam 11(2):103–110

Lai X, Liu R, Ruan C, Zhang H, Liu C (2014) Occurrence of aflatoxins and ochratoxin a in rice samples from six provinces in China. Food Control:1–20

Leggieri MC, Bertuzz T, Pietri A, Battilani P (2015) Mycotoxin occurrence in maize produced in northern Italy over the years 2009–2011: focus on the role of crop related factors. Phytopathol Mediterr 54(2):212

Liu Z, Gaoa J, Yu J (2006) Aflatoxins in stored maize and rice grains in Liaoning Province, China. J Stored Prod Res 42:468–479

Mahato D, Lee K, Kamle M, Devi S, Dewangan K, Kumar P, Kang S (2019) Aflatoxins in food and feed: an overview on prevalence, detection and control strategies. Front Microbiol 10:1–10

Makun HA, Dutton FM, Njobeh PB, Mwanza M, Kabiru AY (2011) Natural multi-occurrence of mycotoxins in rice from Niger state, Nigeria. Mycotoxin Res 27(2):97–104

Martins ML, Martins HM, Bernardo F (2001) Aflatoxins in spices marketed in Portugal. Food Addit Contam 18(4):315–319

Mazaheri M (2009) Determination of aflatoxins in imported rice to Iran. Food Chem Toxicol 47:064–2066

Milhome MAL, Lima CG, de Lima LK, Lima FAF, Sousa DOB, Nascimento RF (2014) Occurrence of aflatoxins in cashew nuts produced in northeastern Brazil. Food Control 42:34–37

Mohajeri FA, Ghalebi SR, Rezaeian M (2013) Aflatoxin M1 contamination in white and Lighvan cheese marketed in Rafsanjan, Iran. Food Control 33:525–527

Mphande FA, Siame BA, Taylor JE (2004) Fungi, aflotoxins, and cyclopiazonic acid associated with peanut retailing in Botswana. J Food Prot 67(1):96–102

Mudili V, Siddaih CN, Nagesh M, Garapati P, Kumar KN, Murali HS, Batra HV (2014) Mould incidence and mycotoxin contamination in freshly harvested maize kernels originated from India. J Sci Food Agric 94:2674–2683

Muhammad K, Tipu MY, Abbas M (2010) Monitoring of aflatoxin M1 in market raw milk in Lahore city, Pakistan. Pak J Zool 42:697–700

Murashiki TC, Chidewe C, Benhura MA, Maringe DT, Dembedza MP, Manema LR, Nyanga LK (2017) Levels and daily intake estimates of aflatoxin B1 and fumonisin B1 in maize consumed by rural households in Shamva and Makoni districts of Zimbabwe. Food Control 72:105–109

Murshed S (2020) Evaluation and assessment of aflatoxin M1 in Milk and Milk products in Yemen using high-performance liquid chromatography. J Food Qual:1–8

Nadira AF, Rosita J, Norhaizan ME, Mohd Redzwan S (2016) Screening of aflatoxin M1 occurrence in selected milk and dairy products in Terengganu, Malaysia. Food Control:1–6

Nazhand A, Durazzo A, Lucarini M, Souto E, Santini A (2020) Characteristics, occurrence, detection and detoxification of aflatoxins in foods and feeds. Foods 9(5):1–26

Nazir A, Kalim I, Sajjad M, Usman M, Iqbal M (2019) Prevalence of aflatoxin contamination in pulses and spices in different regions of Punjab. Chem Int 5(4):274–280

Nilchian Z, Rahimi E (2012) Aflatoxin M1 in yoghurts, cheese and icecream in Shahrekord-Iran. World Appl Sci J 19:621–624

Odoemelam SA, Osu CI (2009) Aflatoxin B1 contamination of some edible grains marketed in Nigeria. E-J Chem 6(2):308–314

Offiah N, Adesiyun A (2007) Occurrence of aflatoxins in peanuts, Milk, and animal feed in Trinidad. J Food Prot 70(3):771–775

Ostadrahimi A, Ashrafnejad F, Kazemi A, Sargheini N, Mahdavi R, Farshchian M, Mahluji S (2014) Aflatoxin in raw and salt-roasted nuts (pistachios, peanuts and walnuts) sold in Markets of Tabriz, Iran. Jundishapur J Microbiol 7(1):1–5

Oveisi MR, Jannat B, Sadeghi N, Hajimahmoodi M, Nikzad A (2007) Pres- ence of aflatoxin M1 in milk and infant milk products in Tehran, Iran. Food Control 18:1216–1218

Ozbey F, Kabak B (2012) Natural co-occurrence of aflatoxins and ochratoxin a in spices. Food Control 28(2):354–361

Panahi P, Kasaee S, Mokhtari A (2011) Assessment of aflatoxin M1 contamination in raw milk by ELISA in Urmia, Iran. Am Eurasian J Toxicol Sci 3:231–233

Picinin LCA, Cerqueira MMOP, Vargas EA, Lana ÂMQ, Toaldo IM, Bordignon-Luiz MT (2013) Influence of climate conditions on aflatoxin M1 contamination in raw milk from Minas Gerais state, Brazil. Food Control 31:419–424

Polovinski-Horvatovic M, Juric V, Glamočić D (2009) Twoyear study of incidence of aflatoxin M1 in milk in the region of Serbia. Biotech Anim Husbandry 25:713–718

Ramakrishna Y, Bhat RV, Vasanthi S (1990) Natural occurrence of mycotoxins in staple foods in India. J Agric Food Chem 38(9):1857–1859

Reddy KRN, Abbas HK, Abel CA, Shier WT, Oliveira CAF, Raghavender CR (2009) Mycotoxin contamination of commercially important agricultural commodities. Toxin Rev 28(2–3):154–168

Rezaei M, Karimi F, Parviz M, Behzadi AA, Javadzadeh M, Mohammadpourfard I, Fallahzadeh RA, Aghamirlou HM, Malekirad AA (2014) An empirical study on aflatoxin occurrence in nuts consumed in Tehran, Iran 2013. Health 6:649–653

Ruangwises N, Ruangwises S (2010) Aflatoxin M1 contamination in raw milk within the central region of Thailand. Bull Environ Contam Toxicol 85:195–198

Rychlik M, Humpf H, Marko D, Dänicke S, Mally A, Berthiller F, Klaffke H, Lorenz N (2014) Proposal of a comprehensive definition of modified and other forms of mycotoxins including “masked” mycotoxins. Mycotoxin Res 30(4):197–205

Sadia A, Jabbar MA, Den Y (2012) A survey of aflatoxin M1 in milk and sweets of Punjab, Pakistan. Food Control 26:235–240

Sani AM, Nikpooyan H, Moshiri R (2010) Aflatoxin M1 contamination and antibiotic residue in milk in Khorasan province, Iran. Food Chem Toxicol 48:2130–2132

Santos L, Marín S, Mateo EM, Gil-Serna J, Valle-Algarra FM, Patiño B, Ramos AJ (2011) Mycobiota and co-occurrence of mycotoxins in capsicum powder. Int J Food Microbiol 151:270–276

Sefidgar SAA, Mirzae M, Assmar M, Naddaf SR (2011) Aflatoxin M1 in pasteurized milk in Babol city, Mazandaran Province, Iran. Iran J Public Health 40:115–118

Serraino A, Bonilauri P, Kerekes K, Farkas Z, Giacometti F, Canever A, Zambrini A, Ambrus Á (2019) Occurrence of aflatoxin M1 in raw Milk marketed in Italy: exposure assessment and risk characterization. Front Microbiol 10:1–10

Set E, Erkmen O (2010) The aflatoxin contamination of ground red pepper and pistachio nuts sold in Turkey. Food Chem Toxicol 48:2532–2537

Shadbad MRS, Asarin M, Tahavori A, Ghaderi F, Nemati M (2012) Determination of aflatoxins in nuts of Tabriz confectionaries by ELISA and HPLC methods. Adv Pharm Bull 2(1):123–126

Siddappa V, Nanjegowda DK, Viswanath P (2012) Occurrence of aflatoxin M1 in some samples of UHT, raw & pasteurized milk from Indian states of Karnataka and Tamilnadu. Food Chem Toxicol 50:4158–4162

Somorin YM, Bertuzzi T, Battilani P, Pietri A (2012) Aflatoxin and fumonisin contamination of yam flour from markets in Nigeria. Food Control 25:53–58

Strosnider H, Azziz-Baumgartner E, Banziger M, Bhat R, Breiman R, Brune M, DeCock K, Dilley A, Groopman J, Hell K, Henry S, Jeffers D, Jolly C, Jolly P, Kibata G, Lewis L, Liu X, Luber G, McCoy L, Mensah P, Miraglia M, Misore A, Njapau H, Ong C, Onsongo M, Page S, Park D, Patel M, Phillips T, Pineiro M, Pronczuk J, Rogers H, Rubin C, Sabino M, Schaafsma A, Shephard G, Stroka J, Wild C, Williams J, Wilson D (2006) Workgroup report: public health strategies for reducing aflatoxin exposure in developing countries. Environ Health Perspect 114(12):1898–1903

Suliman SE, Abdalla MA (2013) Presence of aflatoxin M1 in dairy cattle milk in Khartoum state-Sudan. Int J Sci Tech Res 2:10–12

Susan OK, Obansa AI, Anthony MH, Chidawa MS (2012) A preliminary survey of aflatoxin M1 in dairy cattle products in Bida, Niger state, Nigeria. Afr J Food Sci Tech 3:273–276

Torović L (2018) Aflatoxins and ochratoxin a in flour: a survey of the Serbian retail market. Food Addit Contam 11(1):26–32

Udomkun P, Wiredu AN, Nagle M, Müller J, Vanlauwe B, Bandyopadhyay R (2017) Innovative technologies to manage aflatoxins in foods and feeds and the profitability of application—a review. Food Control 76:127–138

Vargas EA, Preis RA, Castro L, Silva CMG (2001) Co-occurrence of aflatoxins B1, B2 , G1, G2 , zearalenone and fumonisin in Brazilian corn. Food Addit Contam 18(11):981–986

Weledesemayat GT, Gezmu TB, Woldegiorgis AZ, Gemede HF (2016) Study on aspergillus species and aflatoxin levels in sorghum (*Sorghum bicolor* L.) stored for different period and storage system in Kewet districts, northern Shewa, Ethiopia. J Food Sci Nutr 2:1–8

Worldometers.info. (2020) Population by Country (2020) – Worldometer

Wu F (2006) Mycotoxin reduction in Bt corn: potential economic, health, and regulatory impacts. Transgenic Res 15(3):277–289

Wu Q, Jezkova A, Yuan Z, Pavlikova L, Dohnal V, Kuca K (2009) Biological degradation ofaflatoxins. Drug Metab Rev 41(1):1–7

Xiong JL, Wang YM, Mac MR, Liu JX (2013) Seasonal variation of aflatoxin M1 in raw milk from the Yangtze River Delta region of China. Food Control 34:703–706

Zhang Z, Nie D, Fan K, Yang J, Guo W, Meng J, Zhao Z, Han Z (2019) A systematic review of plant-conjugated masked mycotoxins: occurrence, toxicology, and metabolism. Crit Rev Food Sci Nutr 60(9):1523–1537

Zinedine A, Brera C, Elakhdari S, Catano C, Debegnach F, Angelini S (2006) Natural occurrence of mycotoxins in cereals and spices commercialised in Morocco. Food Control 17(11):868–874

Zuheir IMA, Omar JA (2012) Presence of aflatoxin M1 in raw milk for human consumption in Palestine. Walailak J Sci Tech 9:201–205