Chapter 5

Aflatoxin: A Risky Menace for African's Food Commodities

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Additional information is available at the end of the chapter

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Abstract

Aflatoxins contamination of African food and food commodities exhibits a serious threat to human and animal health over the past few decades. To protect the safety of food commodities, regular monitoring for afltoxins has began to implicate in developing countries. The food contaminating species *Aspergillus flavus* and *Aspergillus parasiticus* are responsible for production of aflatoxins. Various studies have followed ELISA, TLC, HPLC, immunoassay, etc for quantification of aflatoxins. The data from different reports demonstrate that staple foods in most countries are particularly vulnerable to attack by aflatoxigenic fungi and found contaminated with aflatoxins. In our study from Ethiopia, we have utilized a quick and precise biosensor and thin layer chromatography method to measure contamination of aflatoxins in maize. Our data revealed that all the samples tested were greater than the safety level of aflatoxins as recommended by Food and Drug Administration (FDA) and European Union (EU). Utilization of internationally developed biosensor for presence of fungal toxin in food samples is the first approach that was applied in the developing country like Ethiopia. In the end, we conclude that fungal contaminants and there toxic products are potential threat to the agro and food industry in Africa and require immediate control measures.

Keywords: aflatoxins, food commodities, *Aspergillus*, cancer, Africa

1. Introduction

Africa's crop agriculture is very complex, involving substantial variation in crops cultivated across various countries as well as involving different regions and ecologies among each country. Among these, crops that constitute the staple food of African countries are at risk to fungal

infections, which results in aflatoxin contamination due to the poor agronomic practices, storage condition of crops and more importantly processing of food materials under favourable temperature and humidity conditions [1]. The extent of contamination of food commodities by aflatoxin also varies with different geographical locations among the country. According to United Nations Food and Agriculture Organization, 25% of world's agriculture commodities are contaminated with fungal toxins, which leads to severe economic and health loss to the affected country [2].

Mycotoxins, i.e., aflatoxins represent the class of fungal polyketide secondary metabolites that are mainly produced by two fungi viz. *Aspergillus flavus* and *Aspergillus parasiticus* [3]. These fungi are known to produce four major kinds of aflatoxins, i.e., aflatoxin B_1 (AFB_1), aflatoxin B_2 (AFB_2), aflatoxin G_1 (AFG_1) and aflatoxin G_2 (AFG_2). Among these four principle classes of aflatoxins, AFB_1 is found to be predominant in natural environment and reported carcinogenic in animal models if the toxicity exceeds beyond the safety level [3, 4]. The agricultural commodities that are prone to aflatoxins toxicity are corn and corn products, peanuts, cottonseed, milo, animal feed and majority of tree nuts [5, 6]. Aflatoxins toxicity has always been a topic of debatable interest in international market and economic development of country, which are the part of trade market. To overcome this problem, many countries have set standard safety levels of aflatoxins in food and food products and animal feed [7, 8]. Increased risk of hepatocellular carcinoma in the presence of hepatitis B virus infection [9] and esophageal cancer [10] has been associated with aflatoxins contamination of food in most of the developing countries from Africa. Intensive exposures of AFB_1 at a concentration in excess of 2 ppm are reported to cause non-specific liver problems and death within few days, whereas chronic effect of AFB_1 leads to immunosuppression and nutritional deficiency [11].

Various food commodities like maize and maize products, peanuts, cottonseed, milo, animal feed and majority of tree nuts are considered as one of the best substrates for the fungi to grow and produce toxicgenesis. Many surveys across the globe showed that the food commodities that constitute the staple food of African countries could be highly contaminated with aflatoxins. Aflatoxins in feed also possesses negative impacts on the production of healthy livestock, affecting a decrease in milk and egg yield, which results in toxic residues in dairy, meat and poultry products. Aflatoxins are reported to be prevalent among various parts of Africa. Some of the previous studies reported that 90% of East African maize samples showed the evidence of high level of aflatoxins, and some parts of West Africa showed the exposure of aflatoxins is as high as 99% [12]. Aflatoxins not only support severe health risk, but also favour significant economic loss to farmers due to the rejection of their crops by international buyers if it is contaminated with fungal toxins. For example, in Kenya, two World Food Programs of the United Nations purchased maize samples that were confiscated and destroyed because of the lack of acceptable levels of aflatoxins in the purchased crops [13]. This is of particular concern to smallholder farmers as aflatoxins toxicity primarily occurs where there is a high moisture content and high temperature, which is supported by inadequate storage structures. Implementation of national prevention and control strategies like proper pre- and pro-harvest treatment of various infected food commodities and standard storage facilities are required to reduce the risk of aflatoxin contamination by fungi.

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2. Chemical and biological basis of aflatoxins

Aflatoxins are the class of mycotoxins that have been well-known for their delirious outbreak of 'Turkey 'X' disease' in England and were first isolated and characterized from *A. flavus* which is reported to be a common contaminant of poorly stored grains [14]. Aflatoxins are secondary metabolites, which are naturally occurring contaminants of food and elaborate the toxins under favourable conditions of temperature, relative humidity and poor storage conditions. They are now known to be mainly produced by *A. flavus*, *A. parasiticus*, *Aspergillus nomius* and two different *Emericella* species [15]. Aflatoxins have received more attention due to their effects on agricultural production loss, threats to human health because of their high toxicity and carcinogenic nature as well as potential threats to food safety [16]. Till date, there are roughly 20 known aflatoxins reported based on chromatographic and fluorescence characteristics but only six of these aflatoxins, i.e., AB_1, AB_2, AG_1, AG_2, aflatoxin (AFM_1) and aflatoxin M_2 (AFM_2) (**Figure 1**) are widely studied because of severe toxicity and more prevalence

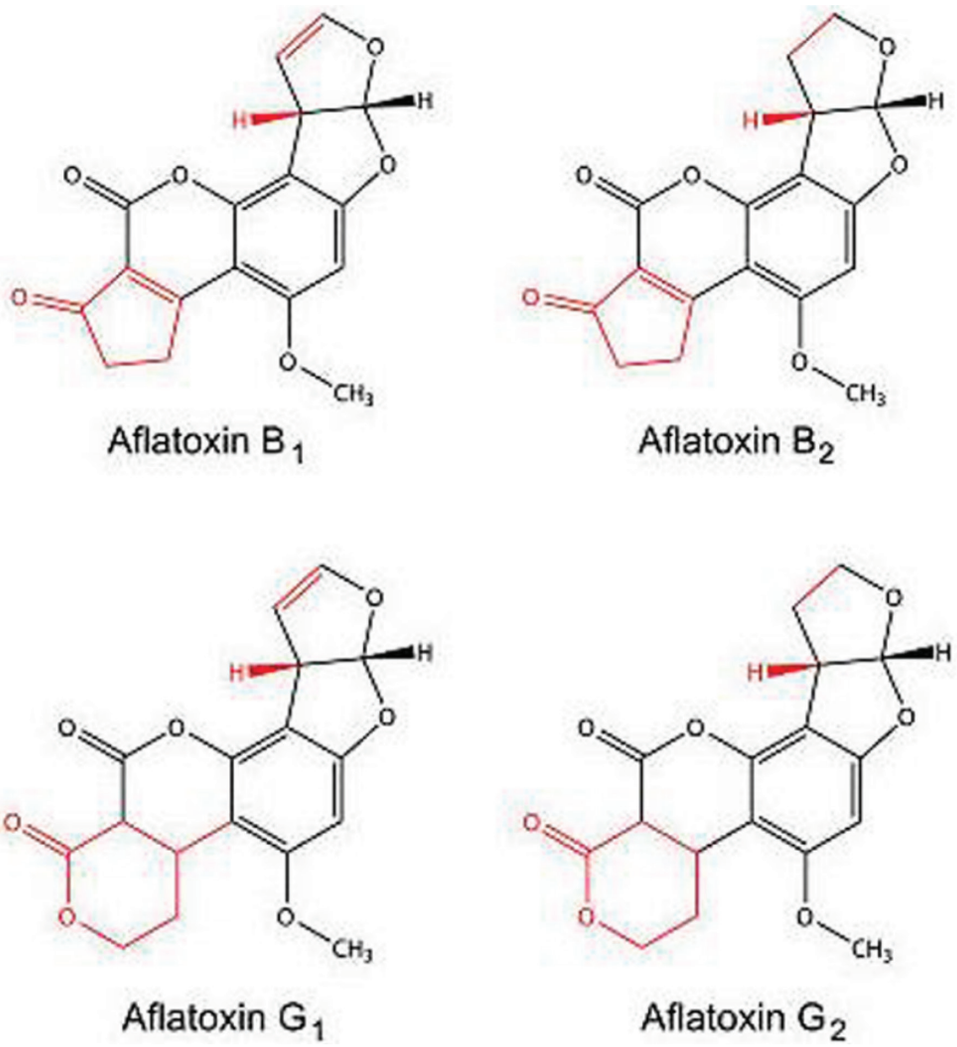

Figure 1. Chemical structure of major class of aflatoxins (Source: www.istockphoto.com).

in food and food products. Other aflatoxins have paid less attention as they exist very rare in nature, since they are metabolic derivatives mostly found in pure cultures [17]. AFB_1 is the most dangerous among these toxins; however, the order of acute and chronic toxicity is AFB_1 > AFG_1 > AFB_2 > AFG_2 [18].

2.1. Chemical basis of major aflatoxins

The major aflatoxins have been classified into B and G groups due to their fluorescence properties in the presence of UV to give blue and green colourations, respectively [19]. The B series aflatoxins, AFB_1 and AFB_2 are chemically known as difurocoumarocyclopentenones and the G series aflatoxins, AFG_1, AFG_2 are difurocoumarolactone series (**Figure 1**). Structurally, the dihydrofuran moiety, containing a double bond and the constituents linked to the coumarin moiety play an important role in producing biological effects. For the B series aflatoxins, cyclopentenone was reported to be responsible for the major toxicity [20]. On the other hand, M groups of aflatoxins are chemically called as methoxycyclopenta. It is usually considered that AFM_1 is a detoxification end product of AFB_1, which is due to the result of mutagenic and carcinogenic process, and is found to be the main mono-hydroxylate derivative of AFB_1 in liver by means of cytochrome P_{450}-associated enzymes [21]. The common aflatoxins are AFB_1, AFB_2, AFG_1 and AFG_2. Their molecular weights are 312.3 g/mol for aflatoxin B_1, 314.3 g/mol for aflatoxin B_2, 328.3 g/mol for aflatoxin G_1 and 330.3 g/mol for aflatoxin G_2. Aflatoxin M_1 and M_2, which are metabolites of aflatoxins were first isolated from milk of lactating animals that were fed on aflatoxin preparations [22].

2.2. Biological basis of aflatoxins

2.2.1. Aflatoxins producing fungi

Aflatoxins are difuranocoumarin derivatives produced by a polyketide pathway mainly by strains of *A. flavus* and *A. parasiticus*; in particular, *A. flavus* is a common contaminant in agriculture. In spite of these two fungi, *Aspergillus bombycis*, *Aspergillus ochraceoroseus*, *A. nomius* and *Aspergillus pseudotamarii* are also reported as aflatoxin-producing species, but they are found less predominant in nature [23]. All the aflatoxins-producing fungi exhibits a great variation in terms of qualitative and quantitative differences in the toxicology abilities that are markedly attributes by different strains within each fungal species. For instance, only about half of *A. flavus* strains may produce over 106 μg/kg aflatoxins in comparison to other *Aspergillus* strains [14]. *A. flavus* only produces type B toxins [24] while, other species such as *A. nomius* and *A. parasiticus* produce both B and G types [14]. Some strains of *A. flavus*, which are regarded as the S strains based on the size of the sclerotia are known to produce more toxin than toxicogenic *A. flavus* L strains [25].

2.2.2. Biosynthesis of aflatoxins

The aflatoxins constitute a number of structurally related metabolites that differ considerably in their biological effects. However, all of them contain a coumarin ring combined to a

bis-dihydrofurano moiety and additionally either a cyclopentenone ring (B series) or a six-membered lactone ring (G series). Among all of these toxins, AFB_1 is the one with the greatest biological activity. Carcinogenic in several animal species, AFB_1 reveals itself as the most potent hepatocarcinogen known in the rat and the rainbow trout [26]. It has been reported that it is probable that the enzymes of aflatoxin biosynthesis and of other polyketides are similarly arranged in discrete particles in the post-mitochondrial fraction [10]. The aflatoxin biosynthesis is also characterized by 29 clustered aflatoxin pathway genes and can be described in two major stages: an early stage from acetate to versicolorin A (VERA) (coloured pigment in brick-red, yellow or orange) and a later stage from dimethyl-sterigmatocystin (DMST) to AFB_1 (colourless under normal light and fluorescent-blue under UV light) [26].

2.2.3. Modus of operandi of toxicity by aflatoxins in human

Like many other chemical carcinogens, AFB_1 requires bio-activation to a reactive toxic metabolite-activation as an important stage in its toxicity expression [27]. AFB_1 cannot itself be the toxic molecule but it is metabolized in the animal body in a complex network of reactions and it is the result of this metabolism, which determines both acute and chronic toxicity. Many researchers have studied the relationship between the biological activity of AFB_1 and its metabolism, and have found the evidence that AFB_1 needs metabolic activation to exert its carcinogenic and mutagenic effects [28]. After ingestion, AFB_1 presents a short half-life; 65% of the quantity absorbed after 90 min is removed from the blood and plasma and metabolized by the liver to a reactive epoxide intermediate. It has been estimated that in human liver homogenates, the half-life of AFB_1 is 15 min [20, 29]. In the metabolism, however, the first step of it takes place in the hepatocyte with non-reversible detoxification, which leads to the formation of hydroxylated metabolites followed either by reversible detoxification through aflatoxicol formation, or by activation [30].

However, AFB_1 is mainly bio-activated by cytochrome P_{450}-dependent mono-oxygenase, which results in the production of many metabolic products such as aflatoxin Q_1, aflatoxin P_1, aflatoxin M_1 and aflatoxin $B_{1\text{-}8\text{-}9\text{-epoxide}}$. Aflatoxin $B_{1\text{-}8\text{-}9\text{-expoxide}}$ has been found to be the most toxic metabolite [31]. Cytochrome P_{450} mono-oxygenase has been demonstrated as a key factor in the metabolic activation of several chemical carcinogens such as AFB_1, various heterocyclic and aromatic amines and specific nitro-aromatic compounds [31]. Among these metabolic products, aflatoxin $B_{1\text{-}8\text{-}9\text{-epoxide}}$ has been shown as an important metabolite synthesized in the animal liver and can react with guanine residues in DNA and lead to depurination [26]. The net result is gene mutation. The most regularly induced mutation is the GC→TA transversion, potentially leading to carcinogenesis [32]. In addition, the epoxide occurs in endoforms and exoforms. The exo-epoxide is highly electrophilic and reacts with several macromolecules [32]. The activated AFB_1, aflatoxin $B_{1\text{-}8\text{-}9\text{-epoxide}}$ can bind to glutathione, cellular proteins, RNA and DNA. The binding of this toxic compound to DNA has been investigated in rats and was found to take place at the critical nucleophilic sites of DNA and identified to form 2,3-dihydro-2-(N_7-guanyl)-3-hydroxy-aflatoxin B_1 [20], which is also associated with tumour development in animals [33]. However, when bound to glutathione, aflatoxin $B_{1\text{-}8\text{-}9\text{-epoxide}}$ produces another metabolite that is less toxic [10].

Many mineral elements including Zn^{2+}, Cu^{2+} and Fe^{2+} are also essential for this activation by contributing to the cyclization of the polyketide precursors, and also affecting the induction of the enzymes of secondary metabolism [31]. In light of this, AFB_1 may be seen as a multiple menace by its carcinogenic, teratogenic and mutagenic effects, and also by its immunosuppressive effects [31].

3. Method for detection for aflatoxins

Aflatoxins not only possess severe effects on human health but also cause serious economic losses when tons of foods have to be discarded or destroyed as a result of aflatoxin contamination in developing countries, due to which a rapid and sensitive method has been a pre-requisite for quantification of aflatoxins in food samples. To ensure food safety, maximum levels for aflatoxins in food and feed have been set by national and international organizations and various approaches have been developed for the determination of aflatoxin concentrations in food and feed commodities. Following methods are widely used for quantification estimation of aflatoxins in various food commodities.

3.1. Chromatography method

Chromatography is one of the most widely used as well as the oldest method for quantifying aflatoxins. In the beginning of aflatoxin analysis and research, gas chromatography (GC) was frequently used for detection and quantification of aflatoxins. However, modern biology leads to new chromatography-based techniques for the detection of aflatoxins. Examples of these improvements are liquid chromatography (LC), thin layer chromatography (TLC) [34] and high-performance liquid chromatography (HPLC) [35], which, nowadays, is the most commonly used chromatographic technique for detection of a wide diversity of mycotoxins, especially for aflatoxin derivatives [36]. Frisvad and Thrane [37] described an HPLC method for the detection of 182 mycotoxins and other fungal metabolites based on their alkylphenone retention indices and diode array spectra. Nowadays, coupling of HPLC with mass spectroscopy or tandem mass spectroscopy allows for highly accurate determination of toxin concentrations and identification of different types of toxins in a single analysis [38]. Alternatively, fluorescence property is also used for the detection of unmodified aflatoxins in HPLC applications as well as in thin layer chromatography. Furthermore, there are combinations of the above described methods with pre-process techniques, which can detect the concentration of aflatoxin in a solution in a better way. For example, immune-affinity column sample clean-up followed by a normal or reverse phase of HPLC separation along with fluorometric detection is mostly used for quantitative determination of AFM_1 due to the characteristics of specificity, high sensitivity and simplicity of operation [39].

3.2. Immunoassay method

Immunochemical detection for aflatoxins is based on the principle of antibody-antigen reactions (Ab-Ag) [40]. Since different kinds of aflatoxin molecules possess antigenic properties, it

is possible to detect them by raising antibodies against them. Most of the immunological methods are based on enzyme-linked immunosorbent assays (ELISA), which have good sensitivity, speed and simplicity. In addition, some lateral flow immunoassays (LFIAs) are also applied for the qualitative and semi-quantitative detection of aflatoxins in food, feed and milk [41]. Even though several studies have been published on the immunochemical determination of aflatoxins in food, only a few validation protocols are available to show that the results comply with certain regulations because of the requirement for expensive instrumentation.

3.3. Biosensor and other methods

Biosensors, an alternative to overcome the disadvantages of the previous described methods, are multidisciplinary tools with an enormous potential in detection and quantification of aflatoxin with minimum cost. There are different kinds of biosensors that base their performance on different physical or biochemical principles, such as optical, optoelectronic, electrochemical, piezoelectric, DNA and combined. Thus, such devices have a huge impact on healthcare, food management, agronomical economy and bio-defence [42]. Different types of biosensors are applied to detect aflatoxins in various food commodities. However, they mainly work on the principle of conjunction with various immunochemical methods. Such junctions are based on simple principle that employs the property of high affinity of antigen-antibody interaction, which automatically increased the sensitivity and thus reducing the detection time of toxic element [43]. For example, Chauhan et al. [44] used 150 different maize samples that were collected from different Gedeo zones of Ethiopia. Commodity samples included dry maize flour, freshly harvested corn fruits and dry maize kernels. For quantification of aflatoxin in maize samples from Ethiopia, we followed biosensor approach. The assay is based on a single-step lateral flow immunochromatographic principle with competitive immunoassay format. Use of such technique is the first approach utilized in the developing country like Ethiopia.

Further methods also exist which are less common than the previously described methods but have a tremendous potential for detection of fungal toxins. The most important are those ones that utilize the principle of electrochemistry, spectroscopy and fluorescence. Compared with traditional methods for aflatoxin determination, electrochemical techniques offer some advantages such as reliability, low cost, *in situ* measurements, fast processes and easier methodology over common chromatography techniques through a similar performance. Especially, for measurement of AFM_1, the disposable immunosensors have been applied directly in milk following a simple centrifugation step without dilution or other pre-treatment steps. Exhibition of a good working range with linearity between 30 and 240 ng/ml makes this method very useful for AFM_1 monitoring in milk (maximum acceptable level of AFM_1 in milk is 50 ppt) [45]. Spectroscopy techniques are also popularized due to the characteristics of fast, low-cost and non-destructive analytical methods suitable to work with solid and liquid samples. Among them, near infrared spectroscopy (NIRS) is an excellent option for a rapid and low cost detection of aflatoxin in cereals [46]. When incorporated with a bundle reflectance fibre-optic probe, NIRS was successfully applied to quantify AFB_1, ochratoxin A and total aflatoxins in paprika [47]. Aflatoxins have a native fluorescence due to their oxygenated pentaheterocyclic structure, which forms the basis of most analytical and microbiological methods for detection and quantification of aflatoxins [48].

4. Occurrence of aflatoxins in various food commodities

Aflatoxins are toxic secondary metabolites produced by various *Aspergillus* species growing in susceptible agricultural commodities. Many African countries had begun to implicate prevention, control and surveillance strategies to reduce the incidence of aflatoxin in foods. The main mycotoxins, i.e., aflatoxins, have been reported to be widespread in major dietary food products in African countries. These mycotoxins occur mostly in maize, spices and groundnuts and many more food commodities. Our data demonstrate that all the maize samples tested were beyond the safety level of aflatoxins as determined by Food and Drug Administration (FDA) and European Union (EU). Many studies are reported on contamination of food and food products in African countries. The food and food commodities that are prone to aflatoxin contaminations is briefly highlighted in **Table 1**, adapted from various literature.

Country	Food and food commodities	Concentration	Reference
Ethiopia	Shiro and red pepper	100–525 ppb	[49]
	Sorghum, barley, teff and wheat	00–26 ppb	[50]
	Maize	5 μg/kg	[51]
	Pre- and Post-harvest maize	18.38–43.4 μg/kg	[52]
	Maize	40–90 ppb	[44]
	Sorghum	1.17–344 μg/kg	[53]
Nigeria	Groundnut	2000 g/kg	[54]
	Pre-harvest maize	3–138 μg/kg	[55]
	Dried yam chips	27.1 μg/kg	[56]
	Maize	770 ppb	[57]
	Melon seed	2.3–47.7 μg/kg	[58]
	Bush mango seed	0.2–4.2 μg/kg	[59]
	Millet	1.370–28 μg/kg	[60]
	Maize	0–1874 μg/kg	[61]
	Roasted groundnut	3–106 μg/kg	[62]
	Smoke dried fish	1.5–8.11 μg/kg	[62]
	Powdered soy milk	4.58–19.76 μg/kg	[63]
	Mouldy sorghum	0–1164 μg/kg	[64]
	Beans	59.29–106 μg/kg	[65]
	Wheat	85.66–198.4 μg/kg	[65]
	Wheat	17.10–20.53 μg/kg	[66]
	Poultry/Live stock feed	0–67.9 μg/kg	[67]
	Food thickeners	4–9 μg/kg	[68]
	Dried beef	0.003–0.004 μg/kg	[69]
	Fresh beef	0.02–0.03 μg/kg	[69]
	Rice	28–372 ppb	[70]
	Weaning food	4.6–530 ppb	[71]
	Rice	37.26–113.2 μg/kg	[72]
	Maddi	0.2–125 μg/kg	[72]
	Dry sesame	14–140 μg/kg	[72]
	Maize and maize products	102–213 ppb	[73]
	Okra fruits	0.08–8.5 μg/kg	[74]
	Fruits	3.8 μg/kg	[75]
	Suya spices	2.65–43 μg/kg	[76]

Country	Food and food commodities	Concentration	Reference
Egypt	Meat products	2–150 ppb	[77]
	Spices	2–35 ppb	[78]
	Cereal grains	36 ppb	[79]
	Chicken and chicken products	1–4 ppb	[80]
	Nuts and seed	24 ppb	[81]
	Medicinal plants	49 ppb	[81]
Tunisia and Morocco	Poultry feed	0.03–5.38	[21]
	Barley	3.5–11.5 μg/kg	[82]
	Wheat	4.0–12.9 μg/kg	[82]
	Sorghum	0.34–52.9 μg/kg	[83]
	Pistachio	0.24–12.24 μg/kg	[83]
	Cereals and cereals products	5.5–66.7 ppb	[84]
Sudan	Animal feeds	4.1–579 μg/kg	[85]
	Sesame oil	0.2–0.8 ppb	[86]
	Groundnut oil	0.6 ppb	[87]
	Peanut butter	21.17 ppb	[87]
Tanzania	Maize	158 ppb	[88]
	Red chilli	<4 ppb	[89]
Uganda	Maize	1–1000 μg/kg	[90]
	Groundnuts, cassava, millet, etc. Maize	0–55 ppb	[91]
	Cassava	7–12 μg/kg	[92]
	Groundnut and groundnut paste	0–5 μg/kg	[92]
		0–940 μg/kg	[92]
Kenya	Wheat	0–7 μg/kg	[93]
	Animal feed and milk	<5 ppb	[94]
	Groundnut	0–7525 μg/kg	[95]
	Maize	<20 ppb	[96]
	Grains	<10 ppb	[97]
	Groundnut	0–2377 ppb	[97]
Ghana	Maize	0.7–335 ppb	[98]
Benin	Chips	2.2–220 ppb	[99]
	Store maize	14–58 g/kg	[54]
	Maize	5 ppb	[100]
	Dried vegetables	3.2–6.0 ppb	[101]
	Cowpea	3.58 μg/kg	[102]
Mali and Togo	Dried vegetables	3.2–6.0 ppb	[101]
Botswana	Raw peanut	12–329 μg/kg	[103]
Senegal	Peanut oil	40 ppb	[104]
South Africa	Traditionally brewed beers	200–400 μg/l	[105]
	Wheat and products	0.5–2.0 μg/kg	[106]
	Animal feeds	0.8–156 μg/kg	[107]
	Cotton seed meal	0.3–75 μg/kg	[108]
	Grains	<20 ppb	[109]

Country	Food and food commodities	Concentration	Reference
Cameroon	Cow pea	0.2–6.2 μg/kg	[110]
	Soy bean	0.2–3.9 μg/kg	[110]
	Egg	0.002–7.68 μg/kg	[111]
Morocco	Maize flour	0.23–11.2 μg/kg	[21]
	Dried figs	0.28 μg/kg	[112]
	Dried raisins	3.2–13.9 μg/kg	[112]
	Pistachio	0.04–14.30 μg/kg	[112]
Congo	Groundnut	1.5–937 μg/kg	[18]
	Grains	<20 ppb	[109]
Malawi	Groundnut	0–3871 μg/kg	[113]
	Maize		[113]
	Sorghum		[114]
	Local beer		[114]
	Groundnut		[115]
		0–1335 μg/kg	
		1.7–33.0 μg/kg	
		8.8–34.5 μg/kg	
		0.2–4.3 ppb	
Algeria	Wheat and products	0.13–37.42 μg/kg	[116]
Zambia	Peanut butter	20–10740 μg/kg	[117]
Zimbabwe	Ground nut	6.6–247 ppb	[118]
	Peanut and peanut butter	75 ppb	[118]
	Groundnut	1–175 μg/kg	[119]
	Cowpea	1.4–103.4 μg/kg	[119]
Gambia	Groundnut	8.22–813.86 μg/kg	[120]
Burkina Faso	Groundnuts	170 ppb	[121]

Table 1. Incidence of aflatoxins contamination in various foods and food commodities from different parts of Africa.

5. Aflatoxins safety level set up by African countries

Only few African countries are known to have regulations for aflatoxins in food and/or feed. These are summarized in **Table 2**, which was adapted from Anonymous [122] and van Egmond [123].

Country	Food commodity	Aflatoxins type	Regulatory level (ng/g)
Ivory Coast	Feedstuffs	B_1, B_2, G_1, G_2	100
	Mixed feeds	B_1, B_2, G_1, G_2	10
	Mixed feeds: pigs/poultry	B_1, B_2, G_1, G_2	38
	Mixed feeds: ruminants	B_1, B_2, G_1, G_2	75
	Mixed feeds: dairy cattle	B_1, B_2, G_1, G_2	50

Country	Food commodity	Aflatoxins type	Regulatory level (ng/g)
Egypt	Peanuts and products; oil seeds and products; cereals	B_1, B_2, G_1, G_2	10
		B_1	5
	Peanuts and products; oil seeds and products; cereals	B_1, B_2, G_1, G_2	20
		B_1	10
	Maize (food)	B_1, B_2, G_1, G_2	0
	Maize (food)	B_1	0
	Starch and derivatives (food)	M_1, M_2, G_1, G_2	0
	Starch and derivatives (food)	M_1	0
	Milk, dairy products	B_1, B_2, G_1, G_2	20
	Milk, dairy products	B_1	10
	Animal and poultry feeds		
	Animal and poultry feeds		
Kenya	Peanuts and products, vegetable oils (food)	B_1, B_2, G_1, G_2	20
Malawi	All foods	B_1, B_2, G_1, G_2	35
	Peanuts for export (food)	B_1	5
Nigeria	All foods	B_1	20
	Infant foods	B_1	0
	Milk	M_1	0
	Feedstuffs	B_1	50
Senegal	Peanut product feeds	B_1	50
	Peanut product feed components	B_1	300
South Africa	All foods	B_1, B_2, G_1, G_2	10
	All foods	B_1	5
	Feed components	B_1, B_2, G_1, G_2	50
	Mixed feeds for beef cattle, sheep and goats	B_1, B_2, G_1, G_2	50
		B_1, B_2, G_1, G_2	20
	Mixed feeds for lactating cows, swine, calves, lambs	B_1, B_2, G_1, G_2	10
		B_1, B_2, G_1, G_2	0
	Mixed feeds for unweaned piglets, broilers and pullets		
	Mixed feeds for trout		
Zimbabwe	Foods	B_1	5
	Foods	G_1	4
	Groundnuts, maize, sorghum	B_1	5
	Groundnuts, maize, sorghum	G_1	4
	Poultry feed	B_1, B_2	10
	Peanut butter, cereal flour	B_1, B_2, G_1, G_2	20
Mauritius	Peanuts	B_1, B_2, G_1, G_2	15
	Peanuts	B_1	5
	Other products	B_1, B_2, G_1, G_2	10
	Other products	B_1	5
Algeria	Nut, cereals	B_1	20

Table 2. Aflatoxins safety level in several countries of Africa.

6. Strategy to control aflatoxins in Africa

Measure for control of aflatoxins in Africa is not only crucial for implications of health safety, but also required to enhance the economy in the affected countries. According to Cassel et al. [125], the number of different approaches has been implicated to diminish and eradicate mycotoxins from different African countries. For example, control strategies include delaying of mould growth in crops and other feedstuffs, decontamination of mycotoxins affected foods and continuous monitoring of aflatoxins in agricultural crops, animal feedstuffs and human food. Apart from these measures, other prevention measures include separation of infected peanuts in Malawi, reduction of toxicity in peanut meal in Senegal for export, regulation of aflatoxins proportion in animal feed according to the susceptibility of respective animal species in Zimbabwe, selection of groundnut varieties less susceptible to aflatoxin contamination in Burkina Faso and improvement in handling and storage practices during production around 1960s in Nigeria and in 1990s in Gambia [124]. According to Cassel et al. [125], time of harvest is an important factor in influencing the occurrence and levels of aflatoxin. For example, harvesting maize above 20% moisture content followed by rapid drying to at least 14% within 24–48 hours of harvest minimizes aflatoxin level efficiently. Chulze [126] reported that it is possible to control aflatoxins in stored commodities by maintaining good atmosphere and use of preservatives or natural inhibitors in the form of antioxidants and essential oils can be applicable but the cost can be prohibitive on a large scale.

In recent times, there have been initiatives undertaken by international bodies with the aim to control aflatoxins in developing countries, especially from Africa. One of the best initiatives initiated is the Partnership for Aflatoxin Control in Africa (PACA), which is based on a Memorandum of Understanding that was undersigned between the African Union Commission and Mars Incorporated with a vision of sharing food safety resources and expertise to control aflatoxins contamination in food crops, which constitutes a significant threat and a major problem to African agricultural commodities as well as raw materials in global market [127]. Another initiative includes various projects that aim to control aflatoxin contamination in maize and peanuts. These projects aimed in developing and implementing control strategies by scaling up different bio-techniques intervention to improve the health and income of farmers and their families as well as to generate wealth in the crop value chain [128]. The project is funded by Bill and Melinda Gates Foundation and African Agricultural Technology Foundation (AATF) through the International Institute of Tropical Agriculture (IITA) and UK aid from the UK government, respectively.

7. Conclusion

The literature reviewed reveals that African population is highly exposed to food borne aflatoxins, due to the tropical climate that is present in most of the African countries and provides optimal conditions for fungus to grow happily. These fungal toxins have been shown to cause a variety of toxic and severe health effects in humans and thus lead to reduced life expectancy

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in Africa automatically. However, where quality control is absent, unsafe levels of aflatoxin are present. AFB_1 was identified as the most predominant and toxic among all the aflatoxins types. Their vicinity in African foods and feeds is unavoidable due to which, humans and animals are suffering from aflatoxins contamination on various and regular bases that lead to a wide range of health effects. Particularly, AFB_1 has been directly correlated to hepatocarcinoma and deaths among humans and animals across the world. Although, this may be the case globally, the status in sub-Saharan Africa is very critical, as rising levels of aflatoxins exposure through different dietary products are a common problem as evidence by various literatures highlighted in **Table 1**. Again, the problem is further exacerbated by increased prevalence of AFB_1 in this continent, as such endemic diseases like malaria, hepatitis and HIV/AIDS are identified in peoples who consumed aflatoxins contaminated food. In Africa, we have already experienced the most fatal aflatoxin poisoning outbreaks including two episodes especially one in Kenya and other in Nigeria.

It is obvious that impoverished and less privileged people of developing countries of Africa are indirectly linked to greater risk of further poverty and food scarcity, if control measures are not undertaken for the regulation of aflatoxins contamination in agriculture commodities. Utilization of recommended prevention and control strategies may make food more costly and less usable, since farmers will have to focus in drying and storage equipment to protect food that is directly related to more investment. Even though there are various methods available for detection of aflatoxins, their plight is worsened by the absence of well-equipped state of art laboratories for testing mycotoxins levels, which are economically and financially inaccessible. However, it will be better to confirm that contamination levels of fungal toxins are minimal to safeguard the health of people in developing countries whose lifespan is relatively short. It is unfortunate for the people in developing countries that international bodies like the World Health Organization (WHO) do not consider aflatoxins as a high priority risk; hence, little attention has been paid to the health issues resulting from the consumption of contaminated food.

Developed countries and international agencies should come forward for necessary financial and technical assistance to support developing countries to carry out research and education. This will also directly benefit to developing countries in terms of increased foreign exchange earnings, from the sale of products that meet required standards and better health through the consumption of safer food, which are not beyond the safety level of mycotoxins.

In the end, implementation of national prevention and control strategies like proper pre- and pro-harvest treatment of infected maize and standard storage facilities are required to reduce the risk of aflatoxin contamination by fungi in foods from African countries. Since, very few countries have set the safety level of aflatoxins in food, more studies are required from different parts of Africa to generate data for different governments to work on policy making decision strategy and required to set the safety level for aflatoxins in foods. The quantity of aflatoxins reported in various researches as shown above possesses a potential threat to agro as well as food industry in Africa and require immediate control measures. It is also important to implement control strategies to differentiate the food samples that are safe for human and animal consumptions for saving lives.

Conflict of interest

The author declared no conflict of interest.

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