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Review

Mycotoxins in Sub-Saharan Africa: Present situation, socio-economic impact, awareness, and outlook

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ABSTRACT

Many studies have reported the occurrence of mycotoxin in human foods and animal feeds in Sub-Saharan Africa (SSA). Aflatoxins, ochratoxins, fumonisins, and zearalenone are among the most hazardous mycotoxins produced by fungal species, mainly in the genera *Aspergillus*, *Penicillium*, and *Fusarium*. Due to their high stability, mycotoxins are a cause of concern not only during crop production, but also in storage, transport, processing, and post-processing steps. Mycotoxin contamination is one factor that reduces the competitiveness of agricultural commodities from SSA for export. Moreover, these impurities negatively impact the health of humans and livestock which affects household security, livelihood, productivity, and income and leads to significant costs and economic losses for the producing countries. Limited knowledge or awareness of most actors along the food and feed chain is considered to be one of the major problems delaying effective counter measures. In the last decades, various accurate and sensitive analytical methods have been developed to detect levels of mycotoxins on food and feed samples such as HPLC, LC-MS, immuno-based assays, and optical methods. Nevertheless, immuno-based techniques are still the most useful for identifying mycotoxins in the field and farm levels as they can be conducted onsite. Although tolerable limits for mycotoxins have been established in many SSA countries, most contamination still exceeds maximum thresholds and these toxins continue to pose considerable risk to public health. To address mycotoxin problems in SSA, therefore, possible intervention strategies should provide support for capacity building and supply chain coordination, increased public awareness, and knowledge through education and extension, as well as improved incentives for management of respective fungal species.

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Nomenclature

AFs	Aflatoxins
ANVISA	Brazilian Sanitary Surveillance Agency
DART	Direct Analysis in Real Time
DESI	Desorption Electrospray Ionization
EC	European Commission
EU	European Union
ELISA	Enzyme-Linked Immunosorbent Assay
FMs	Fumonisins
GAP	Good Agricultural Practices
GC	Gas Chromatography
GMP	Good Manufacturing Practices
HACCP	Hazard Analysis, and Critical Control Point
HSI	Hyperspectral Imaging
IARC	International Agency for Research on Cancer
LC	Liquid Chromatography
MS	Mass Spectrometry
NIRS	Near Infrared Spectroscopy
OTs	Ochratoxins
PAT	Patulin
SSA	Sub-Saharan Africa
TLC	Thin Layer Chromatography
TRC	Trichothecenes
USD	United States Dollars
USFDA	United States Food, and Drug Administration
ZN	Zearalenone

1. Introduction

The problem of food insecurity predominately occurs in countries with developing and transitional economies, where significant proportions of the population have inconsistent access to safe, nutritious, and affordable food. Food security is the building block on which vigorous and healthy lives are built. Factors related to food security and malnutrition not only influences the wellbeing of people, but also affects larger issues of society, economics, and politics. What is documented, but not always evident, is that one of the main factors of food insecurity is production and postharvest losses. According to FAO (2011), around a third of all foodstuffs produced for world's population are lost from field to consumer, amounting to roughly 1.3 billion metric tons per annum. Mycotoxins are one of the most significant contributors to food and feed losses in developing countries, especially in Sub-Saharan Africa (SSA).

Filamentous ascomycetes of genera *Aspergillus*, *Penicillium*, and *Fusarium* are mainly responsible for mycotoxin contamination (Barrett, 2000; Pereira, Fernandes, & Cunha, 2014). Although hundreds of mycotoxins have been identified, the most frequently occurring and toxicologically recognized classes are aflatoxins (AFs), ochratoxins (OTs), fumonisins (FMs), zearalenone (ZN), trichothecenes (TRC), patulin (PAT), and their derivatives. From the African perspective, AFs, OTs, and FMs are considered to be widespread in major dietary and export oriented crops (Bandyopadhyay, Kumar, & Leslie, 2007; Mutiga, Hoffmann, Harvey, Milgroom, & Nelson, 2015; Mutegi et al., 2013; Probst, Bandyopadhyay, & Cotty, 2014; Vismer, Shephard, Rheeder, van der Westhuizen, & Bandyopadhyay, 2015; Warth et al., 2012). Since those crops affected by fungal infection are also used as feed for livestock (Ezekiel, Sulyok, Warth, Odebode, & Krska, 2012, 2014), mycotoxins further affect the food chain as they reduce animal growth rates and biotransfer to livestock products (Bryden, 2012). Several studies have reported that mycotoxins are able to resist decomposition or catabolism in the digestive systems of animals, allowing these compounds to persist in meat, eggs, milk, and dairy products (Gizachew, Szonyi, Tegegne, Hanson, & Grace, 2016; Ibqal, Nisar, Asi, & Jinap, 2014; Iqbal, Jinap, Pirouz, & Ahmad Faizal, 2015; Prandini et al., 2009). This gives rise to certain partially-metabolized mycotoxins, such as aflatoxin type-M_1 (AF-M_1), which is present in milk from animals or humans who have consumed foods or feeds contaminated by AF-B_1 (De Ruyck, De Boevre, Huybrechts, & De Saeger, 2015).

Presently, emphasis on the health risk of mycotoxins contaminated food and feedstuffs consumption has increased considerably. Mycotoxin contamination has been exemplified in many experimental, clinical, and epidemiological studies to be immunosuppressive, teratogenic, mutagenic, carcinogenic, genotoxic, and hepatotoxic to humans and animals alike, depending on the level of exposure (Binder, Tan, Chin, Handl, & Richard, 2007; Fung & Clark, 2004; Sherif, Salama, & Abdel-Wahhab, 2009). The IARC has classified AFs as a proven carcinogen (Group 1) since they have been directly associated with the occurrence of liver cancer, whereas OT-A and FMs are listed in Group 2B and ZN is found in Group 3 (IARC, 2002). In the body, mycotoxins reduce transport of

soluble nutrients (Fink, 2008a,b), disrupt metabolism of proteins, carbohydrates, and lipids as well as alter growth factor expression and impair growth in children (Gong, Turner, Hall, & Wild, 2008; Khlangwiset, Shephard, & Wu, 2011). Moreover, mycotoxin contamination lowers product quality and reduces export values, which may lead to significant economic losses for producing countries. They can also indirectly waste natural resources as well as lead to hunger and malnutrition. Regarding the effects on human health, animal productivity, and trade, the prevalence of mycotoxin has led many countries and organizations to establish strict regulations for their content in food and feed, and consequently, establish legislation to control their possible dissemination (Juan, Ritieni, & Mañes, 2012).

The formation of mycotoxins is mainly dependent on conditions related to climate, crop production, handling, and storage, but can also be influenced by additional factors. Unfavorable postharvest and storage conditions are normally conducive to increasing vigor of fungal growth, especially when the crop has been infected during cultivation (Paterson & Lima, 2010). During production, factors such as genotype, water stress, soil conditions, and insect activity have all been found to be influential in determining the likelihood of mycotoxin contamination (Wagacha & Muthomi, 2008). Additionally, socio-economic factors such as unavailability of materials, tools, and equipments as well as inadequate marketing and transportation systems, lack of information, and inadequate governmental policy, regulations, and legislations can further contribute to situations favoring mycotoxin contamination.

Mycotoxin-producing fungi are ubiquitous and cannot be easily eliminated, but contamination can be mitigated to acceptable levels for consumption through strategic interventions. Several pre- and postharvest strategies have been developed to counter both the economic losses and adverse health effects caused by mycotoxins in food and feed. At the pre-harvest level, these interventions focus on the reduction of fungal infection in the field, such as good agricultural practices (GAP) (Cleveland, Dowd, Desjardins, Bhatnagar, & Cotty, 2003; Munkvold, 2003), host plant resistance (Brown et al., 2013) and bio-control (Cotty, Antilla, & Wakelyn, 2007). Postharvest interventions include good manufacturing practices (GMP) focusing on timely harvest and prompt drying as well as transportation and storage improvements (Hell et al., 2008; Turner et al., 2005). Dietary interventions such as use of supplements (e.g., enterosorbents and green tea polyphenols) enable detoxification and elimination of mycotoxins once ingested (IARC, 2015), while changing dietary staples to less susceptible crops (e.g. from maize to rice) and increased diet diversity have been recommended for reducing the impact of mycotoxins in humans (Bandyopadhyay et al., 2007; Wu, Groopman, & Pestka, 2014). However, various strategies have not been proven to be sustainable over extended periods and many are not economically and logistically realistic for poorer communities, which typically suffer the highest exposure to mycotoxins.

Although major health issues and considerable economic problems in SSA have been linked to mycotoxins and the associated health disorders in humans and animals, reports on mycotoxin contamination have not been as comprehensive in SSA as for other parts of the world. Reviews on the topic exist from previous decades (Bankole, Schollenberger, & Drochner, 2006; Sibanda, Marovatsanga, & Pestka, 1997), but considerable research has been presented since which this paper aims to condense. Therefore, data about mycotoxin occurrence in different commodities in SSA have been compiled and an overview of the methodologies reported on mycotoxin analysis is featured. Also, socio-economic consequences, regulations, and awareness with regards to mycotoxin problems are highlighted. Finally, the future challenges of mycotoxin reduction in SSA are addressed.

2. Classification, occurrence, and toxicological aspects of mycotoxins

2.1. Aflatoxins

Due to their effect on human health, aflatoxins (AFs) have received substantial attention among the various mycotoxins. AFs are mainly produced via a polyketide pathway by several species and unnamed strains of *Aspergillus* Section *Flavi*, which includes *Aspergillus flavus*, *Aspergillus parasiticus*, *Aspergillus parvisclerotegenus*, and *Aspergillus minisclerotigenes* (Pleadin, VulićPerši, Škrivanko, Capek, & Cvetnić, 2014), Strain SBG (Cotty & Cardwell, 1999), and less commonly *Aspergillus nomius* (Kurtzman, Horn, & Hessetline, 1987). Normally, *Aspergillus flavus* produces only B-type, whereas the other *Aspergillus* species produce both B- and G-type AFs (Creppy, 2002; Zinedine & Mañes, 2009). M-type AFs are not usually found on crops, but are metabolites occurring in milk of mammals whose diet are contaminated with AF-B_1 and AF-B_2 (Iqbal et al., 2015). Approximately 0.3–6.2% of AF-B_1 is converted into hydroxylated metabolite AF-M_1, depending on several factors such as the genotype of the animals, milking practices, seasonal fluctuations, and environmental conditions (Unusan, 2006). Interestingly, Wogan and Paglialunga (1974) reported that AF-M_1 has only 10% of the carcinogenicity of AF-B_1 *in vivo*.

AFs can be acutely hepatotoxic, causing liver damage or cancer in humans and animals after being metabolized to the reactive 8,9-epoxide that may form DNA adducts by alkylating some guanine residues (Hsu et al., 1991). In general, AF-B_1 is considered to be the most noxious and carcinogenic. Among initial symptoms of liver damage from aflatoxicosis are anorexia, malaise, and low-grade fever. Moreover, acute hepatitis accompanied with vomiting, abdominal pain, and eventually even death can be potentially triggered by severe aflatoxicosis (Etzel, 2002; Sherif et al., 2009). Indeed, AFs were found to be the cause of a recent epidemic affecting Eastern province of Kenya and causing over 125 deaths during 2004–2005 (Azziz-Baumgartner et al., 2005). Concerning the toxic, carcinogenic, teratogenic, and mutagenic potentials of AFs, the IARC has classified AF-B_1, AF-B_2, AF-G_1, and AF-G_2 all as Group 1 mutagens, denoting their explicit carcinogenicity to humans, while AF-M_1 is classified in Group 2B (IARC, 2002). AFs may contribute to growth stunting during early childhood (Khlangwiset et al., 2011), and together with other mycotoxins, are commonly suspected to play a role in development of edema in malnourished people as well as in the pathogenesis of kwashiorkor, frequent condition in African children (Coulter et al., 1986; Hendrickse, 1982). In animals, AFs can be considered as a cause of economic losses due to lower resistance to diseases, counteraction of vaccine-induced immunity, and adverse effects on growth and reproduction (CAST, 2003; Fink, 2008a,b).

2.2. Ochratoxins

Ochratoxins (OTs) are primarily produced by the genera of *Aspergillus ochraceus* and *Penicillium verrucossum*. In certain commodities or geographic areas, fungi in the *Aspergillus niger* group may be also important (Richard, 2007; Tjamos et al., 2004). The crops mainly affected are cereals and cocoa (Copetti, Pereira, Iamanaka, Pitt, & Taniwaki, 2010; Gilmour & Lindblom, 2008), coffee (De Moraes & Luchese, 2003; Romani, Sacchetti, Chaves López, Pinnavaia, & Dalla Rosa, 2000) as well as grapes (García-Cela, Ramos, Sanchis, & Marin, 2012; Zinedine & Mañes, 2009). In the grouping of OTs, A-type is the most toxic compound, however B-, and C-types also exist. Kidney function is most often affected by OTs, where both acute and chronic exposures cause lesions to form on the organs (García-Cela et al., 2012). Another kidney disease

often with associated tumors, called Balkan Endemic Nephropathy, is considered to be caused by OT-A exposure (Pfohl-Leszkowicz, Petkova-Bocharova, Chernozemsky, & Castegnaro, 2002). Also, OT-A has been hypothesized to cause oxidative damage to DNA, leading to mutagenesis and potentially cancer (Zepnik, Pahler, Schauer, & Dekant, 2001). Consequently, OT-A has been named as a possible human carcinogen by IARC (Group 2B), citing suggestive evidence of carcinogenesis in animal models, but insufficient evidence from human studies (IARC, 2002).

2.3. Fumonisins

Fumonisins (FMs) are a class of mycotoxins primarily produced by *Fusarium verticillioides* and *Fusarium proliferatum*, but can also reportedly be formed by *Aspergillus niger*. Microbial strains have variable ability to produce the toxins (Richard, 2007). Maize is the major food crop affected by FMs, although noteworthy incidence has been found in sorghum and rice (CAST, 2003; Vismer et al. 2015). Among different isolated types, FM-B_1 is the most highly toxic and has been found to stimulate tumor development (Abel & Gelderblom, 1998), equine leukoencephalomalacia (Marasas et al., 1988), porcine pulmonary edema (Harrison, Colvin, Greene, Newman, & Cole, 1990), nephrotoxicity, and liver cancer in rats (Soriano, Gonzállez, and Catalá, 2005). Sherif et al. (2009) mentioned that FMs can additionally disrupt sphingolipid metabolism, a critical process in cell regulation, by acting as secondary messengers for growth factors, differentiation factors, and cytokines. Links between exposure to FM-B_1 and esophageal cancer can be found in many epidemiologic studies (Rheeder, Marasas, & Vismer, 2002). Accordingly, *Fusaria*-derived toxins such as FM-B_1 and FM-B_2 are listed as suspected carcinogens in Group 2B of the IARC classification (IARC, 2002). Recently, Shirima et al. (2015), who studied the association between child growth and AFs and FMs exposure in Tanzania, reported that FMs exposure alone or in combination with AFs, could be casual factors for child growth impairment.

2.4. Zearalenone

Zearalenone (ZN) is another common mycotoxin produced by various *Fusarium* fungi such as *Fusarium culmorum*, *Fusarium graminearum*, and *Fusarium sporotrichioides*. As the name implies, ZN is most often found in maize, yet it can also be observed in other grain crops such as wheat, barley, sorghum, millet, and rice (García-Cela et al., 2012). It can also be found in beverages made with contaminated crops (Chen et al., 2000). ZN shares a structural similarity with the human sex hormone 17-β-estradiol, which allows it to bind to estrogen receptors in target cells, resulting in association with fertility problems in both humans and animals (Pillay et al., 2002; Sherif et al., 2009). Although IARC found limited evidence of ZN carcinogenicity in animals, it is classified in Group 3 (IARC, 2002). Some ongoing studies speculate that ZN may be associated with the early onset of puberty and probably also increased risk of cervical cancer (Bhatnager, Yu, & Ehrlich, 2002). Sherif et al. (2009) hypothesized that the reproductive system is mainly affected by exposure to ZN due to effects on structure and function of respective organs and may lead to hyperestrogenism in children.

3. Mycotoxin contamination in specific crops

3.1. Groundnut

Groundnut is included as an integral crop and foodstuff in livelihood of the majority of the population in SSA through the provision of income and dietary nutrients, especially proteins (Diop, Beghin, & Sewadeh, 2004). In 2013, groundnut was cultivated on 25.4 million ha resulting in a total production of 45.2 million metric tons worldwide, with Africa contributing 49% of production area and 26% of the total yield (FAOSTAT, 2015). Many studies reported that most groundnut produced in SSA is prone to pre- and post-harvest toxigenic fungal colonization and mycotoxin contamination (Bankole et al., 2006; Ezekiel et al., 2012; Monyo et al., 2012).

The contamination of mycotoxins in groundnut samples from SSA is summarized in Table 1. Preliminary surveys by Awuah and Kpodo (1996) reported considerable levels of AFs in groundnuts obtained from market surveys in Ghana. Later, Egal et al. (2005) observed that 1.7% of groundnut samples from Benin and Togo had AF-B_1 levels higher than 20 μg/kg. In a study focused on dry roasted groundnuts from local vendors, markets, and retail shops in Nigeria, AF-B_1 was found in 64.2% of samples (Bankole, Ogunsanwo, & Eseigbe, 2005). Mutegi, Ngugi, Hendriks, and Jones (2009) analyzed 769 samples of groundnut in Kenya and reported that 87.0% were contaminated with <4 μg/kg of AF-B_1, while 7.5% exceeded national regulatory limited of 20 μg/kg. Similarly, AFs in commercial groundnut products obtained from Kenyan markets were also examined with a reported incidence of 69% and 75% exceeding 10 μg/kg in peanut butter and spoilt peanuts, respectively (Mutegi et al., 2013). A study conducted by Kamika and Takoy (2011) showed that 70% of groundnut samples from the Democratic Republic of Congo were found to exceed the maximum limit of 5 μg/kg for AFs as recommended by EU. In addition, the results exhibited that AF-B_1 levels tend to increase from the dry to the monsoon season. Using a sample of 120 groundnut samples from farmer shops and local markets in Ethiopia, Chala, Mohammed, Ayalew, and Skinnes (2013) revealed heavy contamination of AFs far beyond the EU standard. Recently, Matumba, Van Poucke, Monjerezi, Ediage, and De Saeger (2015) observed that groundnut samples from local markets in Malawi contained distinctly higher AF levels of 122.3 μg/kg, as compared with 2.6 μg/kg in samples destined as export goods.

Table 1
Reports of mycotoxins in groundnut products from locations in SSA.

Product	Mycotoxin(s)	Value(s) μg/kg	Location	Source
Fresh nuts	Total AFs	5.7–22,168	Ghana	Awuah and Kpodo (1996)
	AF-B_1	12.5–528.3	Benin, Togo	Egal et al. (2005)
	AF-B_1	0–7525	Kenya	Mutegi et al. (2009)
	AF-B_1	1.5–937	DR Congo	Kamika and Takoy (2011)
	Total AFs	15–11,900	Ethiopia	Chala et al. (2013)
	Total AFs	7–500	Malawi	Matumba et al. (2015)
Dry roasted nuts	AF-B_1	5–165	Nigeria	Bankole et al. (2005)
	AF-B_2	6–26		
	AF-G_1	5–20		
	AF-G_2	7–10		
Peanut butter	Total AFs	34.2–15.6	Malawi	Matumba et al. (2015)

Table 2
Reports of mycotoxins in maize products from locations in SSA.

Product	Mycotoxin(s)	Value(s) μg/kg	Location	Source
Dried kernels	Total AFs	22–190	Benin	Hell et al. (2000)
	AF-B_1	7.6–27.2	Benin, Togo	Egal et al. (2005)
	Total AFs	5–20	Malawi	Probst et al. (2014)
		2–162	Sierra-Leone	
		1–1407	Somalia	
		0–435	Uganda	
		0–87	Kenya (Rift Valley)	
		0.1–57	DR Congo (Bas)	
		0–122	Cameroon	
	AF-B_1	3–1081	Tanzania	Kamala et al. (2015)
	FM-B_1	16–18,184		
	FM-B_2	178–38,217		
	Total AFs	>20	Uganda	Kaaya and Kyamuhangire (2006)
	Total AFs	4–1400	Nigeria, Ghana	Perrone et al. (2014)
Beer	Total AFs	0–185	Malawi	Matumba et al. (2014)
	Total FMs	493–3303		

3.2. Maize

Maize is a primary foodstuff of many countries in SSA, with estimated per capita consumption ranging from 94 kg/year in East Africa to over 100 kg/year in Southern Africa (Smale & Jayne, 2004). This is considerably lower than rice and wheat, whose approximated per capita consumption in SSA is below 80 kg/year (Awika, 2011). Maize is commonly consumed fresh otherwise it is processed into milled or fermented products. In both rural and urban areas in parts of SSA, the crop contributes up to 40% of the daily caloric intake per capita (Bankole et al., 2006). It is also a major crop grown as feed for livestock. In Africa, total maize cultivation area increased from 28 million to 35 million ha from 2003 to 2013, with total maize production increasing from 46 to 72 million metric tons in the last decade (FAOSTAT, 2015). Globally, maize production systems are vulnerable to degradation by toxigenic fungal species (Doko, Rapior, Visconti, & Schjoth, 1995; Yoshizawa, Yamashita, & Chokethaworn, 1996), but in the developing world, and particularly in SSA, regulation of mycotoxin concentrations is infrequent. Hove, Van Poucke, Njumbe-Ediage, Nyanga, and De Saeger (2016) reported that AF-B_1 and FM-B_1 are two of the most toxicologically-relevant mycotoxins occurring in maize, which have been found in samples during both pre- and post-harvest operations.

Several studies have reported the occurrence of mycotoxins in maize in SSA as documented in Table 2. Udoh, Cardwell, and Ikotun (2000) indicated that 33% of maize samples obtained from different agroecological zones in Nigeria were contaminated with AFs. Also, Hell, Cardwell, Setamou, and Poehling (2000) described increased levels of AFs in maize samples from different agricultural areas of Benin after 6 months of storage as compared to the start of storage. In Benin and Togo, *Aspergillus flavus* was observed in 91% of maize with 3.6% of the samples exceeding the level of 20 μg/kg (Egal et al., 2005). Kaaya and Kyamuhangire (2006) determined AF contamination of maize kernels from traders from three geographical sources in Uganda. The results showed that AF had average levels greater than 20 μg/kg when samples from mid-altitude (dry and moist) areas were extendedly stored, meaning longer than six months. In addition, Mukanga, Derera, Tongoona, and Laing (2010) found a high level of FMs as compared to AFs in maize samples from Zambia. A study by Perrone et al. (2014) detected AFs in maize kernels collected from farms in Nigeria and Ghana. Probst et al. (2014) reported that AF contamination in 124 samples, including all samples from Malawi, and more than 50% of samples obtained from six other locations, exceeded the EU limit for AFs above 4 μg/kg Kamala et al. (2015) mentioned that 87% of maize samples from three agroecological zones of Tanzania were contaminated with more than one mycotoxin, in some cases with remarkably high concentrations, and 45% of samples were co-contaminated by carcinogenic AFs and FMs. Furthermore, Matumba et al. (2014) found exceedingly high amounts of AFs and FMs in maize-based traditional beer from Malawi.

3.3. Sorghum

Sorghum is an important grain crop in SSA with a current the total yield in Africa estimated to be more than 25.7 million metric tons (FAOSTAT, 2015). However, sorghum is affected by many diseases and is susceptible to colonization by a range of fungal species, during cultivation as well as after harvest. Chala et al. (2015) reported that ZN was the most typical mycotoxin found in sorghum, followed by FMs and AFs. The observation was in agreement with another study by Ayalew, Fehmann, Lepschy, Beck, and Abate (2006) who reported considerable levels of ZN and FMs in sorghum samples from Ethiopia. Moreover, Matumba, Monjerezi, Khonga, and Lakudzala (2011) analyzed samples of sorghum grain and malt in Malawi as well as a traditional sweet beverage and beer prepared from the malt. Here, the incidence of total mycotoxins in the grains was very low, with AFs being detected at 1.7–3.0 μg/kg, whereas significantly higher AF contents were found in the malt prepared for beverages, ranging 340–476 μg/kg. As a result, the final AF content in beer samples was 22.32 μg/L, much higher than the regulatory levels for direct human consumption as set by the EU.

Table 3
Reports of mycotoxins in cassava products from locations in SSA.

Product	Mycotoxin(s)	Value(s) μg/kg	Location	Source
Flour	AF-B_1	ND	Tanzania	Muzanila et al. (2000)
	AF-B_1	0.32–1.64	Congo	Manjula et al. (2009)
	FM-B_1	ND		
	AF-B_1	2.7	Tanzania	Sulyok et al. (2015)
	FM-B_1	29.8		
	OT-A	1.9		
Chips	Total AFs	ND	Ghana	Wareing et al. (2001),
	Total AFs	5.2–14.5	Cameroon	Essono et al. (2009)
	AF-B_1	0.4–4.38	Congo	Manjula et al. (2009)
	FM-B_1	ND		
	AF-B_1	0–33.8	Tanzania	Manjula et al. (2009)
	Total AFs	ND	Benin	Gnonlonfin et al. (2012)

3.4. Cassava

Cassava tuber is a main starch crop consumed by millions of individuals in parts of Western, Eastern, and Central Africa (Amusa, Adegbite, Muhammed, & Baiyewu, 2003). In 2013, about 57% (158 million metric tons) of the global production of cassava cultivation was documented in SSA (FAOSTAT, 2015). Cassava tubers are processed by several methods, including sun drying and fermentation, mainly in order to detoxify the material due to high content of cyanogenic compounds. The final diversity of consumed products, mainly subject to local practices and preferences, is exceptional with the prevailing forms being cassava chips and flour. Meanwhile, processing and storage methods include a range of conditions under which mold growth and mycotoxin formation are likely to occur (Westby, Wareing, Gibbs, & Dallin, 1995).

Several studies have found that despite high presence of mold species, including those that produce mycotoxins, little contamination was found in cassava products (Table 3). One primary example given is for flour samples obtained from Tanzanian villages (Muzanila, Brennan, & King, 2000). Similar results were observed in Ghana where more than 40% of dried cassava products were documented to be infested by *Aspergillus* spp. (Wareing, Westby, Gibbs, Allotey, & Halm, 2001) as well as in Benin, where cassava chips were not contaminated with AFs even though *Aspergillus flavus* was found (Gnonlonfin et al., 2012). These findings are indicative that the occurrence of toxin-producing fungi in a food commodity does not necessarily imply mycotoxin contamination, but rather a potential for formation as asserted by Jimenez, Mateouerol, Huerta, and Hernandez (1991). Some opposing results have been reported concerning the distribution incidence of AFs, especially in cassava chips which have been stored extendedly. Manjula, Hell, Fandohan, Abass, and Bandyopadhyay (2009) found AFs in samples from markets in Congo (Brazzaville) and Tanzania. Essono et al. (2009) showed that AFs were first detected in Cameroon after four weeks storage with the occurrence of AFs in positive samples depending on pH, storage duration, population of AF-producing fungi, and type of chip. The prevalence of regulated mycotoxins in cassava flour samples from Tanzania was recently reported as lower than 10% and the defined limits were exceeded only a few samples (Sulyok et al., 2015).

3.5. Cocoa and cocoa products

Cocoa beans, the principal raw material of chocolate, can be subject to fungal infestation during pretreatment at the farm or during subsequent processing (Copetti, Iamanaka, Pereira, Fungaro, & Taniwaki, 2011, 2014). The most commonly reported mycotoxins in cocoa beans and products are OT-A (Copetti et al., 2010; Gilmour & Lindblom, 2008) and AFs (Copetti, Iamanaka, Nester, Efraim, & Taniwaki, 2013, 2014). Mycotoxin accumulation in cocoa most commonly occurs during fermentation, but a significant increase in OT levels has also been observed during drying and storage (Copetti et al., 2011). Although about 50% of the contaminating species are physically eliminated when the shells are removed from the beans, some residual fungi persist and further postharvest processing does not ensure decontamination, which can lead to mycotoxin occurrence in final cocoa products (Bonvehi, 2004; Kumagai et al., 2008; Tafuri, Ferracane & Ritieni, 2004).

Literature reports a few instances of OT-A and AFs in raw cocoa and cocoa products in SSA. A study of OT-A occurrence in Ivory Coast, Ghana, and Nigeria was performed by Bonvehi (2004), where 35 samples of cocoa beans, cocoa butter, cocoa mass, and cocoa nibs were inspected. Three samples (8%) showed OT-A levels above the maximum of 2 μg/kg. The most severe contamination cases were observed in cocoa beans and cocoa mass. Amezqueta, Gonzalez-Penas, Murillo, and Lopez de Cerain (2004) also observed that 68% of cocoa beans from Ivory Coast and Cameroon were contaminated with OT-A.

3.6. Coffee

Coffee is a high-value commodity on the world market, accounting for approximately USD 27.1 billion of trade in 2012 (FAOSTAT, 2015). Global coffee consumption has nearly doubled over the past 40 years and is forecasted to be greater than 9 million tons by 2019 (Paterson, Lima, & Taniwaki, 2014). In respect to world coffee production, Africa is ranked third, however the product is subject to damage by several pests and diseases through which fungal contamination and formation of mycotoxins can occur (Paterson, Baker, & van der Stegen, 2001). Mycotoxin contamination has been documented to occur at several stages of processing such as harvesting, preparation, fermentation, drying, transportation, and storage (Silva, Batista, & Schwan, 2008; García-Moraleja, Font, Mañes, & Ferrer, 2015). Several reports have confirmed the presence of OT-A in unroasted beans (De Moraes & Luchese, 2003; Romani et al., 2000), roasted coffee (Leoni, Valente Soares, and Oliveria, 2000), and instant coffee (Lombaert et al., 2002; Patel, Hazel, Winterton, & Gleadle, 1997). While the majority of the studies about mycotoxin in coffee have been focused on non-African countries, documentation in SSA has been limited. Studies by Micco, Grossi, Miraglia, and Brera (1989) and Nakajima, Tsubouchi, Miyabe, and Ueno (1997) reported <0.1 μg/kg of OT-A in Arabica coffee from Kenya and Ethiopia, while levels up to 2.2 μg/kg were found in Tanzanian coffee samples as described by Studer-Rohr, Dietrich, Schlatter, and Schlatter (1995).

3.7. Meat, eggs, milk, and dairy products

Meat, milk, and dairy products are highly nutritious foods containing many macronutrients, vitamins, and minerals that are essential for growth and development as well as maintenance of good health in humans. Meanwhile, a key pathway for human exposure to AFs is by ingestion of meat and dairy products contaminated with AF-M_1 via metabolism of feed ingredients with high levels of AF-B_1. AF-M_1 can be particularly present in the milk glands of mammals (Fallah, Jafari, Fallah, & Rahnama, 2009). In meat products, mycotoxins may originate from residue in animal feeds, direct growth of toxigenic molds (Bailly & Guerre, 2009), or from the addition of flavoring materials such as spices (Fazekas, Tar, & Kovícs, 2005). The presence of AF-M_1 is an important problem worldwide, especially in developing countries since individuals of every age group regularly consume these products in their diets (Fallah et al., 2009). In addition, elevated AF-M_1 contents in milk and dairy products, such as milk powder, have economic consequences since these products cannot be traded on global markets where legislation is more stringent.

Several studies have been published which determine the prevalence of AF-M_1 in eggs and milk in SSA. In 2010, Tchana, Moundipa, and Tchuanguep detected AF-B_1, AF-B_2, and AF-M_1 in egg samples from Cameroon. They mentioned that contamination of aflatoxins in eggs may negatively affect the growth of chicks after hatching. The occurrence of AF-M_1 in milk has been documented in Kenya (Kang'ethe & Lang'a, 2009), Sudan (Elzupir & Elhussein, 2010), Cameroon (Tchana et al., 2010), South Africa (Mulunda & Mike, 2014), and Ethiopia (Gizachew et al., 2016) as presented in Table 4. Studies from urban centers in Kenya have reported AF-M_1 levels in milk up to 0.68 μg/L (Kang'ethe & Lang'a, 2009). In Sudan, Elzupir and Elhussein (2010) revealed that 95% of the milk samples were contaminated with the maximum level of AF-M_1 at 6.9 μg/L, while AF-M_1 was also detected in 15.9% of cow milk samples from

Table 4
Reports of mycotoxins in eggs and milk from locations in SSA.

Product	Mycotoxin(s)	Value(s) μg/L	Location	Source
Fresh eggs	Total AFs	0.002–7.604	Cameroon	Tchana et al. (2010)
Fresh milk	AF-M_1	6.9	Kenya	Kang'ethe and Lang'a (2009)
	AF-M_1	0.22–6.90	Sudan	Elzupir and Elhussein (2010)
	AF-M_1	0.006–0.527	Cameroon	Tchana et al. (2010)
	AF-M_1	0.15–0.17	South Africa	Mulunda and Mike (2014)
	AF-M_1	0.028–4.98	Ethiopia	Gizachew et al. (2016)
	AF-B_1	7–419		

Cameroon (Tchana et al., 2010). Mulunda and Mike (2014) evaluated the quality of milk consumed on daily basis in South Africa by both rural and urban populations in regard to AF-M_1 contamination. The results showed the highest incidences of AF-M_1 were observed in commercial samples as compared to rural samples. Furthermore, Gizachew et al. (2016) found occurrence of AF-M_1 in all milk samples and that only 8% of those contained $\leq$0.05 mg/L of AF-M_1. Also, out of 156 feed samples collected from farmers, feed producers, processors, and traders, only 16 samples contained AF-B_1 at levels of $\leq$10 μg/kg. Nevertheless, limited studies have been conducted on AFs in dairy feeds in SSA with the exception Kenya, where considerable analysis of AFs in maize has been performed (Kang'ethe and Lang'a, 2009; Muture & Ogana, 2005). Overall, continuous exposure to AF-M_1 is a health hazard for consumers, in particular for children. Together with animal milk, Darwish, Ikenaka, Nakayama, and Ishizuka (2014) mentioned that chronic exposure to AF via human intake can been seen by the prevalence of AF-M_1 in breast milk specimens obtained from Ghana, Kenya, and Nigeria.

4. Food security, society and economic impacts of mycotoxins

Food safety is a critical measure for food security in SSA, where mycotoxin formation in key staple crops causes significant post-harvest losses, negative impacts on health, and economic welfare as well as direct loss of human life due to fatalities (Lewis et al., 2005; Mutegi et al., 2013). Contamination can directly reduce *availability* of food, particularly for low-income people. Farmers who produce contaminated crops may also experience income reduction due to product rejection, lower market value, or exclusion from high-value markets. Several direct results stem from lower income including limited ability to purchase food, which translates into reduced *access* to food. Mycotoxins also diminish *utilization* of the contaminated product by either complete market rejection or forced alternate uses. Overall, foods contaminated with AFs also present a clear food security threat regarding their impact on human health, especially concerning the established causal association with liver cancer, synergistic effects with hepatitis B, and potential association with growth inhibition and immune system suppression.

Economic losses arising from mycotoxicosis in Africa are formidable (Otsuki, Wilson, & Sewadeh, 2001; Wu, 2004). While developed countries may incur economic losses due to the trade issues of mycotoxin contaminated foodstuffs, developing countries, such as those in SSA, tend to incur both the economic losses as well as additional costs related to health difficulties. The economic impact of AFs can be observed through direct decrease in marketable amounts of a crop, reduced value of contaminated products in domestic markets, regulatory rejection of products by high-value markets, and damages suffered via afflicted livestock, including disease, morbidity, mortality, and contamination of animal products (Zain, 2011). The economic considerations also include the cost of regulatory and research programs intended to reduce health risks for humans and livestock. Hussein and Brasel (2001) pointed that most studies on economic impact are based on individual factors of mycotoxin exposure or contamination, which is mainly due to the fact that economic models to gauge global impact have been problematic to establish.

At the domestic level, most economic impact analyses of AFs have been investigated for the USA. Coulibaly, Hell, Bandyopadhyay, Hounkponou, and Leslie (2008) reported that annual economic losses for US farmers resulting from AFs exceeded USD 100 million on average. Wu (2006) made a substantial estimate with an average annual loss of USD 163 million to US maize growers. Besides, the costs of managing AFs, including research and monitoring, expenditures in the USA are approximated at between USD 0.5–1.5 billion (Robens & Cardwell, 2003). According to Cardwell, Desjardins, Henry, Munkyold, and Robens (2004), AF contamination of crops in Africa causes annual losses of more than USD 750 million. In other nations, Lubulwa and Davis (1994) estimated the annual cost of AFs in Indonesia, Thailand, and Philippines to be nearly USD 1 billion per year due to a combination of market and livestock health losses. From the African perspective, the first study that caught significant policy attention was a World Bank estimate that EU regulation of AFs reportedly costs African food exporters USD 670 million annually. However, the economic model used to compute this value was based on production appraisals and considered climate effects on AF contamination. Also, it did not take into account actual AF levels in the foodstuffs, nor actual volumes of trade of different foodstuffs between Africa and the EU (Otsuki et al., 2001). While much of the previous investigation has focused on trade losses, fewer studies have been carried out to determine the additional cost of human effects by AF contamination in SSA, such as medical expenses primarily from those suffering from liver cancer as well as indirect costs (pain and suffering, anxiety, and reduction in quality of life) associated with the incidence of mycotoxosis. Morhason-Bellow et al. (2013) ascribed the problems with quantifying the impact of mycotoxin exposure in SSA to misdiagnosis, limited access to health care, technical restrictions of medical personnel, and poor infrastructure as well as the low technological level of data systems.

5. Awareness and knowledge on mycotoxins

With regard to consumer awareness of AFs in SSA, Jolly et al. (2006) reported that the evident signs of such as discoloration, insect infestation, or rotting could help most Ghanaian participants to identify fungal contamination in grains. In addition, an overwhelming majority of participants were not aware of AFs, let alone their harmful health effects. Awuah, Agyemang, Fialor, and Jolly (2008) found very poor awareness of aflatoxins in Ghanaian populations, with only 8% of the 1983 respondents indicating knowledge of the word “aflatoxin”. Several findings claimed that education level was positively correlated to cognizance of AF contamination in foods and feeds. Dosman, Adamowicz, and Hrudey (2001) found that subjects who held a higher level of education were more informed, and hence more likely to be aware, of

dangers posed by mycotoxins, than people with less education. As stated by Stronsnider et al. (2006), education and awareness are significant aspects to combating issues related to AF exposure. James et al. (2007) mentioned that sustained public education increased awareness of aflatoxin contamination in Benin, Ghana, and Togo. Similar results were obtained by Jolly, Bayard, Awuah, Fialor, and Williams (2009), who reported that education was interconnected to knowledge and linked to proactive control of AFs in Ghana. Ezekiel et al. (2013) also posited that education is very integral to consumer awareness of AF contamination in Nigeria.

Interestingly, Jolly et al. (2009) observed that white-collar male subjects were more concerned with expenses associated with minimizing AF levels, whilst women showed a heightened mindfulness towards positive health benefits from effective counteraction. Baker (2003) ascribed this behavior to the strongest reaction of women toward low-evident hazards to food safety. Furthermore, another study by Kumar and Popat (2010) showed that farmer knowledge of AFs was affected by socio-economic characteristics such as education level, farm size, participation in social and extension services, market orientation, economic motivation, level of innovation, and overall perception. It was highlighted that farmers do not consider control of mycotoxins an issue, simply because the domestic markets do not provide price incentives for uncontaminated products. In addition, farmers were found to be ignorant of negative health effects linked to mycotoxin consumption. This finding corroborated the results of Mohd Redzwan, Rosita, Mohd Sokhini, and Nurul'Aqilah (2012), who observed that demographic and socio-economic factors influenced respondents' awareness of AFs in their diets and that income level was the variable most significantly correlated with respondent knowledge.

6. Legislation and regulations of mycotoxins in foods and feeds

Legislation and regulations are continually evolving issues, since countries increasingly recognize that addressing mycotoxin contamination in foods and feeds will not only reduce healthcare costs, but also offer advantages with respect to international trade as well as access to high-value markets. Regulations in individual countries usually depend on the ultimate use, with the strictest limits defined for human consumption and export products and the lowest for industrial uses. Indeed, "safe" limits of AFs for human consumption range 4–20 μg/kg. The EU has set the strictest standards, such that any products for direct human consumption can only be marketed with concentrations of AF-B_1 and total AFs not greater than 2 μg/kg and 4 μg/kg, respectively (EC, 2007; EC, 2010). Likewise, US regulations have specified the maximum acceptable limit for total AFs at 20 μg/kg (Wu, 2006; FAO, 2004). In India, a tolerance limit of 30 μg/kg for AFs in all foods has been defined. Kenya adopted a maximum allowed level of 10 μg/kg of AF-B_1 in groundnuts and several grain foods. Brazil has fixed the limit of total AFs in nuts at 30 μg/kg (Freitas-Silva & Venâncio, 2011). Meanwhile, the EC also defined the limit for OT-A at 3 μg/kg for all products originating from cereals, while level of 1000 μg/kg for FMs and 200 μg/kg for ZN are set for maize intended for direct human consumption (EC, 2007).

For cocoa, and its respective products, several countries have set regulatory limits for OT-A and AFs. An expert panel of the EU recommended a maximum limit of OT-A of 1 μg/kg in chocolate, chocolate powder, and chocolate drinks, while 2 μg/kg is set in cocoa beans, cocoa nibs, cocoa mass, cocoa cake, and cocoa powder (Tafuri, Ferracane & Ritieni, 2004). In Brazil, ANVISA set limits of 10 μg/kg for cocoa beans and 5 μg/kg for commercialized cocoa products and chocolate, for both OTA and total AFs (Copetti et al., 2014). According to EU coffee legislation, the maximum limit of OT-A is established at 5 μg/kg for coffee beans and ground coffee and 10 μg/kg for instant coffee (EC, 2006).

Likewise, the international regulations for the maximum limit of AF-M_1 in milk and dairy products range 0.05–1.0 μg/kg. The EC limits AF-M_1 levels at 0.05 μg/kg for milk and milk products. In this regulation, the EC states that "even if AF-M_1 is regarded as a less dangerous genotoxic carcinogenic substance than AF-B_1, it is necessary to prevent its presence in milk, and consequently in dairy products, intended for human consumption and for children in particular". The EC has also set a limit for AF-B_1 at 5 μg/kg in lactating dairy feeds. According to the USFDA, AF-M_1 in milk should not exceed 0.5 μg/kg (National Grain and Feed Association, 2011). Similarly, in Australia and Switzerland, maximum levels of 0.05 μg/kg for milk, 0.25 μg/kg for cheese, and 0.02 μg/kg for butter are set. In Nigeria, 1.0 μg/kg is fixed as the regulatory limited for milk (Iqbal et al., 2015), whilst South Africa presently allows permits up to 0.05 μg/kg of AF-M_1 in milk and milk products (Mulunda & Mike, 2014). For animal-based products traded across the EU, the minimum level of OT-A contaminations is established to be 0.052 μg/kg, which is applied mainly to pork-based products (Jørgensen, 2005). With respect to the USFDA standards, permissible limits of AFs in maize feed for rearing and finishing processes of cattle and pigs range 100–300 μg/kg, whereas limits for other feedstuffs are established to be 20 μg/kg.

The literature shows that protective legislation is still nonexistent in many developing countries, particularly in SSA where traditional practices and diets contribute the most to prospective health risks. This might be due to lack of capability and resources to detect contamination and enforce regulations (Waliyar et al., 2015; Williams et al., 2004; Wild, 2007; Wild & Gong, 2010).

7. Measurement of mycotoxins in foods and feeds

Various analytical methods have been reported for monitoring of toxic contaminants in food and feedstuffs based on different measurement principles such as the use of chromatography, spectroscopy, electrochemistry, colorimetric detection, and rapid test strips (Chauhan et al., 2015; Wang et al., 2015). Most analytical measurements for mycotoxins include common procedures such as sampling, homogenization, and extraction followed by clean-up to separate byproducts in the suspension which may occlude sample concentration, and final separation and detection steps. Quantification is usually accomplished either by chromatographic techniques in a combination with a variety of detectors, or by immunochemical methods (Pereira et al., 2014). Among chromatographic techniques, thin layer chromatography (TLC) is routinely used for screening since it presents many advantages, however it is limited in its ability to measure toxins accurately unless quantitative densitometry is used (Gilbert & Anklam, 2002). Benoit et al. (2010) reported that TLC is not appropriate for AFs analysis in cassava due to co-migration of an interfering compound with AFs. Currently, liquid chromatography (LC) as well as gas chromatography coupled to mass spectrometry (GC-MS) are the most commonly used in quantitative analysis of mycotoxins (Lindenmeier, Schieberle, & Rychlik, 2004; Pereira et al., 2014). Likewise, modern LC-MS/MS multitoxin method has been developed to investigate various mycotoxin contaminations, however this method has compromised method accuracy due to matrix effects (Sulyok et al., 2015; Warth et al., 2012). Overall, the aforementioned methods require extensive clean-up of samples, sophisticated equipment, trained professionals, and relatively long analysis time in addition to high costs and use of dangerous reagents (Singh, Jayas, Paliwal, & White, 2007; Wang et al., 2015). Regarding immunoassay-based methods, enzyme-linked

immunosorbent assay (ELISA) has been extensively applied for the determination of mycotoxins. Lee, Wang, Allan, and Kennedy (2004) explained that ELISA is an appropriate tool for rapid and accurate analysis which allows high sampling rate, yet is also cost-effective and requires only small sample volumes for analysis (Sherry, 1997). However with all ELISA techniques, a positive result needs to be verified by HPLC (Henry et al., 2001).

Another relevant application for screening of fungal contamination and presence of toxins in food and feed is NIRS (Berardo et al., 2005; Peiris, Pumphrey, & Dowell, 2009). For instance, Pearson, Wicklow, Maghirang, Xie, and Dowell (2001) reported that scattering and absorbance characteristics are influenced by presence of *Aspergillus flavus* in grain kernels since fungal development causes the endosperm to become powdery which changes the absorbance spectra depending on different level of AFs. Berardo et al. (2005) showed that it was possible to quantify fungal infection, and metabolites such as mycotoxins, produced in maize grain by *Fusarium verticillioides* using NIRS. Nevertheless, NIRS only produces an average spectrum which lacks in spatial information from the sample with respect to distribution of the chemical composition. On the other hand, HSI is a promising method that can be employed to investigate both the distribution and composition of mycotoxins in contaminated food samples, especially grains. This method can provide both localized information and a complete spectrum for certain regions of the electromagnetic spectrum in each pixel (Manley, Williams, Nilsson, & Geladi, 2009). Recently, Wang et al. (2015) demonstrated the potential of HSI for quantitative identification and distinction of AFs in inoculated maize kernels.

For AF-M_1 analysis in milk and dairy products, Wang, Liu, Hsu, and Yu (2011) established a direct enzyme-linked immunosorbent assay (cdELISA) which is both accurate and cost-competitive as well as a gold nanoparticle immunochromatographic strip method for detecting AF-M_1 in dairy products. Although this technology is quick and reliable, with the entire analytical procedure requiring about 10 min and no sample pretreatment required, it can only give a positive/negative result. Mass spectrometry has also been applied for AF-M_1 analysis. This technique is based on ambient desorption ionization principles such as desorption electrospray ionization (DESI) (Takats, Wiseman, Gologan, & Cooks, 2004), laser desorption with electrospray ionization assistance (ELDI) (Shiea et al., 2005), and direct analysis in real time (DART) (Cody, Laramee, & Durst, 2005). Maragos and Busman (2010) mentioned that the advantage of these techniques include mycotoxin analysis of samples in ambient conditions without differentiation of the constituents and reduced time requirements for sample pretreatment. DART technology functions by analyst ionization using helium atoms to produce reactive species. Busman, Bobell, and Maragos (2015) used MS-DART to examine AF-M_1 in milk and confirmed the capability for easy, quick, and accurate determination of mycotoxins from complex mediums.

8. Way forward

Food security is a critical issue in many countries around the world. Globalization has placed a great strain on agro-based economies to supply the world's food, making it necessary to develop and execute innovative solutions that are economically as well as socio-culturally appropriate to ensure food safety. At the same time, in addition to food *quantity*, attention must be given to food *quality* attributes, particularly nutrition and safety. There is much potential for generating new approaches and knowledge to strengthen food security. Minimizing postharvest losses through reduction of mycotoxin contamination from farm to fork is one of key pathways of alleviating poverty, increasing food availability, and improving nutrition in SSA. Moreover, reducing contamination of crops and food products would have environmental benefits and contribute to climate protection. This would mainly be a result of increased productivity and reduced resource utilization, in combination with reduced destruction of forests and non-agricultural ecosystems to produce crops which are otherwise lost due to mycotoxin contamination.

One enduring critical issue is how developing countries in SSA can evolve more quickly and efficiently towards improved mycotoxin control and benefit from the alleviation of health related issues. As a result, the ability to meet increasingly more stringent food safety norms locally, and possibly even standards imposed by industrialized countries, remains a key challenge. Therefore, the process of market modernization, which includes mycotoxin management, must be supported and encouraged. Participation of farmers and consumers in extension activities is an essential point for creating awareness of mycotoxins and transferring knowledge for effective management. In addition, effective farmer incentives will be vital to adopt strategies for reduced contamination. This is especially true where official capacity for enforcement is limited. The emergence of farmer rewards will depend on consumer knowledge as well as willingness to pay. As markets develop, there is a public role in risk communication so that consumers understand which risks are important and how risk avoidance behaviors are effective.

Also, there is the need to introduce dietary diversity wherever possible and find possible alternatives to staple foods that are frequently contaminated with mycotoxins. This may not only reduce negative health effects, but may also provide the most sustainable methods of reducing mycotoxin exposure in human populations. If the weight of evidence increases that mycotoxin exposure is associated with growth impairment and immunotoxicity, then reducing mycotoxin exposure in would also improve child growth results. It is overwhelmingly clear that the scale of economic impact due to negative health effects associated with consumption of mycotoxins in SSA is still unknown due to unavailability of consistent and dependable data. Thus, if economic and health costs of mycotoxins can be properly analyzed, this would encourage policy makers to impose regulations, and provide necessary support to many of those living in SSA countries who are consuming products which are heavily contaminated.

Nevertheless, investments in extension training, infrastructure, and pre- and postharvest technology would be main factors to consider. It is imperative to establish formal GMPs as well as implement HACCP principles to identify, assess, and control mycotoxin risks over the entire food production system. However, solving the problem of mycotoxins in SSA still requires the cooperation and effective communication among personnel involved in research, extension, and industry. These cooperations may offer the opportunity to obtain greater efficiency in moving to higher standards as well as to address weak enforcement capacity through leveraging market incentives. Finally, overcoming the socio-economic constraints is essential to achieve the goals of food safety and security.

9. Conclusions

This review has provided an in-depth examination into the occurrence and impact of mycotoxins in food and feed systems of SSA. From the literature, it is clear that both human and animal populations in this region are at high risk for chronic exposure to dangerous levels of mycotoxins, particularly via consumption of main staple crops. This poses serious consequences related to issues of health and well-being. In addition, mycotoxins cause significant financial losses to the peoples and nations of SSA. To

address the growing food insecurity issues, the adoption and implementation of science-based technologies is invaluable. Overall, tackling the problem of contamination through awareness, development, and upgrading production and processing systems in the food supply chain are critical initial steps towards appropriate strategies for increasing food security, alleviating malnutrition, and increasing economic sustainability with respect to mycotoxins.

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