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The Socio-Economic Impact of Mycotoxin Contamination in Africa

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Abstract

The proliferated contamination of agricultural commodities by mycotoxins and their attendant toxic effects on humans and animals which consume such commodities constitutes a major concern to food safety and security. These highly toxic food contaminants are produced by various filamentous fungi species that are ubiquitous in nature, however, favourable climatic conditions in the tropics favour their proliferation in these regions. Africa, by virtue of its location along the equator makes it highly accommodative to proliferation of mycotoxigenic fungi species, as such, it is the most affected of all the continents. Other factors such as poverty, and climate change further complicates the mycotoxin situation on the continent. Economic impact due to mycotoxin contamination in Africa is thus alarming. The effects of mycotoxins can in fact be felt in the overall health of humans and animals, sustainable development, food security and safety, damage to the African agricultural export brand, negatively impacting Africa's self-sustainability and increased dependence on foreign aid, not excluding high cost of research, mitigation and regulation of the prevalence of these toxins in African countries. This book chapter presents an exhaustive appraisal of the socio-economic impact of mycotoxins on Africa. Our observations herein are expected to stimulate policy makers, as well as, all stakeholders along the food supply chain to identify critical areas of collaboration and strengthen alliances in order to ameliorate the effects of these toxicants on the continent of Africa, and the world at large.

Keywords: mycotoxins, socio-economic impact, Africa, fungi, immunosuppression, hepatotoxic, socio-economic impact, health impact

1. Introduction

Globally, the consumption of contaminated foods accentuates a clear food security threat, and the central elements leading to contamination are microorganisms, specifically, fungi, which produce low-molecular weight toxic secondary metabolites known as mycotoxins. About 25% of the global food and feed output is contaminated by mycotoxins, which negatively affects human and animal health, productivity, livelihood, household security, income and causes significant economic losses [1]. Very often, contamination of agricultural commodities by mycotoxins results from a cumulative process, which begins from pre-harvest through post-harvest stage and continues throughout the entire food production chain [2]. Some factors that drive mycotoxin contamination along the African food and feed chain are the mid and hot tropical climates that are favourable growth conditions for fungi, food shortages, ignorance of the cause and implications of mycotoxins, food dumping and adulteration of foods with mouldy agricultural products as well as inadequate regulatory mechanisms [3, 4].

A recent investigation on the mycotoxin issue across the entire continent of Africa led by Professor Sheila Okoth of the University of Nairobi (Kenya) and commissioned by the Technical Centre for Agricultural and Rural Cooperation (CTA) in conjunction with Partnership for Aflatoxin Control in Africa (PACA), confirmed and re-affirmed the seriousness of the mycotoxin issue [5, 6]. Economic losses arising from mycotoxicosis in Africa are alarming; losses incurred by developed nations are usually trade-related, whereas Africa tends to incur both economic losses and additional costs related to health challenges. This immense socio-economic impact of mycotoxins threatens the UN's sustainable development goal of improving nutrition, achieving food security and attaining a healthy agro-economic growth [6]. Often, socio-economic impact of mycotoxin contamination in Africa can be measured through reduced food availability, specifically amongst the rural poor, regulatory rejections of goods mainly at ports of exit, reduced market value of contaminated produce in domestic markets, decreased marketability of crops, forced alternative uses, increased livestock and human diseases, as well as mortality. Moreover, this impact should not exclude the high cost of research and regulatory activities aimed at reducing health risks because of the existence of causal relationships between mycotoxins and their impact on health. It is also overwhelming that in Africa, an annual cost of over USD 750 million is been accrued to aflatoxin (AF) contamination of crops, while the European Union (EU) regulation of AFs reportedly costs food exporters an estimated USD 670 million yearly [7]. Misdiagnosis, poor infrastructures, undependable and inconsistent data amongst other factors make it difficult to account for the additional and indirect costs associated with mycotoxin exposure in Africa. If the scale of economic and health impact of mycotoxin contamination is well understood, it will hasten policy makers towards imposing regulations and supporting affected populations. This chapter discusses on some pertinent socio-economic impacts of mycotoxin contamination in Africa.

2. Common mycotoxins in Africa and associated factors that facilitate their prevalence

Mycotoxins are secondary metabolites produced by filamentous fungi, especially those members within the *Aspergillus*, *Penicillium*, *Fusarium* and *Alternaria* genera, and notable for their toxigenicity and disease-causing effects amongst humans and animals. Different studies on mycotoxins since the discovery of AF in early 1960s have led to the identification of over 300 mycotoxins, few of which have received significant attention due to their health and economic importance.

2.1. Common mycotoxins in Africa

From an African context, the major mycotoxins of significance in terms of health and the economy are the AFs, fumonisins (FBs), ochratoxins (OTs), trichothecenes (THs) and the zearalenones (ZEAs). This is equally relative to their widespread occurrence in major food and feed commodities, aggravated by favourable climatic conditions in the continent. Of all the several occurring mycotoxins, the AFs are considered the most important. This is particularly associated with its prevalence in commodities and potency of aflatoxin B₁ (AFB₁), an AF form known to be the most noxious naturally occurring carcinogen. They have thus received substantial attention as compared to other mycotoxins as they frequently contaminate food and feed commodities in Africa [8]. Though there are about 20 different identified forms of these AFs [9], those of significant and economic importance are AFB₁, aflatoxin B₂ (AFB₂), aflatoxin G₁ (AFG₁) and aflatoxin G₂ (AFG₂). Equally important are also aflatoxins M₁ (AFM₁) and M₂ (AFM₂), which are hydroxylated metabolites of AFB₁ and AFB₂, respectively [10]. FBs, particularly fumonisin B₁ (FB₁), have been classified as a group 2B carcinogen by the International Agency for Research on Cancer (IARC) [11], and is highly prevalent in African staples such as maize, millet and sorghum [12]. The OTs are isocoumarin derivatives, occurring as ochratoxin A (OTA), B (OTB), C (OTC), D (OTD) and their methyl and ethyl esters [13]. Similar to FB₁, OTA is a prevalent toxin, classified as a Group 2B potential carcinogen to human [11]. The THs, which are tetracyclic sesquiterpenes with an epoxy-ring [12, 14], are divided into type A consisting of T-2 and HT-2 toxins and type B with deoxynivalenol (DON) and nivalenol (NIV), the most important representatives [12]. Zearalenone (ZEA) and its hydroxylated derivatives α - and β - zearalenone (α -ZEA and β -ZEA) are lactone derivatives commonly found in food commodities [15]. It has been reported that ZEA usually co-occurs with one or more of the THs, because of the ability of its producing fungi to synthesize more than one mycotoxin [16]. The occurrence of modified and emerging forms of these mycotoxins including 3-acetyldeoxynivalenol (3-ADON), 15-acetyldeoxynivalenol (15-ADON), beauvericin (BEA), the enniatins (ENNs) and moniliformin (MON) have also been reported in African commodities [12]. The prevalence of these mycotoxins in African food crops have been reviewed extensively in literature [17–20], and can be strongly associated with a number of factors which are discussed in the next section.

2.2. Factors that facilitate the prevalence of mycotoxins in Africa

The prevalence of mycotoxins in African food and feed commodities have been well documented in literature, and major factors that contribute to this have been identified as climate change, poverty, limited/lack of awareness, pro-regulation and legislation, poor agricultural practices, amongst others. Climate change has in fact been proposed as probably the most serious environmental issue facing our planet [21], and Africa has been the most affected. In fact, 2016 was identified as the hottest year in about a century, and accordingly, a manifestation of this was the 2016 *El-nino* drought episode of Southern Africa, which resulted in agricultural losses amounting to millions of US dollars (US\$). Such imbalances, drastic changes in rainfall, temperature and CO₂ patterns could increase the risk of pathogen migration and influence colonization of crops by mycotoxigenic fungal genera [22]. Since mycotoxin production is climate dependent, changes in climatic conditions have been suggested and proven to lead to possible drastic modifications in fungal population and attendant mycotoxin production [23, 24]. These would not only favour the emergence of new mycotoxigenic fungal strains, but also attendant mycotoxin production in agricultural commodities.

Africa is the poorest continent in the world [25]. Nearly one in five people living in Africa is undernourished and/or go hungry, the highest prevalence of such in the world [26]. This can have a huge significance on the quality of food commodities consumed in Africa. There are limited resources to adopt relevant technologies/systems to control mycotoxins proliferation, and in dire need for food and “quenched” hunger, the quality and safety of food ingested is totally irrelevant (even though visibly contaminated). Under such circumstances, having food is much more vital and subsequently prioritized. Further to this, limited public awareness on the mycotoxins issue has been identified as a critical factor on the prevalence of mycotoxins in Africa. Knowledge is power. The available information on the incidence, public health importance, prevention and control of mycotoxins in many African countries is still grossly lacking, with no indication that such will be addressed anytime soon. Equally important is the lack of appropriate mechanisms to promote and educate consumers on the harmful effects of mycotoxins, good agricultural practices and post-harvest handling of commodities. Due to all these factors, the issue of mycotoxins on the continent has remained infamously persistent, with attendant grave implications. The next section of this chapter discusses in detail the socio-economic impact of these fungal pollutants on the African continent.

3. Socio-economic impact of mycotoxin contamination in Africa

Mycotoxin contamination have contributed significantly to the elusive sustainable development in Africa. The ever daunting and manifest challenges to food safety and security, good health and economic empowerment are all undisputable evidences to this fact.

3.1. Impact of mycotoxins on human and animal health in Africa

3.1.1. Impact of mycotoxins on human health in Africa

The most significant impact of mycotoxin contamination in Africa has been shown to be on human health. A World Bank report in 1993 observed that the various health problems

modulated by exposure to mycotoxins accounted for up to 40% of lost disability-adjusted life years (DALYs) [27], and it is no doubt that Africa is the most affected. In 2004, an outbreak caused by food poisoning with AFs occurred in Kenya, where 317 cases of illness were reported and 68 of the persons were children below the age of 5 and 90 were from 5 to 15 years. In this incidence, at least 123 deaths were recorded [28–30]. In sub-Saharan Africa, about 250,000 deaths are caused by hepatocellular carcinoma annually and this can be linked to risk factors such as AFs and high prevalence of hepatitis B [31]. AF contamination in groundnuts and maize in Nigeria contributed to 7761 liver cancer cases, which results in a total burden of 100,965 DALYs [32]. In 2014, due to AF contamination, about 3334 cases of hepatocellular carcinoma was calculated in Tanzania, 95% of which ended as deaths resulting to a loss of 96,686 DALYs [33].

Based on several studies in Southern Africa, AFs contamination have been strongly linked with child undernutrition, increased mortality and morbidity due to their negative effect on micro-nutrient absorption and immune function [34]. In addition to these, immune disruption by AFs may aggravate health impacts of principal diseases plaguing Africa such as malaria, kwashiorkor and HIV/AIDS [35]. In Nigeria, posthumous autopsy of infants who suffered from kwashiorkor showed a significant level of AFs in their brains, because of consumption of contaminated maize based gruel [36]. According to Jolly *et al.* [37], high levels of AFB₁ and acute aflatoxicosis symptoms were found within Ghanaian population that also had abnormal liver function and high level of HBV infections. Turner *et al.* [38] reported decreased levels of secretory immunoglobulin A (IgA) in Gambian children exposed to AFs. In Kenya, the mean birthweight of the children of women exposed to AFs prenatally was lesser than that of those who had not been similarly exposed [39].

In the Gambia, maternal dietary intake was indicated to be an important factor in carcinogenic-induced damage in the unborn baby, due to a highly significant correlation between AF-albumin adduct levels in the mothers venous and respective cord sera [40]. In the same country, children with reduced level of salivary Secretory Immunoglobulin A (sIgA) have been linked with exposure to AFs [38]. The consumption of FBs contaminated maize have been correlated to the high incidence of oesophageal cancer in parts of South Africa [41] and Malawi [42]. According to Ferlay *et al.* [42], Malawi has the highest prevalence rate (24.2 per 100,000 persons) of oesophageal cancer in the world. ZEA as a naturally occurring endocrine-disrupting chemical has been implicated in the manifestations of gynecomastia with testicular atrophy in rural males in Southern Africa [43]. In 1977 to 1978 an outbreak of ergotism occurred in Wollo, Ethiopia where 140 persons were affected, four children lost both or at least one leg and the mortality as high as 34% [44]. In North Africa, particularly Tunisia and Egypt, cases of human nephropathies have been strongly associated with elevated exposure to OTA and outbreaks of ochratoxicosis, *i.e.*, illness due to ochratoxin exposure [45–47]. Alpha-ZEA has been implicated as a potential risk factor for breast cancer in Tunisia [48]. Likewise, high levels of OTA in Moroccan foods and other agricultural commodities have been linked to some chronic illnesses [49, 50]. **Table 1** shows some other mycotoxins and the toxic effects they provoke on human health. Further studies are required to establish the association between other poorly investigated diseases and dietary exposure to other mycotoxins (emerging, modified and multiple mycotoxins).

Though tremendously difficult to estimate in Africa, the net monetarized impact of mycotoxins on human health in Africa [including physical pain, death (in severe cases), temporary or permanent impairment, loss of productivity, costs of diagnosis, treatment, hospitalization

Mycotoxins	Toxic effects	Reference
Ergot alkaloids	Ergotism: central nervous system disorder, gastrointestinal symptoms, & gangrene	[51]
Citrinin	Hepatonephrotoxic	[51]
Cyclopiazonic acid	Weight loss, diarrhoea, nausea, necrosis, & convulsion	[51]
Patulin	Genotoxic, teratogenic, carcinogenic, & acute toxicity to kidney	[51]
Sterigmatocystin	Carcinogenic, & hepatotoxic	[51]
Rubratoxin	Liver damage, nephrotoxic, & haemorrhage	[51]
Gliotoxin	Neurological syndrome, & immunosuppressive	[51]
Moniliformin	Acutely toxic, & cardiac impairment	[51]
Fumitremorgen	Tremors, & convulsion	[51]
AFs	Carcinogenic, & immunosuppressive	[52]
OTs	Mutagenic, carcinogenic, & nephrotoxic	[53–56]
FBs	Carcinogenic, nephrotoxic, hepatotoxic, immunosuppressive, atherogenic, & embryotoxic	[57, 58]
DON	Immunosuppressive, immunostimulative, & causes fertility problems	[59–62]
ZEAs	Infertility, reduced milk production, vaginal secretions, & vaginitis	[63, 64]
T2-toxin	Cardiovascular defects, gastroenteritis, & alimentary toxic aleukia	[65, 66]

Table 1. Mycotoxins and their toxic effects on human health (adapted from Capriotti *et al.*) [51].

and health care (morbidity), cost of anxiety, pain, misdiagnosis, suffering and reduced life quality etc.] could be enormous, and demanding on national budget. A case in point, a study conducted in Gambia observed that diseases consistent with mycotoxin exposure (in particular Hepatitis B and its associated medical complications) results in a total monetized DALY worth over 94 million US\$ of GDP, which equals 9.4% of the nation's GDP. This is a huge loss to the health of the populace and country [67]. Similarly, in Senegal, the cumulative cost in terms of health due to AFs is estimated at no less than 92 million US\$ of the nation's GDP [67]. In 2014 in Tanzania, the economic impact (in monetary terms) of AFs was estimated between 6 million and 264 million US\$ due to the resultant health impact [33].

3.1.2. Impact of mycotoxins on animal health in Africa

Very little work has been done on the health impact of mycotoxins on animals in Africa. This is understandable as the health effects and losses in animals (such as feeding efficiency, infertility, meat, milk and egg quality losses, susceptibility to diseases etc.) are subtler to decipher. Moreover, in Africa, people have limited resources and may prioritize the care of humans above the 'waste of resources' on animals. To this effect, when mouldy cereals are too bad to be consumed, they are usually not disposed, but blended with non-mouldy ones and used as animal feed, or in some cases fed directly to the animals. However, monogastric farm animals such as poultry, swine and dogs are at particular high risk, because their basal diet (feed) is made up of cereals [68]. These animals also lack reservoir that harbours microorganisms that can break down secondary metabolites of fungi before they are absorbed into the intestine. In South Africa, there have been two episodes of aflatoxicosis (illness resulting from AFs)

amongst dogs through the consumption of contaminated dog food. The first occurred in 1987 where 10 cases of fatality were reported, and histopathological evaluation revealed chronic symptoms of necrosis, bile duct proliferation, hepatocellular fatty degeneration, fibroplasia etc. were observed [69]. The second episode occurred in 2011, where over 220 dogs died and several others were affected in the Gauteng province. Subsequent clinical examinations revealed that the dogs were exposed to highly contaminated feed (with levels of AFs ranging from 5 µg/kg and 4946 µg/kg), which is well above regulatory limits [70]. In addition to AFs, other mycotoxins such as FB₁, ZEA, and OTA were all later implicated in this outbreak [71]. Mwanza *et al.* [72] evaluated the productivity and general health of domesticated animals in Limpopo Province of South Africa in relation to fungi and mycotoxin contamination, the results revealed that these animals were at risk to mycotoxin contamination which possibly plays an important role in abortions, low productivity, chronic and acute diseases, as well as reduced immunity in these animals, which are similar effects often seen in other rural communities in the country, as well as other parts of Africa, however, no clinical investigation is usually conducted to determine the possible causes of such illness/effects [72].

3.2. Impact of mycotoxins on food security in Africa

The CTA has clearly alarmed that mycotoxins significantly threatens achieving food security and safety in Africa, which is one of the UN's sustainable development goals [5]. Food supplies are limited and often of poor quality, with mycotoxins proliferation frequently implicated as the culprit. About 35% of global food and feed produce is contaminated by mycotoxins. The attendant food losses/wastages is in the ranks of 1 billion metric tons annually [73–75], and there is little doubt that majority of these losses come from Africa. In a continent where about 60% of the populace are farmers (mainly at a subsistence level), and majority of households relay on their homegrown food for survival, these statistics on mycotoxins are disturbing. The eminent reality of global warming further complicates the situation as Africa is the continent that is most affected due to its position at the equator. A recent study predicts that fungal pathogens and pests are proliferating at a rate of 5–6 km annually from the equator to polar regions of the earth [76]. Drought and plant stress makes crops more susceptible to diseases and fungal attack, and consequently increases mycotoxin contamination, which reduces crop quality and yield, as well as decreases in livestock productivity, disease tolerance and fertility. Moreover, adaptation of known mycotoxigenic fungal species to climate change conditions could result in a more aggressive and invasive behaviour of the fungi leading to colonization of new territories, increased production of mycotoxins, and perhaps the potential of producing entirely new mycotoxins, which poses a significant threat to food security, safety and health in Africa and other developing countries [76–78].

3.3. Impact of mycotoxins on trade and damage to the African agricultural export market brand

Mycotoxins affect trade in Africa majorly by reducing the value of commodities offered for sale. Reduced value can manifest at different trade levels through the lowering of prices, inspection cost, disposal, rejection of lots or treatment of lots at additional cost prior to sale, compensation in case of claims and cost of sampling and analysis along the value chain. Not less than 2.3 million bags of maize were found unsuitable for marketing (as well as consumption) during the outbreak of aflatoxicosis in Kenya from 2004 to 2006 [79]. Following another AF alert in Kitui,

Kenya in 2009, it was reported that maize prices dropped by half from 1800 to 900 Kenyan shillings [79]. The enforcement of regulatory standards primarily by developed nations which are the main destinations of African agricultural export commodities have resulted in a more critical situation for the African agricultural trade [52, 80]. EU regulation of mycotoxins was expected to reduce African export of nuts, cereals, oil seeds and dried fruits by 64%, reportedly costing 670 million US\$ yearly [81]. Between 2000 and 2014, the cumulative economic loss on domestic and international trade in Gambia was about 23 million US\$, which amounts to a yearly loss of about 1.52 million US\$ [67]. The International Institute of Tropical Agriculture (IITA) [82] reported an annual loss of 1.2 billion US\$ on a global scale due to AF contamination and established that 38% of this loss (450 million US\$) is incurred by African nations.

Another major socio-economic impact of mycotoxins on Africa is the damage to the African agricultural tradename. Brand in general terms can be described as an intangible and invaluable feature that distinguishes an entity from its competitors, and comprises expectations, imaginations, emotions and loyalty by the customers [83]. As a matter of fact, in the field of accounting, it is regarded as the most valuable asset on the balance sheet [84, 85]. Damage to brand can have a significant and enduring (and in some cases irredeemable) impact on subsequent business performance, productivity, reputation, financial gains and business prospects. Unfortunately, the mycotoxin issue has caused significant damage to African food and agricultural trade brand, particularly in the export market. Some of the consequences can be observed in the lack of trust for African food/feed commodities, 'redundant scrutiny' (which may result in transaction delays and perhaps more food spoilage), rejections, etc. A case in point was the significant levels of AFs in groundnuts exported from Africa to Europe in 2007 [86], leading to the serious concern about the future of such and other exports from the African continent.

In 2000, 57 cases of border refusal of African exports to the EU were recorded but these cases have increased over the years and as at 2012, 525 cases were recorded [87]. More specifically, from 2002 to 2008, 130 export rejections from Egypt, 90 from Nigeria, 91 from Ghana, 5 from Morocco and 1 from Tunisia were recorded due to mycotoxin contamination [88]. Also in 2008, Rwanda suffered border rejections of sorghum, maize, soybean flour, destined to United Kingdom due to AFs contamination [89]. Between 2007 and 2012, 13 consignments of groundnut and groundnut related products from Nigeria were also rejected by the EU [90]. The National Agency for Food and Drug Administration (NAFDAC) of Nigeria reported that up to 42 semi-processed and processed food products of Nigeria origin destined for the European Union were rejected in 2015 and 2016 for failing to meet standards [91]. Twenty-eight of these items were destroyed, 6 subjected to official detention, 6 withdrawn from consumers and from the market, and 9 were re-dispatched [91]. Based on data from European Commission Rapid Alert System (RASFF), 35% of food/feed commodities rejections by the EU borders in 2014 were due to mycotoxin contamination at levels above the EU legislative limits [76]. It should be noted that the cost of a rejected food shipment is significant (about 10,000 US\$ per lot in demurrage fees) even if the lot can be returned to the country attempting to export [92].

3.4. Impact of mycotoxins on national budget due to mitigation costs

Some African countries have started to set up interventions to reduce the prevalence of mycotoxins in their jurisdiction, however, most of these interventions have high cost implication with regards to their design and implementation. In 2014, the Economic Community for

West African States (ECOWAS) in collaboration with the African Union's PACA and other stakeholders developed the "ECOWAS Aflatoxin Control Action Plan (ECOACAP)" which identified key actionable strategic interventions in order to combat the prevalence of AFs across ECOWAS member States. Policy 4.3 SO3 of this plan recommended that ECOWAS member states increase budgetary allocations and investments to at least 1% of national GDP for the development and enforcement of AFs control efforts [67]. An annual cost of 7.5 million US\$ was calculated by member states of the African Groundnut Council (Mali, Nigeria, Gambia, Sudan, Niger and Senegal) for the implementation of an AF contamination reduction program [90]. The Maize Trust, an initiative principally funded by the government of South Africa, spends over 4 million US\$ per annum on funding projects directly targeted at improving the South African maize industry, and one of the outlined key objectives is to combat mycotoxins in South African maize [93]. Details of other interventions sponsored by other African governments can be found in the PACA report [94].

3.5. Impact of mycotoxins on Africa's self-sustainability and increased dependence on foreign aid

Africa has been caught in a vicious circle of the cause and effects of mycotoxin contamination and poverty. Mycotoxins aggravates poverty, and due to poverty, many African countries lack the resources to sponsor effective mycotoxin research and mitigation interventions, which further worsens the situation on the continent. As such, majority of the mycotoxin projects conducted on the continent are sponsored by external sources, hence, increasing Africa's dependence of foreign aid. For instance, the US government via the Feed the Future (FTF) initiative of the United States Agency for International Development (USAID) Bureau for Food Security budgeted 2–5 million US\$ per year in 2010, and 15–20 million US\$ per year in 2014, for AF-specific researches in African countries and developing countries in other continents [95]. Ghent University, Belgium sponsored an international thematic network 'Mytox-South' established in 2017, with an initial approved funding of 600,000 EUR. This intends to build/strengthen the human capacity of researchers from the Southern Hemisphere, leveraging on infrastructure and expertise at Ghent University in order to combat the mycotoxin problem and associated food security and safety issues at global level [96]. The Standards and trade development facility (STDF) sponsored a six month project on strengthening AF control in the Republic of Malawi through the Malawi Programme for Aflatoxin Control (MAPAC) with a budget of 46,265 thousand US\$ [97]. Details on other foreign mycotoxin interventions in Africa worth millions of US\$ can be found from these sources [94, 98, 99].

Interestingly, even the private sector has not been left out. Recently, the spotlight has turned on strengthening coalitions with the private sector, while leveraging on the efforts of different actors for effective management of mycotoxins in Africa. In October 2016, PACA and CTA convened a roundtable event in Entebbe, Uganda to identify concrete areas of collaboration and evaluate avenues for effective public-private sector partnership and engagement in the common agenda for tackling mycotoxin prevalence. CEOs and other representatives from various private establishments such as Cereal Millers' Association—Kenya, AFRI-Nut—Malawi, CTA, Meds For Kids—Haiti, GrainPro—East Africa, PACA, USAID, Nestlé—West Africa, various Women's organisations in Zimbabwe and Uganda, were in attendance, amongst others [5, 6].

4. Commitment to research and awareness as effective tools in mitigating the impact of mycotoxins in Africa

Mycotoxicology research is an important component of mycotoxin management. Particularly in Africa, more research needs to be done in order to establish safe limits and guard against potential health hazards. Availability of stringent scientific data provides the basis for government regulatory bodies to assess the risk of exposure, as well as, establish/enforce or reassess regulatory limits for mycotoxins [52, 100]. For example, from central African countries, there is hardly any information on mycotoxins. This may be due to ignorance on the mycotoxin issue, poverty, lack of research facilities and skills/manpower in these countries [17]. In a recent study by Adekoya *et al.* [101], the perceived understanding, practices and health risks related to fungal and mycotoxin contamination amongst fermented food sellers was evaluated. It was observed that up to 98% of respondents were unaware of mycotoxin contamination [101]. Elsewhere, findings by Changwa [102] in South Africa indicated that there are several knowledge gaps on the mycotoxin issue, such as causes of mycotoxins, health implications, prevention and control of mycotoxins, which corroborates the observation of Adekoya *et al.* [101]. In a recent round-table discussion on future directions in research facilitated by the European Horizon2020 project, MycoKey, it was agreed that forging partnerships between scientists and appropriately-placed communication experts constitutes a critical avenue for creating awareness and communicating risks, while maintaining overall confidence in the quality and safety along the food supply chain [103].

Despite all said, it must be acknowledged that mycotoxin research in Africa has yielded fruitful and positive results. While some of these studies were funded by governments in the continent, many are equally funded by research organizations and governments of other developed nations. For example, researchers at IITA and the University of Ibadan, in partnership with the Agriculture Research Service (ARS) of the United States Department of Agriculture developed a natural, safe and affordable solution to the problem of AF called “Aflasafe™”, intended for use by groundnut and maize farmers. The product which contains non-toxigenic strains of *A. flavus*, is reported to be able to reduce AF levels in maize by 80–100%, and together with other good agricultural practices will increase the crop value by at least 25%, as well as improve the health of children and women [104, 105]. Due to the immense success of Aflasafe™, expansion of the biocontrol research reached Ghana, Tanzania, Burkina Faso, Senegal, Kenya, Mali, and Zambia [105]. AflaSTOP is another project which started in 2012, aimed at identifying the most effective, efficient, low-cost, innovative storage and drying technology to combat AF contamination, and other post-harvest losses in Kenya, Tanzania and Rwanda [106]. The Aflasafe™ and Aflastop projects together with other mycotoxin projects described herein [95, 105] cost about 15–20 million US\$ in 2014 and 2–5 million US\$ in 2010, sponsored by the US Government under the Feed the Future (FTF)—USAID Bureau for Food Security [95, 105].

Last year 2017, Ethiopia farmers/researchers supported by Ethiopia’s Agricultural Transformation Agency, was able to produce and market much of the 27 tons of new, disease-resistant wheat seed, in direct response to an annual attack of rapidly-evolving fungal diseases that can infect their locally grown crops worth as much as 200 million US\$ [107]. Elsewhere, several African scientists are working on a project aimed at reduction of AF contamination

via RNA interference (RNAi) in peanut plants. Three peanut varieties endemic to Africa are currently been genetically transformed at Kenyatta University in Nairobi, Kenya, by means of RNAi molecular constructs. Many of the African scientists involved in the project have been trained hands-on at the National Peanut Research Laboratory (NPRL) in Dawson, Georgia [99]. At the University of Johannesburg and Stellenbosch University both in South Africa, microbial means of degrading and detoxifying mycotoxins have also been proposed as a possible way of reducing/eliminating mycotoxins in food [108–110].

Previously, much of research was focused on producing enough food to meet the teaming population of the world, however, it is becoming more obvious that reducing food spoilage/loss and contamination could be a more efficient approach towards addressing issues of food security particularly in Africa. As a way forward, research objectives should be prioritized to ensure a positive impact for public health, food safety and security and economic development. Recently, a global initiative has been launched, The Mycotox Charter, which provides a global platform for the various players along the food supply chain to commit to the mycotoxin cause, by means of a globally applicable statement and clearly outlined principles and practices targeted at reducing mycotoxin contamination in food and feed and associated health problems [111]. It is hoped that such an initiative will achieve its objectives in addressing these problems linked to mycotoxins.

5. Conclusion

The impact of mycotoxins on Africa has been and is still illustrious. Limited knowledge/awareness, poverty, bad governance and climatic conditions have further aggravated this unfortunate situation. Africa is the largest continent in the world and the most plagued by the mycotoxin menace. Despite the notoriously incessant occurrence and exceptionally high levels of mycotoxins reported in dietary food for humans and animals, and the associated lethal consequences, regulation for their control and management is significantly limited in this part of the world. It has been projected that between 2015 and 2050, the population of Africa will increase by 1.3 billion people. In fact, according to the UN, the population of Nigeria alone is projected to surpass that of the entire US by 2050. This teaming population puts immense pressure on the already scarce food resources on the continent. More compelling is the fact that Africa's population is comprised mainly of the younger age (with two-fifths between the ages of 0–14 years, and one-fifth in the age bracket to 15–24 years), where good food and health plays a critical role in the overall development of individuals. As such, the proliferation and widespread effect of mycotoxins in Africa is of great concern. The eminent reality of climate change is also looming steadily with Africa at the epicentre. Biodiversification of fungi due to adaptation to climate change leads to threats of newer mycotoxins or more of existing ones. In order to stay aligned with the UN's sustainable development goals (particularly goal No. 2: end hunger, achieve food security and improved nutrition and promote sustainable agriculture), a concerted effort is needed to adequately address the issue of mycotoxin in Africa and other developing countries of the world. Critical areas to concentrate efforts include development of efficient and cost-effective intervention strategies, public awareness, strengthening research and human capacity development as well as harmonizing and enforcing regulations.

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