Mycotoxins Contamination of Food in Somalia

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Introduction

A paper was recently published in the American Chemical Society (ACS) Journal of Agricultural and Food Chemistry (JAFC) by scientists from the Queens University, Belfast, Northern Ireland, UK and their collaborators. A total of 140 samples (42 maize, 40 sorghum, and 58 wheat) were collected from a number of markets in Mogadishu, Somalia, and analyzed by ultra-performance liquid chromatography-tandem mass spectrometry (UPLC-MS/MS) multi-mycotoxin method that could detect 77 toxins. All of the maize samples tested contained eight or more mycotoxins, with aflatoxin B1 (AFB1) and fumonisin B1 (FB1) levels reaching up to 908 and 17 322 µg/kg, respectively, greatly exceeding the European Union (EU) and USA allowed limits and guidance values for these toxins. This write up is intended to bring to the attention of the Somali Government and Somali Community at large the serious nature of the risks presented by the issue of contamination of food and animal feed with toxins, at levels well beyond the limits set by advanced industrialized countries as well as international organizations such the World Health Organization (WHO). This review will:

1. Discuss the salient points of this recent paper on mycotoxin contamination of food in Somalia and the serious implications and impacts of this on health and economic well-being of the people of Somalia.
2. Explain, in layman's terms, what are mycotoxins.
3. Briefly discuss severe health risks they pose to both human and animal population;
4. Explain how they are tested and detected, with emphasis on simple and cheap filed tests that can performed by people who do not have laboratory training;
5. Methods of lowering mycotoxin concentrations in food and animal feed;
6. Look at new environmentally safe technologies that have been developed to combat mycotoxins.
7. Finally, summarize some of the world-wide organizations that can provide both research expertise and funding, with especial emphasis on those focused in Africa, particularly the African organizations and research centers and their collaborators who are engaged in fighting this serious problem will be listed.

1. Human-Health Impacts of Mycotoxins in Somalia [1]

Mycotoxins are chemically diverse secondary metabolites that can contaminate food commodities in the field and during storage, transportation, and food processing, impacting both human and animal health. Susceptibility of cereals to mycotoxin contamination, particularly aflatoxins (AFs), fumonisins (FUMs), and deoxynivalenol

(DON), have been widely described. Apart from acute toxicosis, chronic exposure to AFs has been associated with carcinogenicity, particularly in conjunction with chronic hepatitis B virus (HBV) infection. Governmental and international institutions, have thus set specific mycotoxin regulations and established maximum tolerated levels of mycotoxins in foodstuffs.

Somalia had a turbulent recent history with a civil war followed by violent domestic conflicts and had no strong central government since 1991. Consequently, the problem of food safety has not been addressed. As such, there are no regulations in place, and there is very little information regarding mycotoxin occurrence in food and the resulting exposure of the Somali population. The only available report on mycotoxin concentrations in maize focuses on AFB1, fumonisin B1 (FB1), and DON only, which were assessed via enzyme-linked immunosorbent *assay* ***(***ELISA) (see reference 1).

The goal of this study was to assess multi-mycotoxin occurrence in staple foods for the first time in Somalia. Generated data was employed to assess the possible impact of exposure to aflatoxins and fumonisins and could be used to assess the impact of other mycotoxins on the health of the Somali population. The researchers of this study hope its conclusions encourage further research and bolster initiatives in the region aimed at providing safe food to the people of Somalia.

a) **Sampling method**: A market survey of three Somali staple foods (i.e., maize, sorghum, and wheat) was performed utilizing a multi-analyte liquid chromatography tandem mass spectrometry (LCMS/ MS) approach. Approximately 80% of domestic cereal output in Somalia comes from the Bay, Bakool, and Lower and Middle Shabelle regions around the larger inter-riverine area between the Shabelle and Juba river valleys of southern Somalia. A set of 140 samples, which included 42 maize samples (21 white and 21 yellow), 40 sorghum samples (20 white and 20 red), and 58 wheat samples (25 locally grown and 33 imported), were collected from different local markets in Mogadishu, Somalia, between October 2014 and February 2015. Because the aim of the study was to perform a market survey to reflect real exposure of the Somali consumers living in Mogadishu, samples of 1 kg were bought from local retailers and shipped to the United Kingdom. All samples were stored in a dark and dry place at 4 °C until their analysis.

b) **Sample Analysis**: Sample extraction and analysis was performed using a previously validated multi-mycotoxin LC-MS/MS method (for details see reference 1).

c) **Point Estimates of Dietary Exposure**: In the present study, a deterministic model based on an average consumers' exposure was applied as this was deemed to be the most relevant for long-term exposure assessments by both the World Health Organization (WHO) and the European Food Safety Authority (EFSA). As an estimation, the degree of mean dietary exposure was expressed

as the average probable daily intake (APDI) for maize. Because there is no nationwide data on demographic characteristics, maize-consumption patterns in the Somali population relied on data available for neighboring countries (a conservative approach). The average food consumption was based on the data available for Kenya and Ethiopia, adapted from Food and Agricultural Organization Statistical data (FAOSTAT) food-balance sheets quoting 163 g per person per day for maize. Also, no data on average body weight is available for the Somali population; thus, an assumed body weight of 60 kg was used as outlined by the WHO. The APDI of each mycotoxin was calculated according to the following equation:

$$\text{APDI} = (C \times K)/\text{bw}$$

where APDI is the average probable daily intake (ng/(kg bw)/day) for each mycotoxin, C is the mean concentration of a mycotoxin in the food (ng/ g), K is the average consumption of maize (g/person/day), and bw is the assumed body weight of 60 kg.

d) Characterization of Risks from Consumption of Contaminated Grains:

The Margin-of-Exposure Assessment method of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO) and the Scientific Panel on Contaminants in the Food Chain (CONTAM Panel) of the EFSA was followed. It recommends the application of the margin of exposure (MOE) for risk characterization and indication of the level of health concern of substances that are both genotoxic and carcinogenic, such as AFs. The magnitude of the MOE gives an indication of the risk level (i.e., the smaller the MOE, the higher the potential risk posed by exposure to the compound of concern), with MOEs of 10, 000 or higher (based on an animal study) being of low concern for public health. To assess the aflatoxin-related liver-cancer burden due to the consumption of contaminated grains, AFB1 was used as it is the major proportion of total aflatoxins in the analyzed samples and its ingestion is directly linked to the development of liver cancer. The associated risk was characterized by estimating liver-cancer rates for average staple-grain consumers and expressed as the number of cancers per 100 000 people per year.

e) Results: All the maize samples and 18% of the sorghum samples exceeded the EC maximum limits for AFB1 (2 µg/kg) and for total aflatoxins (4 µg/kg) in cereals. Levels of contamination up to 454 and 270 times the EU maximum limits for AFB1 and total aflatoxins, respectively, were found in maize samples. Levels of AFB1 in sorghum samples exceeded EU maximum limits by up to 52 times. Comparing different types of maize and sorghum, the levels of mycotoxins were lower in yellow maize and in white sorghum compared with in white maize and red sorghum. Such extreme high concentrations of aflatoxins in maize may have severe health implications for the consumers, considering the daily consumption of maize in Somalia. FUMs contaminated 100% of maize samples and 38%

sorghum samples. FB1, the most prevalent and most toxic fumonisin, which has been classified as a group 2B possible human carcinogen contaminated all maize samples with concentration levels in the range of 843−17,322 and 1601−8113 µg/kg for white and yellow maize, respectively. In addition, 75% of white-sorghum samples were found to contain FB1 at concentration levels ranging from 13.5 to 160 µg/kg. The APDIs of AFG1 and AFG2 for yellow maize were 11.4 and 23.6 ng/(kg bw)/day, respectively. For total aflatoxins (AFB1, AFB2, AFG1, and AFG2), the APDIs were 1614 and 649 ng/(kg bw)/day for white and yellow maize, respectively. For the comparative purpose of this study, the estimated APDI for aflatoxins was compared with those from other continents as well as with those from countries within Africa. ***The exposure to total AFs for the Somali population was substantially higher than the estimated mean exposures to aflatoxins of populations in Europe (0.93−2.4 ng/(kg bw)/day), the United States (2.7 ng/(kg bw)/day), Asia (53 ng/(kg bw)/ day), and Africa (1.4−850 ng/(kg bw)/day)***. AFB1 has been shown to be a potent liver carcinogen, causing hepatocellular carcinoma (HCC) in humans and a variety of animal species. Liver cancer is the third leading cause of cancer deaths in the world, with the highest rates in Africa and East and Southeast Asia. The prevalence of HCC is 16-32 times higher in developing countries than in developed countries. More than a quarter of the 550,000−600,000 new HCC cases reported worldwide each year may be attributable to AF exposure. Other studies have evaluated the relationship between the incidence of HCC and human exposure to aflatoxins in a number of African countries, including Kenya, Mozambique, and Swaziland. With average dietary AFB1 exposure estimated at APDIs of 1402 and 584 ng/(kg bw)/day through the consumption of white and yellow maize, respectively, Somali individuals are at high risk of developing primary liver cancer.

The levels of FUM exposure were also estimated in the maize samples analyzed. To assess the risk resulting from dietary exposure to FUMs in maize, the APDIs were compared with provisional-maximum-tolerable-daily-intake (PMTDI) values, for which exceedance indicates the potential for health risks. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) recommends a PMTDI of 2 µg/(kg bw)/day for FB1 and FB2 separately or combined. The average APDIs for FB1 in the Somali population was 11.89 and 10.77 µg/(kg bw)/day for white maize and yellow maize, respectively, representing 595 and 539% of the PMTDI. Total fumonisins (FB1 and FB2) that the Somali population were exposed to were 16.70 and 13.89 µg/(kg bw)/day from white-maize and yellow-maize consumption, respectively, representing 835 and 694% of the PMTDI. These high exceedances of the PMTDI indicate potential health risks from fumonisin dietary exposure. Exposure to high fumonisin levels through the consumption of contaminated maize has been associated with the risk of developing liver lesions, which was observed in experimental animals, and

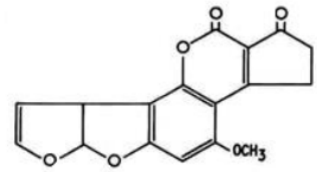
human esophageal cancer. In areas of South Africa and Brazil, where the APDIs for fumonisins were calculated to be 8.67 and 1.60 µg/(kg bw)/day, respectively, high rates of esophageal cancer have been reported. A recent study that assessed the distribution of cancer cases in Somalia found that the most common type of cancer was esophageal cancer (32% of all cancer cases) and concluded that environmental risk factors and nutritional habits have a strong impact in this population. The current study points to exposure to high levels of fumonisins, which could be one of the risk factors contributing to esophageal-cancer incidences in this population.

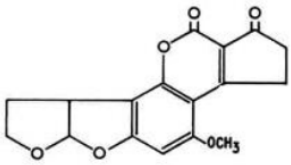
f) **Recommendations**: The data presented in this study indicate an urgent need to address mycotoxin contamination and exposure in the population of Somalia and also underlines a need for further toxicological-data collection to estimate the full impact on Somali society. Further studies are critically needed to assess the risk of mycotoxin exposure in different age groups and in different foodstuffs in order to understand where the greatest interventions can be performed (i.e., pre- and postharvest) to reduce the human burden of mycotoxins in the diet. Somalia is a country where the mycotoxin problem has been totally neglected. Furthermore, from the data presented within this study, it can be seen that consumers should be urgently advised on maize consumption and that it is crucial to develop and implement mycotoxin regulations, mycotoxin-monitoring schemes, and mycotoxin mitigation strategies to protect an entire nation from the catastrophic human-health consequences associated with such enormous levels of mycotoxin exposure.

2. What are Mycotoxins?

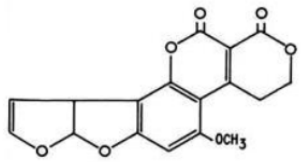
The term mycotoxin was first used in the 1960s to describe the toxin associated with contaminated peanuts in animal feed and the loss of turkeys in England (Turkey-X-disease). This mycotoxin was later identified as the *Aspergillus flavus* toxin aflatoxin B1. Bennett [2] defined mycotoxins as “natural products produced by fungi that evoke a toxic response when introduced in low concentrations to higher vertebrates and other animals by a natural route”. Mycotoxins are secondary metabolites (*secondary metabolite: A compound that is not necessary for growth or maintenance of cellular functions but is synthesized, generally, for the protection of a cell or micro-organism,*

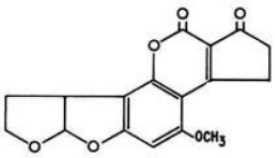
during the stationary phase of the growth cycle. Many are used in foods, pharmaceuticals, and other industrial applications.), defined by Bennett and Bentley [3] as “metabolic intermediates or products, found as a differentiation product in restricted taxonomic groups, not essential to growth and life of the producing organism, and biosynthesized from one or more general metabolites by a wider variety of pathways than is available in general metabolism”. The term was later applied to other toxic fungal natural products [4].



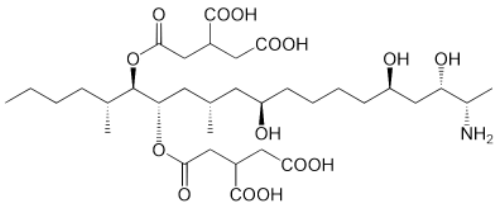


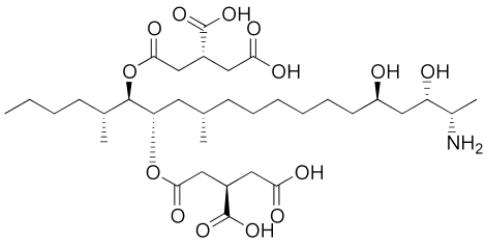
Aflatoxin B1, ***Aflatoxins B2***





Aflatoxin G1 ***Aflatoxin G2***





Fumonisin B1 ***Fumonisin B2***

Traditionally, toxigenic fungi contaminating agricultural grains have been conventionally divided into two groups those invade seed crops have been described as “**field**” fungi (e.g., *Cladosporium*, *Fusarium*, *Alternaria* spp.), which reputedly gain access to seeds during plant development, and “**storage**” fungi, (e.g., *Aspergillus*; *Penicillium* spp.), which proliferate during storage [4]. Currently, this division is not so strict because according to Miller [6] four types of toxigenic fungi can be distinguished: (2) Plant pathogens as *Fusarium graminearum* and *Alternaria alternata*; (3) Fungi that grow and produce mycotoxins on senescent or stressed plants, e.g., *F. moniliforme* and *Aspergillus flavus*; (4) Fungi that initially colonize the plant and increase the feedstock’s susceptibility to contamination after harvesting, e.g., *A. flavus*; (5) Fungi that are found on the soil or decaying plant material that occur on the developing kernels in the field

and later proliferate in storage if conditions permit, e.g., *P. verrucosum* and *A. ochraceus*.

The involvement of *Aspergillus* spp. as plant pathogens has been reported and aflatoxin-infected crops have from time to time been returned to agricultural soils. This practice may prove hazardous, since both *A. flavus* and *A. parasiticus* can infect crops prior to harvesting [7]. The phytotoxic effects of the aflatoxins have been investigated, with respect to seed germination, and the inhibition of root and hypocotyl elongation [8, 9]. Aflatoxin has been reported to occur within apparently healthy, intact seeds which suggest that the toxin can he transported from contaminated soil to the fruit [10]. Aflatoxin B1 (AFB1) can be translocated from the roots to the stems and leaves. If the soil microorganisms do not rapidly degrade the aflatoxin contained within the plowed under stover and grains, the possibility that the roots of the seedlings of the following year's crop will both absorb and translocate the aflatoxins to both the stems and leaves exists [11]. This could be hazardous to the plant's growth and development as well as to the consumer's health.

Fungal growth

a. Field fungi: fungi that attack plants that grow in the field (occurring *prior to harvest)* grow under special conditions. (***Fusarium***)

b. Storage fungi: Storage fungi usually invade grain or seed during storage and are generally not present in large quantities before harvest in the field. The most common storage fungi are species of **Aspergillus and Penicillium**. Contamination occurs through spores contaminating the grain as it is going into storage from the harvest. The development of fungi is influenced by the:

- Moisture content of the stored grain
- Temperature
- Condition of the grain going into storage
- Length of time the is grain stored and
- Amount of insect and mite activity in the grain

Among the different type of mycotoxins, aflatoxins (AFs) are widespread in major food crops such as maize, groundnuts, tree nuts, and dried fruits and spices as well as milk and meat products [12]. When animal feeds are infected with AF-producing fungi, AFs are introduced into animal source food chain. AFs are toxic metabolites produced via a polyketide pathway by various species and by unnamed strains of Aspergillus section Flavi, which includes A. flavus, A. parasiticus, A. parvisclerotegenus, A. minisclerotigenes [13], Strain SBG [14], and less commonly A. nomius [15]. Normally, A. flavus produces only B-type aflatoxins, whereas the other Aspergillus species produce both B- and G-type aflatoxins [16]. The relative proportions and level of AF contamination depends on Aspergillus species, growing and storage conditions, and additional factors [17]. For instance, genotype, water or heat stress, soil conditions,

moisture deficit, and insect infestations are influential in determining the frequency and severity of contamination [18]. For M-type aflatoxins, these compounds are normally not found on crops, but their metabolites are found in both the meat and milk of animals whose feedstuffs have been contaminated by AF-B1 and AF-B2 [12]. Susceptibility of cereals to mycotoxin contamination, particularly aflatoxins (AFs), fumonisins (FUMs), and deoxynivalenol (DON), have been widely described, and the high occurrence in Africa has been reported. Consequently, the Sub-Sahara Africa (SSA) region has suffered from many mycotoxin-poisoning incidences, some resulting in fatalities associated with acute exposure to AFs and FUMs.

3. Health Risks of Mycotoxins in Food and Animal Feed

Recently, emphasis on the health risks associated with consumption of AFs in food and feedstuffs has increased considerably. As a result of this, many experimental, clinical, and epidemiological studies have been conducted showing adverse health effects in humans and animals exposed to AFs contamination, depending on exposure. High-dose exposure of the contaminant can result in vomiting, abdominal pain, and even possible death, while small quantities of chronic exposure may lead to liver cancer [20]. The International Agency for Research on Cancer (IARC) has classified both B- and G-type aflatoxins as Group 1 mutagens, whereas AF-M1 is classified in Group 2B (IARC, 2015). Furthermore, AFs may contribute to alter and impair child growth. Together with other mycotoxins, AFs are commonly suspected to play a role in development of edema in malnourished people as well as in the pathogenesis of **kwashiorkor** (*also known as "edematous malnutrition" because of its association with edema (fluid retention), is a nutritional disorder most often seen in regions experiencing famine. It is a form of malnutrition caused by a lack of protein in the diet*) in malnourished children.

Moreover, AF contamination negatively impacts crop and animal production leading not only to natural resource waste, but also decreased market value that causes significant economic losses.

Due to these effects, different countries and some international organizations have established strict regulations in order to control AF contamination in food and feeds and also to prohibit trade of contaminated products [22]. The regulations on "***acceptable health risk***" usually depend on a country's level of economic development, extent of consumption of high-risk crops, and the susceptibility to contamination of crops to be regulated [23]. Indeed, the established safe limit of AFs for human consumption ranges 4-30 µg/kg. The ***EU*** has set the strictest standards, which establishes that any product for direct human consumption cannot be marketed with a concentration of AF-B1 and total AFs greater than 2 µg/kg and 4 µg/kg, respectively [24, 25]. Likewise, **US** regulations have specified the maximum acceptable limit for AFs at 20 µg/kg. However, if the EU aflatoxin standard is adopted worldwide, lower income countries such as those in ***Asia*** and ***Sub-Saharan Africa (SSA)*** will face both economic losses and additional

costs related to meeting those standards. This situation requires alternative technologies at pre- and post-harvest levels aimed to minimize contamination of commercial foods and feeds, at least to ensure that AF levels remain below safe limits.

4. Mycotoxin detection technologies

Analytical methods for mycotoxins in cereals and cereal-based products require three major steps, including extraction, clean-up (to eliminate interferences from the extract and concentrate the analyte), and detection/determination of the toxin (by using suitable analytical instruments/technologies). Clean-up is essential for the analysis of mycotoxins at trace levels, and involves the use of solid phase extraction and multifunctional or immune-affinity columns. Different chromatographic methods are commonly used for quantitative determination of mycotoxins, including gas-chromatography (GC) coupled with electron capture, flame ionization or mass spectrometry (MS) detectors and high-performance liquid chromatography (HPLC) coupled with ultraviolet, diode array, fluorescence or MS detectors. The choice of method depends on the matrix and the mycotoxin to be analyzed. Liquid chromatography-tandem mass spectrometry (LC-MS/MS) is spreading rapidly as a promising technique for simultaneous screening, identification and quantitative determination of a large number of mycotoxins. In addition, commercial immune-metric assays, such as enzyme-linked immunosorbent assays (ELISA), are frequently used for screening purposes as well. Recently, a variety of emerging methods have been proposed for the analysis of mycotoxins based on novel technologies, including immune-chromatography (i.e. lateral flow devices), fluorescence polarization immunoassays (FPIA), infrared spectroscopy (FT-NIR), molecularly imprinted polymers (MIPs) and optical biosensors.

Examples for Commercially Available Rapid Analysis Test Systems:

A) Test kits based on ELISA or LFD
1. Charm Sciences Inc.
2. EnviroLogix Inc.
3. Neogen Corporation
4. R-Biopharm AG
5. Romer Labs®
6. VICAM

B) Test kits based on fluorescence polarization immunoassays
1. Aokin AG
2. Diachemix Inc.

C) Test kits based on fluorometry
ToxiMet Ltd

Strength and weakness of enzyme-linked immunosorbent assay (ELISA), lateral flow detection (LFD) or fluorescence polarization immunoassay (FPI)

	ELISA	Lateral Flow detection (LFD)	Fluorescence Polarization Immunoassay (FPI)
Strength	1. Easy handling 2. Low expenditure of time 3.Sensitive 4. Multiple analysis	1. Easy handling 2. Rapid 3. Portable 4. No special equipment required	1. Easy handling 2. Low time expenditure 3. Sensitive 4. Portable 5. Quantitative and Qualitative
Weakness	1. Cross reactivity 2.False positives 3.High cost	1. Not qualitative 2. High cost	1. High cost 2. Currently only for certain mycotoxins

5. Technologies to mitigate mycotoxins contamination in food and animal feed

A wide range of AF management options exist in literature. Depending on the “type” or mode of application, management has been classified in this review as pre-harvest stage, specifically biological control, while sorting technology, treatments with electromagnetic radiation, ozone fumigation, chemical control agents, biological control agents, and packaging material are grouped as post-harvest stage. Each of these groups of control/management options are briefly discussed below.

a) Biological Control

Non-aflatoxin forming strains of A. flavus have been used as a biological control for long-term crop protection against AF contamination under field conditions. When the spore number of nontoxigenic strains in the soil is high, they will compete with other strains, both toxigenic and other atoxigenic, for the infection sites and essential nutrients needed for growth. Moreover, soil inoculation with nontoxigenic strains has a carryover effect, which protects crops from contamination during storage. The ability of fungus to compete with closely related strains depends on several factors such as pH and soil type as well as the availability of nitrogen, carbon, water, and minerals.

The International Institute of Tropical Agriculture (**IITA**) and the United States Department of Agriculture - **Agriculture Research Service** together with other partners have been researching in Africa on non-toxigenic biocontrol fungi that act through competitive exclusion strategy. They have successfully developed several country-specific indigenous aflatoxin biocontrol products generically

named as **Aflasafe™** (www.aflasafe.com), which can be used on maize and groundnut. This product is an ecofriendly innovative biocontrol technology that utilizes native nontoxigenic strains of A. flavus to naturally out-compete their aflatoxin-producing cousins. **Aflasafe™** has been shown to consistently reduce aflatoxin contamination in maize and groundnut by 80e99% during crop development, postharvest storage, and throughout the value chain in several countries across Africa. Aflasafe products have been registered for commercial use in Kenya, Nigeria, Senegal and Gambia, while products are under development in seven other African nations]. Each Aflasafe™ product contains four unique atoxigenic strains of A. flavus widely distributed naturally in the country where it is to be applied. Another study on biological control has found that inoculation of antagonistic strains of fluorescent Pseudomonas, Bacillus and Trichoderma spp. on peanuts resulted in significant reduction of pre-harvest seed infection by A. flavus. Other researchers demonstrated that the extract of Equisetum arvense and a mixture 1:1 of Equisetum arvense and Stevia rebaudiana is effective against growth of A. flavus and subsequent production of aflatoxin under pre-harvest conditions. A 71% reduction in AF contamination in soils and in groundnuts when an AF competitive exclusion strain of A. flavus AFCHG2 was applied to Argentinian groundnuts. Non-toxigenic strains of A. flavus were shown to mitigate AF contaminations in maize through pre-harvest field application. Furthermore, the efficacy of a bioplastic-based formulation for controlling AFs in maize were evaluated. The results showed that bio-control granules inoculated with A. flavus NRRL 30797 or NRRL 21882 reduced AF contaminations up to 90% in both non-Bt and Bt hybrids (***Bt corn*** *is a variant of* ***maize*** *that has been genetically altered to express one or more proteins from the bacterium Bacillus thuringiensis including Delta endotoxins. The protein is poisonous to certain insect pests. Spores of the bacillus are widely used in organic gardening, although GM* ***corn*** *is not considered organic*).

b) Sorting technology

Sorting processes seek to eliminate agricultural products with substandard quality. Normally sorting, especially for grains, can be achieved based on differentiation of physical properties such as color, size, shape, and density as well as visible identification of fungal growth in affected crops. By rejecting damaged and discolored samples, sorting operations reduce the presence of AFs as well as contaminating materials in food and feed.

Nonetheless, such physical methods are often laborious, inefficient, and impractical for in-line measurements. The application of computer-based image processing techniques is one of the most promising methods for large-scale screening of fungal and toxin contaminations in food and feed. Grains and other agricultural products contain various nutritional substances that are degraded by fungal growth, which in turn influence absorbance spectra of the material. It was

also shown that it was possible to quantify fungal infection and metabolites such as mycotoxins produced in maize grain by Fusarium verticillioides using Near Infrared Spectroscopy (NIRS). NIRS successfully identified kernels contaminated with AFs. Moreover, some researchers highlighted NIRS technique as a fast and nondestructive tool for detecting mycotoxins such as AF-B1 in maize and barley at a level of 20 ppb. Nevertheless, NIRS only produces an average spectrum, which lacks in spatial information from the sample with respect to distribution of the chemical composition. Hyperspectral imaging (HSI) is another method that can be employed to monitor both the distribution and composition of mycotoxins in contaminated food samples, especially grains. This method can produce both localized information and a complete NIR spectrum in each pixel. Hyperspectral imaging (HSI) technique was also used to estimate AF contamination in maize kernels inoculated with A. flavus spores and demonstrated the potential for HSI based in the Vis/NIR range for quantitative identification and distinction of AFs in inoculated maize kernels. Nevertheless, all these spectral techniques require properly trained personal and equipment which is out of the reach of the small subsistence farmers that are typical of the underdeveloped countries in Sub-Sahara Africa.

c) Chemical control agents

A number of studies have determined the effect of synthetic and natural food additives on AF reduction in food products. A prime example of this effect is citric acid on AF-B1 and AF-B2 degradation in extruded sorghum. The effect of sodium hydrosulfite ($Na_2S_2O_4$) and pressure on the reduction of AFs in black pepper was investigated. The study reported that the application of 2% $Na_2S_2O_4$ under high pressure resulted in a greater percentage reduction of AF-B1, AF-B2, AF-G1, and AF-G2, without damage to the outer layer of black pepper. Nevertheless, AF-B2 was found to be the most resistant against the applied treatment. Apart from that, it is evident that respiration from insects increases the temperature and moisture content of grains providing favorable conditions for fungal growth. For this reason, the efficacy of 2, 6-di (t-butyl)-p-cresol) and the entomopathogenic fungus Purpureocillium lilacinum on the accumulation of AF-B1 in stored maize was evaluated. The results clearly showed that the highest reduction of AF-B1 in stored maize occurred with the combination of BHT and urpureocillium lilacinum. In addition, the effects of organic acids during soaking process on the reduction of AFs in soybean media were studied.

The highest reduction rate of AF-B1 was obtained from tartaric acid followed by citric acid, lactic acid, and succinic acid, respectively. These acid treatments convert AF-B1 to β-keto acid that subsequently transforms to AF-D1, which has less toxicity than that of AFB1. Another novel technology was also reported that has been applied to inhibit AF contamination called acidic electrolyzed oxidizing water, which is an electrolyte solution prepared using an electrolysis apparatus

with an ion-exchange membrane, used to decontaminate AF-B1 from naturally contaminated groundnut samples. This decreased the content of AF-B1 in groundnuts about 85% after soaking in the solution. Remarkably, the nutritional content and color of the groundnuts did not significantly change after treatment.

To overcome the development of fungal resistance as well as residual toxicity posed by synthetic additives, the actions of some plant-based preservatives toward AF reduction have been studied in various food products. The effect of isothiocyanates, generated by enzymatic hydrolysis of glucosinolates, contained in oriental mustard flour were evaluated. The findings showed that isothiocyanates reduced A. parasiticus growth in groundnut samples, whereas the AF-B1, AFB2, AF-G1, and AF-G2 reduction ranged between 65 and 100%. Similar results were obtained by other researchers, who reported the inhibition of AFs by isothiocyanates derived from oriental and yellow mustard flours in piadina (a typical Italian flatbread) contaminated with A. parasiticus. These results can be explained by the electrophilic property of isothiocyanates, which can bind to thiol and amino groups of amino acids, peptides, and proteins, forming conjugates, dithiocarbamate, and thiourea structures leading to enzyme inhibition and subsequently to cell death. Due to fungicidal and anti-aflatoxigenic properties of neem leaves, the application of 20% neem powder fully inhibited all types of aflatoxins synthesis for 4 months in wheat and for 2 months in maize, whereas the inhibition of AF-B2, AF-G1, and AF-G2 was observed for 3 months in rice.

d) Biological control agents at post-harvest processing stages

Physical and chemical detoxification methods have some disadvantages, such as loss of nutritional value, altered organoleptic properties, and undesirable effects in the product as well as high cost of equipment and practical difficulties making them infeasible, particularly for lower-income countries. However, biological methods based on **competitive exclusion by non-toxigenic fungal strains** have been reported as a promising approach for mitigating formation of mycotoxins and preventing their absorption into the human body. Among various microorganisms, lactic acid bacteria (LAB) namely Lactobacillus, Bifidobacterium, Propionibacterium, and Lactococcus are reported to be active in terms of binding AF-B1 and AF-M1. The binding is most likely a surface phenomenon with a significant involvement of lactic acid and other metabolites such as phenolic compounds, hydroxyl fatty acids, hydrogen peroxide, reuterin (3-hydroxypropionaldehyde), and proteinaceous compounds produced by LAB. AF binding seems to be strongly related to several factors such as LAB strain, matrix, temperature, pH, and incubation time. Researchers found that Lactobacillus rhamnosus was the best strain with the ability to bind to AF-B1 in contaminated wheat flour during bread-making process. Other microorganisms have also been reported to bind or degrade aflatoxins in foods and feeds. The AF-B1 binding abilities of Saccharomyces cerevisiae strains in vitro in indigenous

fermented foods from Ghana were tested. The results indicated that some strains of Saccharomyces cerevisiae have high AF-B1 binding capacity. These binding properties could be useful for the selection of starter cultures to prevent high AF contamination levels in relevant fermented foods.

e) Packaging materials

In post-harvest management, packaging materials are frequently considered as the final step of product development in order to extend the preservation of food and feed products. During storage and distribution, food commodities can be affected by a range of environmental conditions, such as temperature and humidity as well as light and oxygen exposure. Overall, these factors have been reported to facilitate various physicochemical changes such as nutritional degradation and browning reactions with the latter causing undesirable color changes. The interaction of these factors can also elevate the risks of fungal development and subsequent AF contamination. Many smallholder farmers in lower-income countries traditionally store agricultural products such as grains in containers typically made from wood, bamboo, thatch, or mud placed and covered with thatch or metal roofing sheets. Recently, metal or cement bins have been introduced as alternatives to traditional storage methods, but their high costs and difficulties with accessibility make adoption by small-scale farms limited. Polypropylene (PP) bags which are currently used for grains storage, are still contaminated by fungal AFs especially when those reused bags contain A. flavus spores.

Several studies have reported the application of Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and resulting AF contamination. .PICS bags successfully suppressed the development of A. flavus and resulting AF contamination in maize across the wide range of moisture contents in comparison to non-hermetic containers. This could be a result of PICS bag construction consisting of triple bagging hermetic technology with two inner liners made of high density polyethylene (HDPE) and an outer layer woven PP. In addition, PICS bags reduced the oxygen influx and limited the escape of carbon dioxide, which can prevent the development of insects in stored grain.

f) Benefits of good harvest management

Many innovative management strategies that can potentially reduce AF contamination in food and feed chains have been identified by this review. These strategies have the potential to mitigate adverse effects of AF contamination on food security, public health, and economic development. An understanding of these benefits can motivate policy makers and value chain actors to explore effective ways of managing AFs during pre- and post-production processes.
The quantity and quality of agricultural products are degraded by the presence of AFs, while the opposite is true when AF contamination is effectively prevented. The use of biocontrol methods for instance has been shown to reduce

contamination up to 90%, which potentially reduces complete loss of harvested or stored crops. As mentioned earlier the use of the PICS technology for grain storage can reduce AF contamination due to the controlled environment in the hermitic bags. For subsistent households, such measures can potentially increase availability of harvested food crop for family consumption. Farmers can even afford to sell their excess produce and use the proceeds to purchase other food ingredients they do not produce themselves. Moreover, applications of innovative control technologies can ensure that products are safer to consume, thereby improving utilization efficiency. By reducing significant losses during storage, the control of AF can certify that the foodstuffs are available over extended periods of time, thereby ensuring consistent food availability. Effective control of AF contamination therefore has the potential to enhance food availability, food access, food utilization, and food stability.
AFs are a serious risk to public health, especially in low-income countries where most people consume relatively large quantities of susceptible crops such as maize or sorghum. According to the estimation of the US Center for Disease Control and Prevention, about 4.5 billion people are chronically exposed to mycotoxins. Prolonged exposure to even low levels of AF contamination in crops could lead to liver damage or cancer as well as to immune disorders. In children, stunted growth and Kwashiorkor pathogenesis are caused by breast milk consumption or direct ingestion of AF-contaminated foods.

Controlling AF contamination through the application of effective technologies could potentially avoid such health risks and have significant benefits in a number of ways. First chronic diseases can be prevented to minimize pressure on the health facilities of an economy due to savings on cost of medication and treatment. People will have access to good quality food ingredients for healthy living and making an efficient labor force available for the economy.

g) Economic benefits

The economic benefits of AF reduction are observed through both domestic and high-value international trade markets. At domestic and regional levels, markets might not reward reduced AF in crops, but avoiding contamination could allow, in ideal cases, to increase the volume of sales, which would lead to higher incomes as well as greater returns on investments for producers. Farmers who successfully inhibit AF contamination can also benefit from increased income due to greater product acceptance, higher market value, or access to high-value markets. In reality, there are numerous factors that have to be enhanced in order to create premium class products such as aflatoxin control, consumer awareness, marketing channels, aflatoxin testing, and stricter enforcement of production and market regulations. When such enabling conditions are met, it has been shown that aflatoxin conscious market can pay a premium for aflatoxin safe products even in the domestic market in Africa.

Moreover, the control of AF contamination could reduce costs the associated with consequent effects on humans, such as medical treatments, primarily of individuals suffering from liver cancer, as well as indirect costs such as pain and suffering, anxiety, and reduction in quality of life associated with exposure to AFs. At the international level, many developed countries have established regulations to limit exposure to AFs. Some countries have different limits depending on the intended use, the strictest on human consumption, exports, and industrial products. Despite that stringent measures that makes phytosanitary standards seemingly more expensive, once suppliers internalize the economic costs of compliance in reality, greater economic benefits for society can be achieved. This is due to access to larger and more stable markets, and less incidence of disease. Controlling AF contamination in exportable agricultural commodities could maintain or even increase trade volumes and foreign earnings for exporting economies. Furthermore, the savings from such control measures could be channeled or invested in other economic sectors in order to generate additional income and propel growth and development.

h) Implications for research and policy

AFs are a critical problem for food safety in many lower-income countries where AF formation in key staple crops causes significant post-harvest losses and negative impacts on human life. Currently, several innovative AF control technologies have shown potential to improve health and economic factors for farmers and other actors in commodity value chains. However, the efficacy, safety, and quality of these technologies must be verified prior to adoption. The feasibility of using biocontrol products depends not only on safety regulations in each individual country, but also on the accessibility of such biocontrol tools like **Aflasafe™** to smallholder farmers. The ability to develop and maintain biocontrol strains from local resources, particularly in the production of **Aflasafe™**, are highly cost-effective and facilitate availability. Meanwhile, non-profit governmental or nongovernmental organizations can also promote such products, which are particularly suitable for sustainable development. However, biocontrol adoption still requires a flexible system that allows the use of bio-pesticides together with a favorable policy and institutional supports.

Furthermore, other techniques have been developed such as sorting technologies that offer numerous advantages including (1) rapid, real-time product information via non-destructive measurement, (2) reduction of laborious and destructive analytical methods, (3) continuous monitoring, and (4) integrating into existing processing lines for control and automation. However, investment costs are usually the main factor determining whether such technologies are adopted or not. For simplicity, development of cheap and portable diagnostics techniques that are adaptable to different field networks is imperative. In addition, future research should still be conducted in cooperation with final users to

achieve full adoption potential. Despite technological advances, hand sorting may still be more suitable in lower-income countries where access to equipment is limited. The culls from sorting must be disposed in a manner that they do not enter the food chain, particularly of economically vulnerable populations.

6. New Environmentally Friendly Technologies to combat mycotoxin contamination:

A) NovaSil Clay (from BASF Corporation) for the Protection of Humans and Animals from Aflatoxins and Other Contaminants

Aflatoxin contamination of diets results in disease and death in humans and animals. The objective of this research was to review the development of innovative enterosorption strategies for the detoxification of aflatoxins. NovaSil clay (NS) has been shown to decrease exposures to aflatoxins and prevent aflatoxicosis in a variety of animals when included in their diets. Results have shown that NS clay binds aflatoxins with high affinity and high capacity in the gastrointestinal tract, resulting in a notable reduction in the bioavailability of these toxins without interfering with the utilization of vitamins and other micronutrients. This strategy is already being utilized as a potential remedy for acute aflatoxicosis in animals and as a sustainable intervention via diet. Animal and human studies have confirmed the apparent safety of NS and refined NS clay (with uniform particle size). Studies in Ghanaians at high risk of aflatoxicosis have indicated that NS (at a dose level of 0.25% *w*/w) is effective at decreasing biomarkers of aflatoxin exposure and does not interfere with levels of serum vitamins A and E, iron, or zinc. A new spinoff of this strategy is the development and use of broad-acting sorbents for the mitigation of environmental chemicals and microbes during natural disasters and emergencies. In summary, enterosorption strategies/therapies based on NS clay are promising for the management of aflatoxins and as sustainable public health interventions. The NS clay remedy is novel, inexpensive, and easily disseminated.

B) Aflasafe – a 100% natural biological control product for fighting aflatoxin.

- **What is Aflasafe?**

Aflasafe is **a safe natural solution** to the problem of aflatoxin, homegrown in Africa with help from partners in the USA and Europe. It works from the plot to your plate to **stop contamination from reaching dangerous levels** and keep foods like maize and groundnuts **safe to eat**. Aflasafe tackles toxic tragedy using harmless types of *Aspergillus flavus.* Surprisingly, this is the same kind of fungus that produces aflatoxin, but in this case they are kindlier cousins that **do not and cannot ever produce the toxin**. Each country has its own version of Aflasafe

using a mixture of four fungal strains, all found growing naturally in local soils. The friendly fungi are coated onto ordinary sorghum grain, which acts as a vehicle to help them get established and can easily be broadcast onto fields.

It seems strange for the same fungus to be both poison and cure, but it is a bit like sending a **thief to catch a thief:** only *Aspergillus* can stop *Aspergillus*.

Farmers apply Aflasafe to their plants early on, and the friendly fungi occupy the growing food before the dangerous ones can get a toehold. Aflasafe might look like a poacher but it is really a gamekeeper, staking out its territory and making life difficult for the bad guys.

- **Geographical and food value chain focus**

Aflatoxin is a poison produced by the soil-inhabiting fungus *Aspergillus flavus* that infects crops in the field leading to postharvest losses. Common in human food and animal feed, aflatoxin can occur throughout the food value chains, compromising food security, health and trade in many developing countries. The extent of contamination varies by season, crop and region, often hovering around 25%.

Aflatoxin causes an estimated 5–30% of liver cancer worldwide, the highest incidence being in Africa (30%). It suppresses the immune system and stunts child growth. Internally, approximately 40% of the produce in African markets exceeds the aflatoxin maxima allowed. Externally, Africa potentially loses up to USD 670 million annually in lost export opportunities.

Aflasafe is registered in Kenya, Nigeria, Senegal and The Gambia, where tens of thousands of farmers are using it. Product development is under way in another nine African countries, with plans to commercialize Aflasafe in all the countries of engagement.

- **Technical quality**

The Agricultural Research Service – United States Department of Agriculture (USDA–ARS) invented a natural bio-pesticide for aflatoxins that is safe and cost-effective. Thereafter, the International Institute of Tropical Agriculture (IITA) worked with USDA–ARS and several national partners to adapt and improve this technology for Africa, resulting in Aflasafe. Aflasafe looks like seed sorghum. The grains are ‘killed’ by heating before coating with spores of four native beneficial fungi. These beneficial fungi are native strains of *A. flavus* that cannot ever produce aflatoxins. The beneficial fungi progressively displace toxic strains of *A. flavus*, thus creating a cumulatively safer environment for the crop season after season. Aflasafe consistently reduces aflatoxin contamination in maize and groundnuts by between 80 and 99% at harvest and in storage. Applied pre-harvest but with postharvest benefits, a single application of Aflasafe − just this one single action in each cropping season − is all that is required to protect maize or groundnuts along the entire value chain from plot to plate. Ten kilos of Aflasafe, costing between USD 12 and 20, is applied on each hectare by simply broadcasting 2–3 weeks prior to

flowering. Aflasafe is currently packed in handy 2.5- and 5-kilo bags for easy application by smallholders. (5-minute video on how Aflasafe works)

- **Originality**

Aflasafe is not simply imported from one country to another, nor is its development top-down. It is the first bio-pesticide developed locally through years of continuous national and international collaboration. Aflasafe is not a one-size-fits-all product in its composition or approach. Rather, Aflasafe is painstakingly customized for each country by modulating and making safer the country's particular fungal community. With reduction approaching 100% in some crops and countries, to date, Aflasafe remains the most cost-effective technology for controlling aflatoxins in Africa. It is an all-African initiative: inputs are sourced in Africa and production is on African soil, allowing for rapid manufacture, deployment and distribution across the continent.

- **Feasibility for commercialization**

With up to 500% return on investment for farm-based businesses and their constituent farmers, Aflasafe is an attractive value proposition. Commercialization discussions with the private sector are at an advanced stage. More than 450 tons of Aflasafe were sold in Nigeria, Kenya, Senegal, The Gambia and Zambia in 2014−2016. Pending orders are approximately 1,000 tons. The projected demand in 2017 alone is 1,000 tons (equivalent to 100,000 hectares). In Nigeria, Aflasafe-protected maize fetched 13−17% more profits in 2013−2015. We are working with global marketing experts on three prongs in each country: target market analysis, production scenarios and delivery approaches. For maize in Kenya, our model projects a 40% increase in adoption by Year 5.

- **Potential for upscaling and worth of investment**

Although commercialization is still in the early stages, more than 20,000 farmers are already using Aflasafe through agri-business incentivization (Nigeria) and engagement (Senegal); and government distribution (Kenya). The Aflasafe ***Technology Transfer and Commercialization Project*** − funded by the ***Gates Foundation and USAID*** − was recently launched to ensure Aflasafe reaches millions of farmers in 11 African countries through public- and private-sector partnerships. These partnerships will enhance Aflasafe's availability and accessibility through investments in its manufacture and distribution, thus fostering adoption. The initial target is at least half-a-million hectares of Aflasafe-protected smallholding in five years. Country-specific strategies are being designed to guide the choice of models and investors in each country.

- **Aflasafe has many benefits**
    - It is highly **effective**, cutting aflatoxin in food drastically and making it safe to eat.
    - It is a completely **safe and environmentally friendly** product, sourced from nature.

- Aflasafe **stays with food**, protecting it all the way through storage and onto your plate.
- It only needs to be **applied by farmers once** each growing season, and is **cheap and cost-effective**.
- Aflasafe is a **made-in-African initiative;** production is on African soil using inputs sourced in Africa.

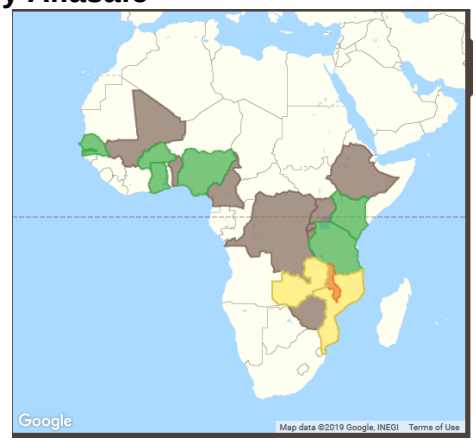
- **How to use Aflasafe**

Aflasafe is very **quick and easy to use**. Apply the product once to your growing crop, and it will protect your harvest all the way until it is eaten. You should apply about 10 kg of Aflasafe per hectare by **hand broadcasting**, i.e. throwing handfuls over the surface of the field, around **2–3 weeks before crop flowering**. The only tricky part is knowing when flowering is due. You need to be familiar with the seed variety that you are growing, or seek guidance from your seed supplier or Aflasafe distributor. Exact timings for Aflasafe application also depend on your location. Although the general principles for using Aflasafe do not vary much from place to place, we are in the process of preparing **country-specific how-to guides** for farmers wherever Aflasafe is available, as both **videos and leaflets**, in the languages spoken locally. For a fully in-depth look at using Aflasafe we offer a comprehensive **training manual** (currently available for West Africa and Kenya). Full information on how to use the product is also printed on all Aflasafe packaging (for info, visit Aflasafe where I am for progress and contacts).

How to Video:

Using Aflasafe GH02 to protect groundnuts, maize and sorghum from aflatoxin - Ghana.mp4

- **Where to buy Aflasafe**



Aflasafe Map Key:

Green: Commercially available
Yellow: Registered
Orange: Testing
Gray: Under development

This list shows you where to get hold of Aflasafe in every country where it is currently available. Aflasafe is close to readiness in many other countries, undergoing final testing or registration for sale, so check out Aflasafe where I am for details.

1. Burkina Faso
SAPHYTO
Tel: +226 20 97 20 18/36
Email: saphyto@saphyto.bf
2. Ghana
Macrofertil Ghana Ltd
Tel: +233 303 20 60 60 / 544 32 50 60
Mobile: +233 245 44 3012
Email: stephen.tour@ldc.com
3. Kenya
KALRO (product registrant)
Email: info@kalro.org
4. Nigeria
HarvestField Industries
Email: info@harvestfield-ng.com
Tel/SMS: +234 (0)807 356 9437, (0)705 149 0042, (0)705 149 0062, (0)907 031 3762
5. Senegal
BAMTAARE Services
Email: dg@sodefitex.sn or goule.gueye@sodefitex.sn
Tel/SMS: +221 77 947 45 26
6. Tanzania
A to Z Ltd
7. The Gambia
BAMTAARE Services
Email: dg@sodefitex.sn or goule.gueye@sodefitex.sn
Tel/SMS: +221 77 947 45 26 (in Senegal)

7. Organizations engaged in abatement of mycotoxin contamination in food and animal feed

a) Partnership for Aflatoxin Control in Africa (PACA)

https://www.aflatoxinpartnership.org/

PACA's Role

To provide leadership and coordination for Africa's aflatoxin control efforts, acting primarily as a catalyst, facilitator, partnership and knowledge broker, project developer and information clearinghouse. PACA will also advocate for the establishment of enabling policies and institutions, increased investment and the mobilization of resources, and should ultimately act as a grant maker to support priority aflatoxin control activities.

The PACA's Secretariat will focus on supporting African governments and work jointly with other key stakeholders to improve governments' effectiveness through three categories of activities:

At the continental level, the Secretariat will support three types of activities:

- Continental and Inter-Regional Forums: Support continental PACA Community Forums and inter-regional Forums to promote alignment and collaboration across countries, share new developments and best practices, and resolve specific challenges / bottlenecks across countries and regions.
- Mainstreaming: Engage stakeholders to mainstream aflatoxin into continental frameworks (e.g., CAADP**, CODEX) to ensure aflatoxin issues are integrated and addressed within these platforms and that there is consistency and congruency between frameworks and harmonization across regions.
- Knowledge Management: Serve as a continental knowledge hub by identifying, documenting, and disseminating best practices and effective technologies; and serving as technical knowledge hub for aflatoxin related information.

At the regional level, the Secretariat will work closely with RECs to support four types of activities:

- Regional Forums: Support RECs to organize regional Forums to promote alignment and collaboration across countries, share new developments, and best practices, and resolve specific challenges and bottlenecks across regions.
- Mainstreaming: Support mainstreaming of aflatoxin in regional frameworks to ensure aflatoxin issues are integrated and addressed within these platforms and that there is consistency and congruency between frameworks and harmonization across countries.
- Country Planning: Work with RECs to support country plan preparation and execution.

At the country level, the Secretariat will work closely with RECs and local country stakeholders through a country steering committee to support the preparation, execution, and oversight of country government-led, and stakeholder aligned country plans. The Secretariat's country activities will build on the country planning work already underway.

PACA Steering Committee Members and Alternates:

- African Union Commission (represented by Dr. Godfrey Bahiigwa)

- African Society of Mycotoxicologists (represented by Dr. Bradley Flett)
- Bill & Melinda Gates Foundation (represented by Ms. Amsale Mengistu)
- East African Community (represented by Mr. Jean Baptiste Havugimana and Mr David Wafula)
- East African Farmers Federation (represented by Mr. Stephen Muchiri)
- Economic Community of West African States (represented by Mr. Ernest Aubee)
- Food and Agriculture Organization of the United Nations (represented by Dr. Blaise Ouattara)
- Global Alliance for Improved Nutrition (represented by Ms. Bonnie McClafferty and Mr. Penjani Mkambula)
- International Institute for Tropical Agriculture (represented by Dr. Ranajit Bandyopadhyay and Dr. Victor Manyong)
- Mars, Incorporated (represented by Dr. David Crean and Robert Baker)
- CAADP Non State Actors Coalition (represented by Mr. Kop'ep Dabugat)
- US Agency for International Development (represented by Dr. Ahmed Kablan and Mr. Patterson W. Brown)
- West and Central Africa Council for Agricultural Research and Development (CORAF/WECARD) (represented by Dr. Abdou Tenkouano
- PACA Secretariat (represented by Dr. Amare Ayalew)

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** Comprehensive Africa Agriculture Development Program (CAADP)

b) Organizations that are working on African Agricultural Issues and their contact information:

1. **Platform for African European Partnership on Agricultural Research for Development (PAEPARD)**
   PAEPARD is a longstanding network of agricultural research for development (ARD) collaborators from Europe and Africa.
   http://aims.fao.org/activity/events/platform-african-%E2%80%93-european-partnership-agricultural-research-development-phase-ii

2. **Forum for Agricultural Research in Africa (FARA)**
   https://faraafrica.org/
3. **European Alliance on Agricultural Knowledge for Development (AGRINATURA)**
   https://agrinatura-eu.eu/
4. **The Joint FAO/WHO Expert Committee on Food Additives (JECFA)**
   Is an international expert scientific committee that is administered jointly by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO).
   http://www.fao.org/food/food-safety-quality/scientific-advice/jecfa/en/
5. **Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA)**

The Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA) was established in 1983 under the Lomé Convention between the African, Caribbean and Pacific Group of States and EU member states.
https://www.devex.com/organizations/technical-centre-for-agricultural-and-rural-cooperation-cta-76636

6. **Peanut Mycotoxin and Innovation Lab (PMIL)**

https://www.griffin.uga.edu/news/peanut-mycotoxin-and-innovation-lab

7. **International Food Policy Research Institute (IFPRT)**

https://www.ifpri.org/donor/cgiar-research-program-agriculture-nutrition-and-health-a4nh-led-ifpri

8. **Consultative Group for International Agricultural Research (CGIAR)**

https://cgiar.org/

9. **CGIAR** (formerly the **Consultative Group for International Agricultural Research**) is a global partnership that unites international organizations engaged in research for a food-secured future. CGIAR research is dedicated to reducing rural poverty, increasing food security, improving human health and nutrition, and ensuring sustainable management of natural resources. It is carried out by 15 centers that are members of the CGIAR Consortium, in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations, and the private sector. It does this through a network of 15 research centers known as the CGIAR Consortium of International Agricultural Research Centers

10. **Biosciences eastern and central Africa - International Livestock Research Institute (BecA - ILRI) Hub**

https://hub.africabiosciences.org/

11. **Capacity and Action for Aflatoxin Reduction in Eastern Africa (CAAREA)**

https://cgspace.cgiar.org/handle/10568/33664

12. **CGSpace: A Repository of Agricultural Research Outputs**

https://cgspace.cgiar.org/

Communities in CGSpace: Select a community to browse its collections:

- AfricaRice [96]
- Africa RISING [1204]
- AgriFood Chain Toolkit [103]
- Animal Genetic Resources Virtual Library [1065]
- Bioversity International [3642]
- Center for International Forestry Research (CIFOR) [5933]
- CGIAR Antimicrobial Resistance Hub [26]
- CGIAR Challenge Program on Water and Food (CPWF) [2206]
- CGIAR Collaborative Platform for Gender Research [915]
- CGIAR Collective Action in Eastern and Southern Africa [47]
- CGIAR Global Mountain Program [8]
- CGIAR Platform for Big Data in Agriculture [56]
- CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) [4292]

- CGIAR Research Program on Livestock [761]
- CGIAR Research Program on Roots, Tubers and Bananas (RTB) [1807]
- CGIAR Research Program on Water, Land and Ecosystems (WLE) [2179]
- CGIAR Research Programs and Platforms [2360]
- CGIAR System [4479]
- CGIAR System-wide Livestock Program [231]
- Feed the Future Accelerated Value Chain Development program in Kenya (AVCD) [53]
- Feed the Future Innovation Lab for Small-Scale Irrigation [11]
- Feed the Future Sustainable Intensification Innovation Lab [20]
- IGAD Livestock Policy Initiative [42]
- International Center for Agricultural Research in the Dry Areas (ICARDA) [206]
- International Center for Tropical Agriculture (CIAT) [13156]
- International Institute of Tropical Agriculture (IITA) [6042]
- International Livestock Research Institute (ILRI) [17213]
- International Potato Center (CIP) [1628]
- International Water Management Institute (IWMI) [6897]
- Pan-Africa Bean Research Alliance (PABRA) [438]
- Technical Centre for Agricultural and Rural Cooperation (CTA) [15151]

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