Building an Aflatoxin Safe East African Community

Technical Policy Paper 5

Aflatoxin and Postharvest Losses

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Cover: Typical maize storage bin used in East Africa. *Joseph Atehnkeng, IITA.*

Foreword

Postharvest losses throughout the East Africa region are significant. Losses can be identified in four key areas:

1) *food security,* from a reduction in the availability of calories and other essential nutrients, often combined with an increase in local prices due to supply deficits;

2) *trade,* from the closing of certain markets through an inability to gain entry based on lack of capacity to meet regulatory or buyer requirements;

3) *environmental*, from the generation of agricultural or solid waste; and

4) *public health,* from the population's consumption of unsafe products that can lead to morbidity and mortality.

Under a regime in which crops and food products exceeding tolerable levels for aflatoxin contamination were removed from circulation, the results would be startling within the region. On-farm consumption of aflatoxin-prone foods, notably maize, groundnut, cassava, and milk, would likely suffer substantial reductions, possibly resulting in serious caloric and protein deficits. Within the confines of a strict quality control protocol, the proportion of rejected commodities along the value chain could soar. Millers and food processors would face input shortages, while urban consumers could face irregular supplies of staple foods that cost more. The disposal of the condemned crops and food products could also pose a potential environmental hazard.

Aflatoxin can colonize more than 40 raw agricultural commodities and their byproducts. These include staple cereals such as maize, rice and sorghum; oilseeds such as sesame and cottonseed; groundnuts and the main pulses; various tree nuts; copra from coconut; cassava and other root crops; several vegetables; and even coffee, cocoa, tea, and sugarcane. Through contaminated feed, aflatoxins may affect livestock such as poultry, swine, cattle, horses, household pets, and many aquaculture species. Derived products such as eggs, butter, milk, and other dairy items can also become contaminated.

This paper provides an overview of postharvest losses across the East Africa region for seven of the most aflatoxin-prone crops also deemed to be of economic and nutritional importance: rice, maize, sorghum, groundnut, pulses, cassava, and sweet potatoe. Recovering crops currently forfeited due to postharvest losses, often reaching as high as 30 percent each season, could play a significant role in improving rural livelihoods and household food security, strengthen regional trade, and promote a more efficient agricultural economy throughout East Africa. Sound aflatoxin control policies and programs can be a major contributor to the reversal of these losses.

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Executive Summary

This document focuses on the junction between aflatoxins and postharvest losses, which together can: a) lessen the availability, marketability, or suitability for consumption or processing of affected agricultural products; b) contribute to pathology in humans, animals, and plants; and c) diminish the nutritional value of food and feedstuffs or impede the uptake of nutrients from those products.

Aflatoxins are toxic, carcinogenic, and mutagenic compounds formed by more than a dozen different fungi. *Aspergillus flavus* is the most important species for aflatoxin impact on agriculture, followed by *Aspergillus parasiticus*. The secondary metabolite, aflatoxin B_1, is especially worrisome because it is widely regarded as the most potent naturally occurring carcinogen and is synergistic for hepatocellular carcinoma (HCC) in people who are hepatitis B positive. However, aflatoxin M_1 also passes through the placenta to the fetus, and is later conveyed from lactating mother and to child during breastfeeding.

Since they are immunosuppressive, aflatoxins are suspected of contributing to vulnerability to communicable diseases such as malaria, tuberculosis, HIV, and hepatitis C, as well as a multitude of infectious diseases. Moreover, there is increasing concern that chronically high levels of aflatoxin may affect gut health, hence nutrient absorption, and may contribute to high mortality among children younger than five years of age. Additionally, since contaminated raw materials can have serious impacts on the health, productivity, and welfare of both terrestrial and aquatic species of economic significance, the poultry, swine, milk, aquaculture, and pet industries consider aflatoxins to be a serious hazard, as does the extension and feed industry.

Aspergillus is found in tropical and subtropical areas globally. Although not every *Aspergillus* isolate produces aflatoxin, toxigenic strains predominate in warm, dry areas. Growth is optimal when temperatures are between 26°C and 38° Drought, nutrient, or night temperature-stressed plants are more susceptible to colonization. Given the variability of weather, occurrence of the fungi is not constant over time. *Aspergillus* species are ubiquitous in the soil, trees, and rotting vegetation, while reservoirs of water and already infected products serve as repositories. While the prevalence of *Aspergillus* in East Africa has never been mapped, both the locational and environmental conditions in much of that region are conducive to its growth. *Aspergillus* can affect several dozen crops. For practical reasons, this report focuses on just seven that have economic significance to the East African Community (EAC): maize, rice, sorghum, groundnuts, pulses, cassava, and sweet potato. These were selected because of their importance in terms of area planted, production, exports, and/or apparent consumption. The crops are all widely grown in EAC countries, although in different proportions that reflect differing agro-ecology, farmer, and consumer preferences, relative profitability and

risk, and to some extent, tradition. United Nations Food and Agriculture Organization (UNFAO) data (FAOSTAT) for 2013 shows more than 350,000 hectares (ha) planted to both pulses and cassava in Burundi; more than 1.5 million ha of maize and pulses in Kenya; 300,000 ha of maize and nearly 500,000 ha of pulses in Rwanda; 2 million ha of pulses and 4 million ha of maize in Tanzania; and 1 million ha of maize and 1.2 million ha of pulses in Uganda. FAOSTAT also shows that cassava and sweet potato predominate in harvested volume in Burundi; maize and cassava in Kenya; cassava and sweet potato in Rwanda; cassava and maize in Tanzania; and cassava, maize, and sweet potato in Uganda. Uganda is the leading exporter of these crops (especially maize), followed by Tanzania (maize) and Kenya (sorghum).

Significant exposure through dietary intake by humans and animals is necessary for aflatoxins to become a public health problem. The World Health Organization's (WHO's) Global Environment Monitoring System Food Contamination Monitoring and Assessment Program (GEMS) has grouped countries for analytical purposes. In their initial typology, Burundi, Rwanda, and Uganda were placed in Cluster A, which is characterized by high consumption of roots/tubers (especially cassava and sweet potato) and fruits (especially bananas and plantains). Kenya and Tanzania were placed in Cluster I, characterized by high consumption of cereal grains (especially maize). Since maize is widely regarded as the food security crop most susceptible to infestation and contamination, it would seem that Kenya and Tanzania should be especially concerned. Yet high consumption of groundnuts—the second most susceptible crop—in all EAC partner states and of different mixes of the other susceptible crops as well, to treat this as a region-wide challenge.

While a few crops present significant risk as discrete commodities, total dietary intake of products susceptible to aflatoxin contamination matters even more. A recent journal article (Palliyaguru 2013) estimates the following exposure levels in nanograms per kilogram of body weight per day (ng/kg bw/day) in the EAC countries based on the GEMS/Food data: Burundi 10-180; Kenya 3.5-133; Tanzania 0.02-50; Uganda 10-180; Rwanda (no data). Specific studies of exposure based on biomarkers suggest higher levels still. Given such ranges, the cautionary principle would suggest that serious policy attention be given by all EAC partners to the aflatoxin challenge.

Although it is often said that aflatoxins represent a postharvest problem, *Aspergillus* is a soil-borne organism, so in fact the challenge begins before land preparation even starts. Fungi disperse through "conidiation." Conidia are asexual, non-motile spores. Wind is believed to be the main dispersal vector but conidia may also be transported by animals.

Aspergillus can infect most susceptible products all along their respective supply chains. If contamination cannot be avoided or contained before food and feed products first become available for use, postharvest loss (PHL) mitigation takes on greater importance as a means of limiting exposure and adverse impacts. In practice, however, since supply chains are continuous, it is somewhat artificial to focus specifically on the postharvest stage.

In fact, there is disagreement within the community of practice in PHL reduction regarding when and where the "postharvest" phase actually begins and ends. This report selectively considers the following loss/intervention points: postproduction; harvesting; field drying; platform drying; threshing/shelling; winnowing; transport to packing shed; storage at the farm level; grading and sorting; handling and transport to first receiver; storage and handling at the trader level; processing; downstream storage; and distribution.

There is also less than full agreement on the best definition and proper indicators of loss, so it is difficult to compare studies or reach aggregate conclusions. Over the past several decades, PHL reduction work has tended to focus on physical losses alone, because they are more tangible and generally more controllable. Yet there are really two main categories of loss, which interact: quantity and quality.

A distinction can also be drawn between the two main types of loss: financial and economic. The former affects private welfare while the latter affects public welfare. Sellers of agricultural products may incur *financial* loss either:

1. When anticipated or potential sales revenue is not received due to volume or value decline or both; or
2. When additional transaction costs (such as product withdrawal and destruction) are incurred; or
3. When there is damage to a brand caused by food recalls.

On the other hand, society as a whole may suffer *economic* loss in four areas of public policy concern:

1. In *food security*, from a reduction in the availability of calories or nutrients and/or an increase in local prices due to supply deficits;
2. In the *trade* arena, from the closing of certain markets (or inability to gain entry) based on incapacity to meet regulatory or buyer requirements;
3. In the *environmental* area, from the generation of agricultural or solid waste; and
4. In the *public health* arena by unsafe products that lead to illness and attendant medical costs.

Given all of this, the challenge of dealing with the intersect between aflatoxin mitigation and PHL reduction for selected crops of interest comes down to:

- Identifying those steps in the supply chain from post-production (while product is still in the field) through distribution in which losses attributable to aflatoxin contamination are known or likely to be most significant;
- Examining currently used PHL reduction measures at those steps to assess (or estimate) whether they may have a positive or negative impact on aflatoxin-associated loss;
- Considering promising new or little-used PHL reduction measures at those steps that might be beneficial from the optic of aflatoxin-associated loss;
- Identifying where further action-oriented research is needed to better link PHL reduction with aflatoxin mitigation; and
- Recommending to decision-makers in the public and private sector as well as donor agencies what changes (if any) should be made with respect to regulations, prevailing agricultural practices, or technology generation and transfer programs in order to make better use of postharvest interventions to respond to the aflatoxin problem.

Yet, even before these steps can be taken, prioritization is needed to conserve resources and achieve the best developmental and commercial returns on investment in risk management. Choices must be made with regard to: relative importance of objective functions; geographic domain; target crops; points of intervention; mix of interventions; and private versus public roles.

Based on the analysis conducted here, as well as the results of the EAC partner state regional expert working group on October 8-10, 2014, the authors of this paper recommend that EAC partner states:

a) Give most weight to area planted to aflatoxin susceptible crops and to apparent national consumption--and less to exports, because the latter will tend to improve if better practices are applied domestically.

b) Treat aflatoxin contamination as an all-EAC challenge, with implications for large swaths of each partner country, even if the mix of affected crops varies within and among countries.

c) Starting with known and suspected hotspots, where the need for mitigation is obvious and widely supported, create a baseline and monitoring system to assess progress, then expand its reach as resources allow.

d) Give the greatest urgency to maize and groundnuts, but also devote significant attention to sorghum, sweet potato, and pulses wherever they are widely grown.

e) From the agricultural perspective, concentrate more on prevalence and mitigation; from the nutrition perspective, more on awareness and food preparation (e.g., cassava chips, garri, kulikuli); and from the health perspective, more on product safety testing and treatment of morbidity.

f) Support more research on aflatoxin management technology development and diffusion, including research in cross-cutting issues such as climate change, gender, and HIV/AIDS.

g) For prevention purposes, support and expand the use of proven biocontrol approaches and products, including not only AflaSafe,™ but also testing others such as Trichoderma viridae and compost-enriched with Pseudomonas aeruginosa.

h) Within the priority commodity systems, take a whole chain approach that begins with good agricultural practices (GAP), extends through good handling practices (GHP) and continues through to good manufacturing practices (GMP).

i) Invest more in postharvest loss reduction than in the past, but define it broadly to start with preharvest preparation and continue through to handling by traders and use by processors.

j) Within the postharvest management segment, broadly defined, focus interventions on locally adapted and validated best practices in harvesting, drying, sorting, and storing.

k) For storage in particular, test and act on the propensity to adoption and relative cost-effectiveness (in terms of loss prevention generally and aflatoxin control particularly) of traditional methods, improved equipment such as new generation metal silos, and hermetic storage solutions.

l) Invest more in behavior-change communications, creating and spreading messages that have been customized by gender, language, and literacy levels.

m) Strive to raise the level of awareness among small farmers, rural households, vulnerable groups, actors within affected supply chains, and providers of technology generation and transfer services.

n) Promote a national campaign against aflatoxin contamination that would involve all major stakeholder groups, whether public, private, civil society, or academic.

o) Consider asking the African Postharvest Loss Information System (APHLIS), to use the architecture developed for tracking PHL generally to also monitor and disseminate geospatial and longitudinal data regarding aflatoxin "hotspots" and outbreaks.

p) Actively support efforts under the Partnership for Aflatoxin Control in Africa (PACA) to serve as the knowledge platform of choice for capturing, organizing, and disseminating technical materials, guides, lessons learned, events, etc.

Introduction

This report considers the intersection between aflatoxins and PHL. That juncture matters greatly to economic and social development in the EAC partner nations and many other developing countries, because it straddles the fields of agricultural development, health, and nutrition. Separately and together aflatoxin contamination and PHL can: a) lessen the availability, marketability, or consumability of food and feed; b) contribute to human, animal, and plant pathology, often resulting in morbidity and sometimes even mortality; and c) diminish the nutritional value of food and feedstuffs or impede their uptake by living beings. If not addressed, these major challenges to food/feed safety, quality, and availability can also undermine trust in both the private sector as provider and the government as protector and regulator. In sum, aflatoxin contamination and PHL together can reduce the realization of human potential, affect the quality of life, lower incomes, disrupt value chains, impede economic growth, and undercut resilience at the individual, household, community, and national levels.

Understanding Aflatoxins

Aflatoxins are a set of toxic, carcinogenic, and mutagenic compounds, formed by two fungi, primarily *Aspergillus flavus* and secondarily *Aspergillus parasiticus,* under certain conditions. Not all strains from these fungi are toxigenic, and those that are toxigenic may generate different levels of aflatoxin. Toxigenic *A. flavus* isolates generate aflatoxins B_1 and B_2, while toxigenic *A. parasiticus* isolates form aflatoxins B_1, B_2, G_1, and G_2. Aflatoxin B_1 is of particular concern because it is widely regarded as the most potent naturally occurring carcinogen--International Agency for Research on Cancer (IARC) Class 1.

Animal species respond differently to the chronic and acute toxicity of aflatoxins. Environmental factors, exposure level, duration of exposure, age, and health all influence susceptibility. The relative susceptibility of humans is unknown, but epidemiological studies in Africa and Southeast Asia, where there is a high incidence of hepatoma, do show an association between cancer incidence and the aflatoxin content of the diet (FDA 2013).

Aspergillus is commonly found in a broad band that circles the globe about 35 degrees latitude north and south of the Equator. It therefore threatens not only most developing countries, but also many emerging economies and areas of many developed countries as well. While it is generally viewed as under control in the United States, aflatoxins have been identified there mostly in maize and maize products, groundnuts and groundnut products, cottonseed, milk, and tree nuts. The European Union (EU) also experiences problems at times, as was shown by the 2012 findings of excessive levels of aflatoxins in milk products from Serbia.

Many observers suspect that global warming, with associated changes in average surface temperatures, as well as more extreme and frequent weather events such as droughts and floods, will tend to expand the band of prevalence, which is likely to exacerbate what is rapidly becoming a global problem.

The United Nations Food and Agriculture Organization (FAO) has asserted that as much as 25 percent of the global food supply may be lost during postharvest handling, and storage, and aflatoxin contamination is a major contributing factor for many crops (FAO 1997). As many as 5 billion people in developing countries worldwide may risk chronic exposure (Shephard 2003; Williams, Phillips et al. 2004). IITA estimates that globally, about US$1.2 billion in international commerce is lost annually due to aflatoxin contamination, with African economies losing US$ 450 million each year (IITA 2013).

Environmental factors, some of which are hard or impossible to control, especially for small-scale farmers, can have a major impact on prevalence. In addition to the genotype of the crop planted and soil type, minimum and maximum daily temperatures as well as daily net evaporation are known risk factors (Wilson and Payne 1994; Ono, Sugiura et al. 1999; Brown, Chen et al. 2001; Bankole and Mabekoje 2004; Fandohan, Gnonlonfin et al. 2005). Water-stressed, nutrient-stressed, or temperature-stressed maize or groundnut plants are more susceptible to colonization by *A. flavus* or *A. parasiticus* (Guo et al. 2008; Horn 2007; IARC 2012; Wu et al. 2011). Although not every *Aspergillus* isolate produces aflatoxins, toxigenic strains predominate in warm, dry areas (Fisher & Henk 2012; Moore 2010; Olarte et al. 2012).

While the prevalence of *Aspergillus* spp.in East Africa has never been mapped (and it may not be possible to do so given the geographic area, variability of conditions, and resource constraints) environmental conditions over most of the EAC domain are suitable to *Aspergillus* occurrence. Some "hotspots," such as portions of the Eastern and Central Provinces of Kenya, have already been documented (CDC 2004), but others are presumed to exist.

Aspergillus species are ubiquitous in the soil, trees, and rotting vegetation (where they completes the nitrogen cycle), while reservoirs of water and already infected products serve as repositories. The densities of propagules are much higher in cultivated fields and desert ecosystems than in forests and savannah (Horn 2003; Klich 1992). Growth is optimal when temperatures are between about 26˚C (80˚F) and 38˚C (100˚F), with relative humidity around 85 percent. For all of these reasons, there is *spatial variation* within each EAC country in terms of both the prevalence of *Aspergillus* and in their formation of aflatoxins. For example, analysis of maize kernels from the three main agro-ecological zones of Uganda showed significant differences (Kaaya et al. 2006): the Mid-Altitude (moist) zone showed the highest aflatoxin contaminated samples (83 percent), with mean aflatoxin levels of 9.7 parts per billion (ppb); the Mid-Altitude (dry) zone showed 70 percent of samples contaminated, with a mean level of 7.7 ppb, while kernels sampled from the Highland zone had the fewest contaminated samples (55 percent) and mean levels of 3.9 ppb. Moreover, temporal variation occurs as the seasons and weather change, which can add to water or temperature stress and affect the severity of insect attack that paves the way for fungal infection.

Aspergillus can colonize more than 40 raw agricultural commodities. These include: staple cereals such as maize, rice and sorghum; oilseeds such as sesame and cottonseed; groundnuts and the main pulses; various tree nuts; copra from coconut; cassava and other root crops; several vegetables; and even coffee, cocoa, tea, and sugarcane. Through contaminated feed, aflatoxins may also affect livestock (poultry, swine, cattle, horses, household pets) and aquaculture species. Derived products such as eggs, peanut butter, milk, and other dairy items can also become contaminated.

Although often considered a postharvest problem, the aflatoxin challenge begins even before crop production. Colonies of *Aspergillus* are often found in decomposing organic matter from prior harvests or fallow areas, as well as in the soil of regularly cultivated fields. The fungi grow in or on many plant and tree species, whether indigenous or introduced. Water bodies can serve as reservoirs. Since *Aspergillus* is highly aerobic, the fungus is ubiquitous in oxygen-rich environments, commonly growing as mold on the surface of a suitable substrate where there is oxygen tension. On the other hand, the fungus exhibits respiratory flexibility, and can use anaerobic respiration (Willger et al. 2009).

Fungi disperse in the field through spread of conidia, which are asexual[1], non-motile spores. "Conidia" comes from the Greek word for "dust", so it is not surprising that wind is believed to be the main vector. However, conidia may also be transported by birds, rodents, and other animals, by humans, and perhaps even inanimate objects. Infected kernels of maize or groundnuts may also harbor very high concentrations of *Aspergillus*; indeed initially infected sites can accumulate aflatoxin and serve as reservoirs. In subtropical areas, apparently healthy kernels can be infected (Miller 1992; Siriacha et al. 1991), which means that aflatoxin concentrations can rise quickly in storage even when little or no contamination was perceived in the product to be stored. Conidia are temperature-resistant, and can persist from one season to the next, even one year to the next.

Aflatoxins can and do emerge all along the supply chain for most susceptible products (Wilson and Payne 1994). This fungal threat may first become evident during production, sometimes obvious in moldy unshelled groundnuts, sometimes hidden inside a single kernel of maize. High prevalence has been associated with weed competition, poor fertility, high crop

[1] Although *A. Flavus* was long believed to have no sexual state, in 2009 heterothallic outcrossing of nuclei from two different individuals was discovered when strains of opposite mating type were cultured together under appropriate conditions.

densities, insect or mechanical damage, and certain crop-specific growth stages. Once present, it typically grows during preharvest activities, and continues during the harvest itself as well as subsequent routine postharvest processes such as plucking (of groundnuts) or shucking (of maize). Inappropriate handling, storage, and transit facilities, equipment, or practices can worsen the situation. Artisanal processing, as well as home-based food preparation, can sometimes accelerate fungal growth or the generation of toxins.

The community of practice emerging around aflatoxin mitigation generally agrees that the best remedy is prevention. That in turn depends on:

a) Increased political will;

b) Greater awareness and understanding of the fungus itself, co-occurrence with other fungi, interactions with host plants, and the etiology of the toxins;

c) Widespread adoption of good agricultural practices (GAP) that promote healthy plants while minimizing the effects of harmful biotic stresses (e.g., pests) and abiotic stresses (e.g., droughts);

d) Extension of GAP into the realm of postharvest handling, rather than stopping at the farm gate; and

e) improving the availability, cost, and utilization of proper testing methods.

Biocontrols are viewed by some as the most promising means of prevention, especially since some remain effective even after harvest and in storage, and may continue to have beneficial effects across seasons.

Yet the scope and magnitude of the problem, uncertain science, the state of sampling and testing, the cost and complexity of solutions, knowledge and resource limitations among farmers and institutions, and the absence of market signals all conspire to prevent satisfactory pre-farm-gate management across all commodities and geographies of interest. If the hazard cannot be avoided or contained before food and feed products first become available for use, PHL mitigation takes on greater importance.

This report examines postharvest practices relevant to seven aflatoxin-susceptible crops of food security interest to the EAC: maize, sorghum, rice, cassava, groundnuts, pulses, and sweet potato. Not all postharvest practices found for these crops within the EAC partner countries have a proven effect in terms of prevention or mitigation of aflatoxin contamination. On the other hand, not all best postharvest practices found globally for these crops are commonly used in the EAC. Further research is needed on what works for this challenge, whether already present in the region or not, and then much broader technology diffusion, adoption, and impact verification should be supported.

Knowledge Platform

The Meaning and Significance of "Loss"

The word "loss" as applied to food production, postharvest handling, and marketing is more complicated than it seems. Over the past year, some advocates for the food loss and waste movement have tended to treat as a food loss any diversion to other purposes of products that could have been consumed by humans, even if the diversion involved feeding animals or fish that would ultimately be consumed as human food. Agricultural economists tend to disagree, and smallholder farmers may not view diversion of some of a season's crop to feeding say, home-grown poultry, as a loss at all, but rather as a blessing.

For purposes of this paper, the authors define "loss" as any reduction in the volume or value of agricultural products of interest that are available for consumption or sale. Since consumption can occur anywhere, and sales mostly occur at common points of exchange (farmgate, assembly point, processing facility, wholesale market, or retail), the place of loss matters for analytical purposes. And since prices vary over time, it also makes a difference to valuation whether the loss occurs right after a bumper harvest when prices are low, or during lean months when prices are high.

Mitigating loss depends on measuring it before and after intervention measures. Yet the metrics remain problematic and imperfect, which makes it difficult to compare studies or reach aggregate conclusions, whether for analysis, programming, or evaluation.

Over the past several decades, development work on PHL reduction has tended to focus on physical losses alone—measured as dry matter in cereals and other relatively non-perishable crops, but harder to define with fresh produce—because they are more tangible and more controllable.

Yet there are really two main categories of loss which interact, quantitative and qualitative losses. *Quantitative losses* in the mass of harvested crops can occur for many reasons, such as adverse weather, pests and disease, spillage, mechanical damage, labor shortages, lack of credit, limited storage capacity, poor handling, or diversion of product. *Qualitative losses* occur when crops lose value because either: a) quality or condition[2] as perceived/required by the buyers has declined; b) preparations for marketing, such as cleaning, sorting, and grading have not been done properly) nutrient content has been compromised; d) bioavailability of nutrients has lessened; and) decay, contamination, or adulteration has made the product unfit for its intended purpose.

[2] Fresh produce is especially susceptible to decline in condition due to maturation and senescence, micro-bacteriological contamination, or inappropriate pesticide residue levels.

There are also two types of loss, distinguishable by whom they impact. Financial losses (to sellers of agricultural products) occur in agricultural commerce primarily when anticipated or potential sales revenue is not received due to either volume and/or value decline, and secondarily when additional transaction costs, such as product withdrawal and destruction, are incurred.

The proximate causes of financial loss can vary widely. Examples include: forced sales at low harvest glut prices in order to avert quantity or quality PHL during storage; insufficient availability of transportation and storage; limited access to off-farm warehousing opportunities that offer cash advances pending final sales; rejection at the border due to sanitary and phytosanitary standards issues (within the World Trade Organization (WTO); or food safety questions.

Economic losses to society may arise directly from the closing of certain markets (or inability to gain engry) because of the value chain's incapacity to meet regulatory or market requirements, such as use of Hazard Analysis and Critical Control Points (HACCP) in the processing of Nile perch intended for the EU market. They may also arise indirectly when negative spillovers affect human, animal, or plant health. Examples include medical and funeral costs incurred when unsafe products or processes cause morbidity or mortality, for example, from dangerously high levels of mycotoxin contamination.

The Meaning and Significance of "Postharvest"

The term "postharvest" is widely used. But, like the term "loss," it is not easy to act on with precision for various reasons.

1. When harvest actually occurred or should have occurred is not always obvious. Theoretically, harvest should begin when either the crop has reached physiological maturity or when it needs to be harvested in order to satisfy marketing requirements (such as fulfillment of a contract, maximizing sale price, or meeting the preferences of retailers or consumers). Yet, in actual practice, the time of harvest is sometimes advanced or delayed due to adverse weather, pest/disease occurrence, shortages of farm labor, lack of storage capacity, response to changing prices, need for liquidity, and so on. Variations may produce either losses or gains.

2. The act of harvesting is not always fully completed in a discrete step, as when maize is left on the stalk and simply turned downward.

3. Harvesting methods for a particular crop may vary, not only manual versus mechanized, but also according to tools employed and common practices, and they usually do vary among crop categories.


Threshing groundnuts following harvest. IITA

4. Many decisions and agricultural activities that actually take place before the harvest can result in losses after harvest. Generally, rain-fed production entails more PHL than systems that feature good irrigation and drainage, because the amount of moisture reaching the root zones has little or no relationship to plant needs. Although selection of improved germplasm may raise marketable yields and produce more uniform and well-timed harvest, some improved varieties are actually less resistant to pests and disease, both in the field and during storage. For some crops, planting density is a factor that affects not just gross yields but the extent of damage from pests or disease. The timing of planting may also matter, especially when very dry or very wet conditions are likely to occur at critical moments in the plant's life cycle.

5. There is great variation in what happens after the harvest to make a product ready for consumption, storage, processing, or distribution. Maize must be dehusked and dried, and at some point the grains may need to be removed. Groundnuts need to be pulled, dried, and shelled. Cassava needs to be processed rapidly. And so on with each crop.

6. There is no consensus within the PHL research community of practice regarding when and where the "postharvest" phase ends. Is it: when products are turned over to a first handler, likely a trader? When they have been aggregated, sorted and graded, and packed? Or not until actually delivered to a buyer in the local market, a processing facility, or supermarket chain? If any of the actors along the supply chain rejects a portion of the volume offered, or applies a price penalty, most observers would agree that the resulting quantitative or qualitative losses should be counted as part of PHL.

Delimiting Postharvest Loss Analysis

Fortunately, yet gradually, PHL practitioners seem to be converging on the idea that a reasonable beginning and end to the postharvest phase should be defined and agreed to, so that better and more comparable metrics can be applied across crops and in different contexts. Building on a scheme developed under APHLIS, this report treats the beginning of the PHL spectrum as the point at which preparations for harvest occur, and the end as the point at which distribution to retailers has occurred.

These are the main steps:

- Post-production
- Harvesting
- Field drying (when applicable)
- Platform drying (when applicable)
- Threshing/shelling (when applicable)
- Winnowing (when applicable)
- Transport to homestead
- Storage at the farmer level
- Grading and sorting
- Handling and transport to first receiver
- Storage and handling at the trader level
- Processing (when applicable)
- Downstream storage (when applicable)
- Distribution to retail or foodservice buyers.

Defined this broadly, PHL captures a very large share of total food loss, although it does not include food waste (which is mainly caused by voluntary withdrawal or disposal, whether or not actually necessary).

There is a longstanding consensus among experts and practitioners that proper harvesting, sorting, drying, and storage are especially critical to effective PHL management. Yet how best to accomplish those purposes varies by crop and product, intended use, and destination market, as well as the resource endowment of actors involved in different value chains.

Choosing when to harvest is more critical for some crops (e.g., groundnuts) than others (e.g., cassava), but in all cases factors to consider include stage of physiological maturity, moisture levels for the product itself, intended handling and use, and availability of required storage. How to harvest also matters greatly when there are real possibilities of mechanical damage that can not only lower perceived market value but open pathways for infection by fungi such as *Aspergillus* or by bacteria or virus.

Similarly, while sorting done right can help reduce human and animal exposure for many susceptible commodities, unresolved issues remain with respect to thresholds and mechanisms for culling, the fate and transport of rejects, compensation for unmarketable volumes, and how best to deal with contaminated product that is retained for home consumption.

The Mycotoxin Challenge

This paper focused on aflatoxins, which are just one category of mycotoxins. *All mycotoxins represent food safety threats*. Yet they vary in terms of toxicity, prevalence, crops/products affected, and the nature and extent of negative impacts. Aflatoxins are the most serious, because:

1. They have multiple impacts on human and animal health and nutrition;
2. There are no effective treatments for aflatoxin poisoning in humans, and
3. They have negative economic and social consequences for agriculture, commerce, and trade.

Yet they should not be the only concer: many different mycotoxin-producing fungi may be present in the same crop; one species of fungi may produce many different mycotoxins; and the same mycotoxin may be generated by several species of fungi (Bankole and Mabekoje 2004; Fung and Clark 2004; Speijers and Speijers 2004).

- *Ochratoxins*, which mostly affect cereals, coffee beans and grapes, are not only recognized as nephrotoxins and teratogens, but they also have immunosuppressant effects and are suspected to be carcinogens.
- *Trichothecenes* (which includes deoxynivalenol, popularly abbreviated as DON or formally known as vomitoxin) most affect maize, wheat, barley, oats, rye, and rice, and present health threats from cytotoxicity, protein synthesis inhibition, and emetic toxicity.
- *Fumonisins*, which mostly affect maize, wheat, and other cereal grains, are known hepatoxins as well as potent cancer promoters. Leading mycotoxicologists around the world increasingly argue that where maize is particularly important to the diet, efforts to mitigate aflatoxin exposure should also take into account and address the likely presence of fumonisins, which appear to act synergistically with aflatoxins in contributing to HCC.

This maize cob is visibly infected with the fungi Aspergillus (and perhaps Fusarium as well, which produces the fumonisin mycotoxin) but aflatoxin contamination can also remain hidden in a single kernel. IITA.

Situational Analysis

Not all of the dozens of crops for which the global literature shows susceptibility to aflatoxin contamination are equally important to food and nutrition security in the EAC countries. Based on various ranking criteria, this paper focuses on: maize, rice, sorghum, groundnuts, pulses, cassava, and sweet potato.

Susceptibility to Aflatoxin Contamination of Selected Crops

Whether or not consumption of any particular commodity represents a risk factor is determined in part by how susceptible to contamination the commodity in question tends to be.

Aspergillus colonies grow routinely in carbon-rich substrates like monosaccharides (e.g. glucose) and polysaccharides (e.g. amylose from starch). The fungi favor situations where there is a high osmotic concentration (e.g. high sugar or salt). However, the literature suggests not only inter-species differences in susceptibility, but also differences among cultivars within a given species, so it is difficult to be precise. While there is no single source of comparative data on susceptibility for the seven crops selected here for consideration--a research gap that should filled--there are various important reference documents in the broader literature that compare at least two at a time.

For example, Bandyopadhyay et al. (2007) found significantly higher risk in maize than sorghum in Nigerian cereals: "Maize was significantly more heavily colonized by aflatoxin-producing *Aspergillus* spp. than either sorghum or millet, with overall aflatoxin levels being correspondingly higher. On average, Nigerians consume 138 kg of cereals annually. If the primary cereal is sorghum instead of maize, then the risk of aflatoxin-related problems is reduced 4-fold; if it is pearl millet, then the risks are reduced 8-fold." While these findings are about a single country in West Africa, the logic of the analysis is applicable elsewhere and certainly to East Africa.

There are also numerous references in the literature to significant aflatoxin contamination in groundnuts in Africa, for example: Senegal (Aly 2005); The Gambia (Colley 2013); Mali (Osiru 2013); Nigeria (Bandyopadhyay et al. 2013); Ghana (Sudini 2013); Kenya (Mutegi et al. 2009); Burundi; Uganda (Kaaya 2006); and Tanzania (Mponda 2012). Together they suggest that this crop is probably second among the seven in terms of susceptibility.

Published references to contamination in sweet potatoes in Africa are modest yet thought-provoking. Various researchers as well as the Comprehensive Africa Agriculture Development Program (CAADP) have given it some priority in Uganda (Kaaya 2006; NEPAD 2014). Jonathan et al. (2012) analyzed samples of *Ipomea batatas* chips, and although they found no aflatoxins in the fresh chips, the levels rose significantly over a nine-month period as the product was stored.

Aflatoxin contamination of pulses, which include common beans, has been found with some frequency in Africa and South Asia. In a nationwide analysis of food commonly consumed in Uganda, Kaaya (2006) found beans to have the highest levels among the sampled items, followed by maize and sorghum. Seenapa (1983) investigated the susceptibility of 22 cowpea seed lines to *Aspergillus* infection and aflatoxin production, and found that all were susceptible to some degree, especially to AFB (B_1 + B_2).

Many fewer references to aflatoxin in cassava appear in the literature. Examples include: Nigeria (Ogiehor et al. 2007), and Tanzania and Republic of Congo (Manjula et al. 2009). Since fresh cassava is highly perishable and barely traded, most are concerned with contamination in artisanally processed products such as chips, *garri*, or *kulikuli*. Examples include: Uganda (Kaaya and Eboku 2010); Benin (Gnonlonfin et al. 2011); Nigeria (Adegoke et al. 2006), Malawi and Zambia (Chiona et al. 2014). On balance, mycotoxicologists do not see cassava as presenting a major threat in terms of aflatoxin contamination, although periodic testing of processed products may be warranted.

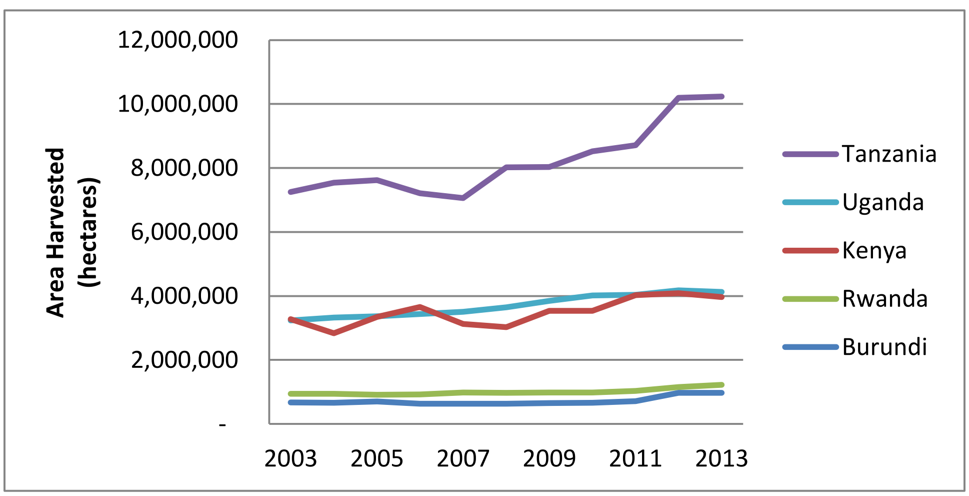
Rice presents a different situation, in that aflatoxins do not appear during the production stage. While there are few references in the literature for Africa, more appear for Asia, so the problem is not trivial.

Given the literature review conducted, as well as the opinions of various world-renowned authorities who were consulted personally, it would seem that EAC should give first priority to PHL/aflatoxins in maize, and second priority to groundnuts, even though production and trade is much smaller. After those crops, sorghum, pulses, and sweet potatoes form a second tier that also merits attention, but selectively, depending on area planted and consumption. Cassava and rice seem to warrant relatively less attention and investment.

Share of Food Supply for Susceptible Food Security Crops

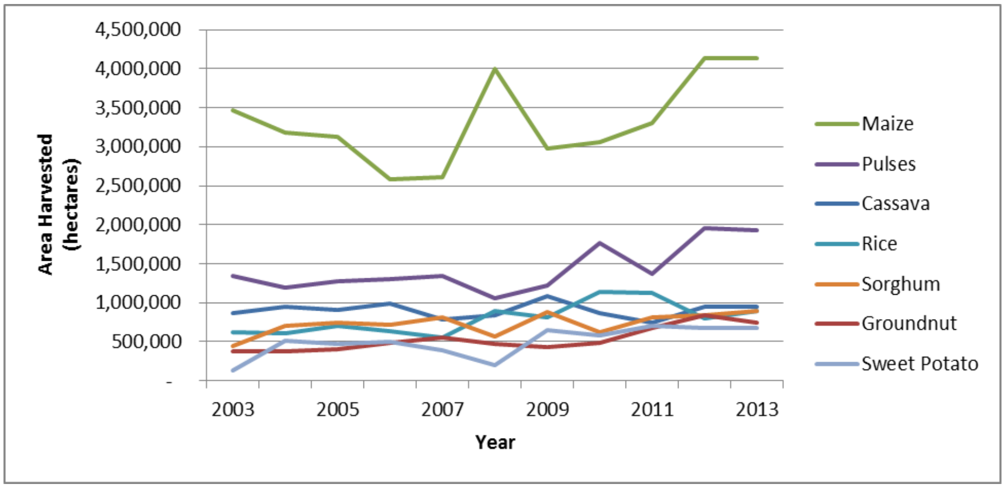
A second factor that contributes to risk is share of food supply, which can be defined in various ways. Based on the latest available FAOSTAT data, the discussion below considers trends in EAC production, availability, export, and consumption for the seven crops.

Figure 1 shows the total area harvested within EAC. Clearly, if all seven crops were equally susceptible, and if prevalence were the same across and within each EAC partner country (though neither condition is true), Tanzania would be the most vulnerable partner state by virtue of share in production. It has more than 10 million ha dedicated to these crops, followed distantly by Uganda and Kenya with about 4 million total ha, and Rwanda and Burundi with just over 1 million.



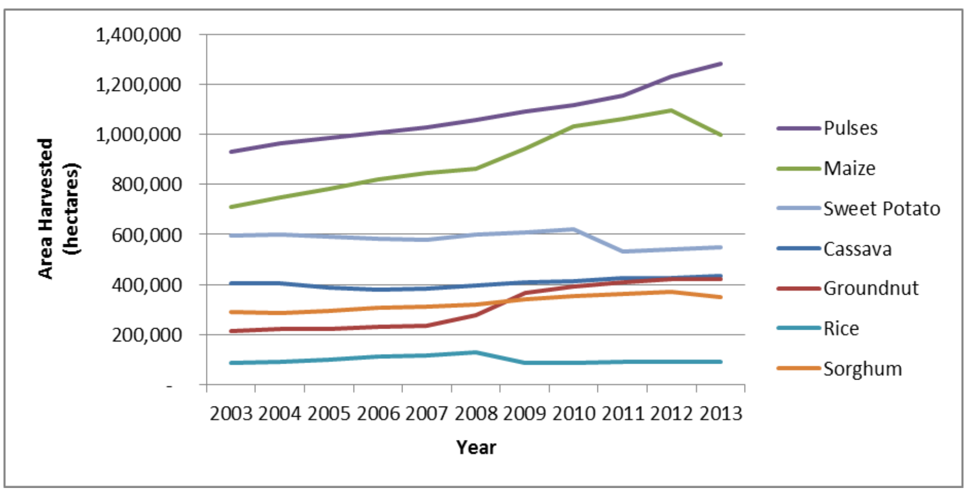
Source: FAOSTAT 2014 *Figure 1: Total EAC harvested area for selected crops.*

Figures 2 through 6 show the total area harvested over time for each of the seven crops, by country, and following the same initial hierarchy. In the case of Tanzania (Figure 2), area planted to maize predominates, with more than double the area for pulses, which in turn cover two to three times the area dedicated to the other five crops.



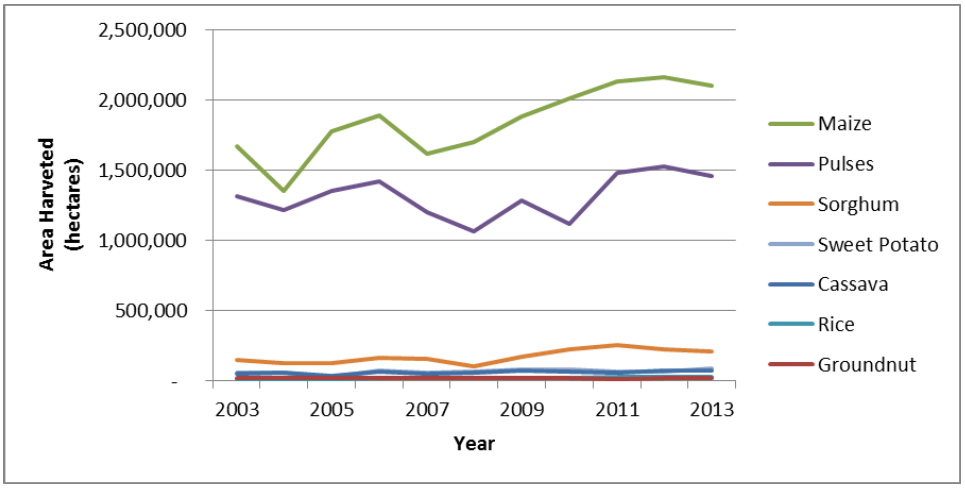
Source: FAOSTAT 2014 *Figure 2: Total Tanzania harvested area for selected crops.*

Figure 3 reveals that Uganda also has a very large area planted to maize, although 30 percent less than to pulses, and less than one quarter the area planted to maize in Tanzania. On the other hand, cassava, sweet potato, and groundnuts are relatively more prominent in Uganda than in Tanzania.



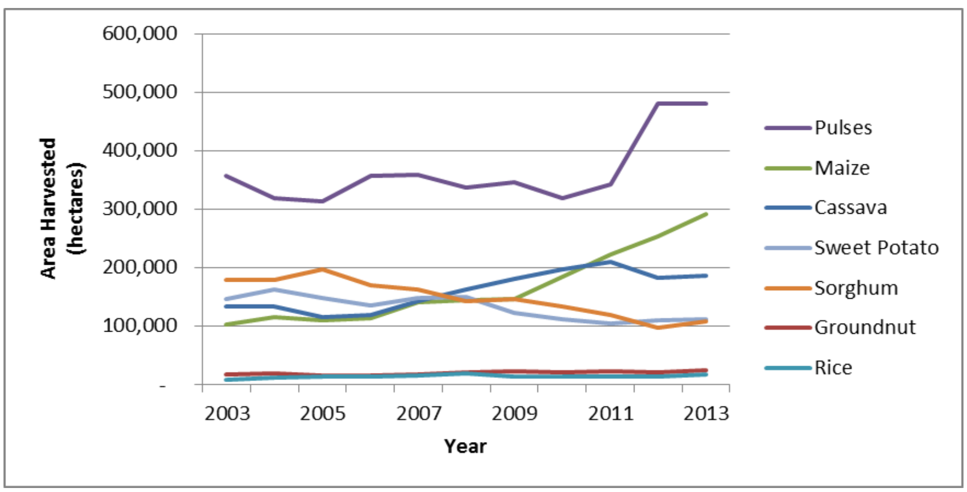
Source: FAOSTAT 2014 *Figure 3: Total Uganda harvested area for selected crops.*

As Figure 4 shows for Kenya, once again maize is the predominant crop by far, with more than 2 million ha planted. Pulses are quite important as well, at around 1.5 million. Sorghum, cassava, and groundnut are much less important in terms of area.



Source: FAOSTAT 2014 *Figure 4: Total Kenya harvested area for selected crops.*

Figure 5 reveals that for Rwanda, pulses are by far the most planted crop, at just under 500,000 ha; maize comes second at nearly 300,000, and both are rising rapidly. With about 200,000 ha, cassava is also significant. Sweet potato, sorghum, groundnut, and rice are relatively minor in terms of area.



FAOSTAT2014

Figure 5: Total Rwanda harvested area for selected crops.

Figure 6 shows that for Burundi, pulses and cassava, each with more than 300,000 ha, are much more significant in area than the other five crops are by themselves. However, maize is still significant at about 125,000 ha.

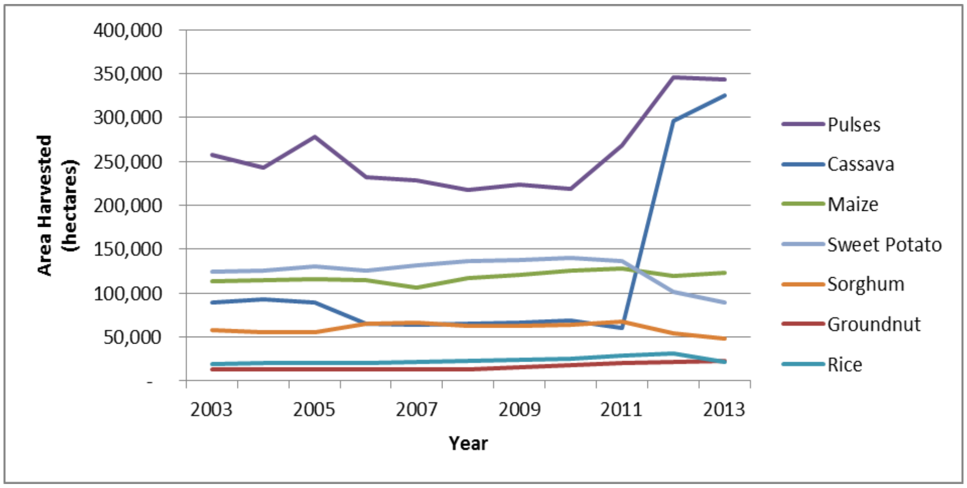


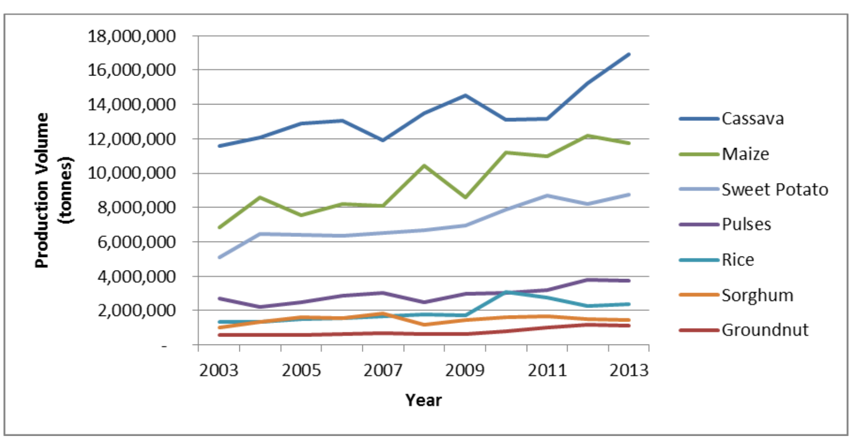
Figure 6: Total Burundi harvested area for selected crops.

FAOSTAT 2014

Production of Selected Susceptible Crops

Figure 7 shows the total production over time reported for EAC partner states for the seven crops of interest. If susceptibility to aflatoxin contamination were equal (which it is not), then cassava would be of greatest concern at about 17 million metric tons (MT), followed not surprisingly by maize with nearly 12 million MT and sweet potato at nearly 9 million MT. With 4 million MT, pulses are important as well. Rice, sorghum, and groundnut follow in descending order. Coupled with well-recognized susceptibility, the criterion of total EAC production keeps the spotlight on maize.

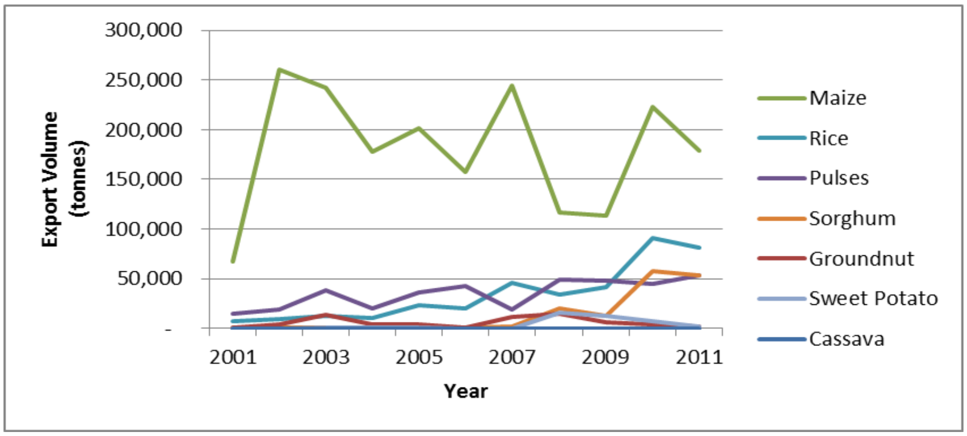
Since total production of groundnuts in this region is the lowest of the seven selected crops, it would seem far less important based on this one criterion than perhaps cassava, sweet potato, and pulses. But susceptibility and prevalence were not factored in here.



Source: FAOSTAT 2014 *Figure 7: Total EAC production for selected crops.*

Export of Selected Susceptible Crops

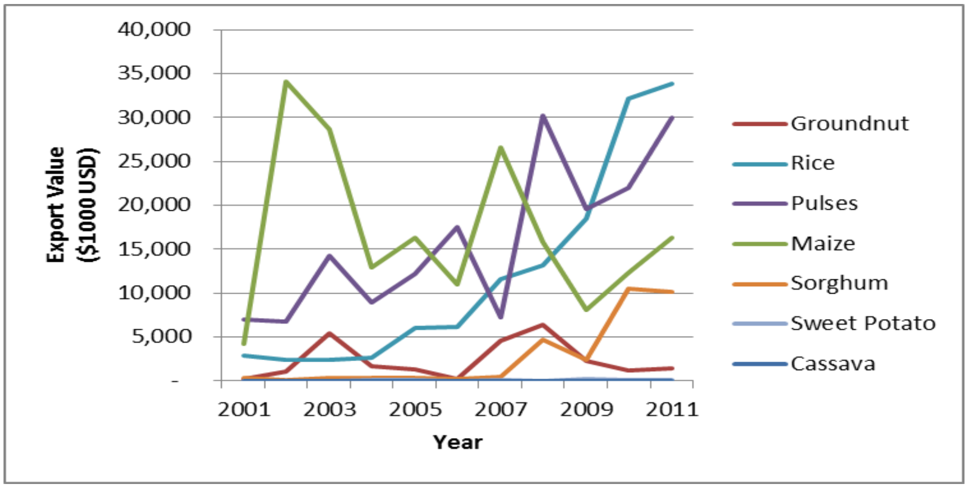
Figure 8 shows the export volume of these seven crops from the EAC countries. For the period 2009-11 at least, overall volume was generally rising. Maize is always the most traded of these crops in terms of volume, though volumes vary from year to year. In recent years, rice has been number two and rising. Exports of sorghum and pulses have held steady. On the other hand, there has been very little regional export volume reported for groundnuts, sweet potato, or cassava.



Source: FAOSTAT 2014 *Figure 8: Total volume of EAC exports for selected crops [at least].*

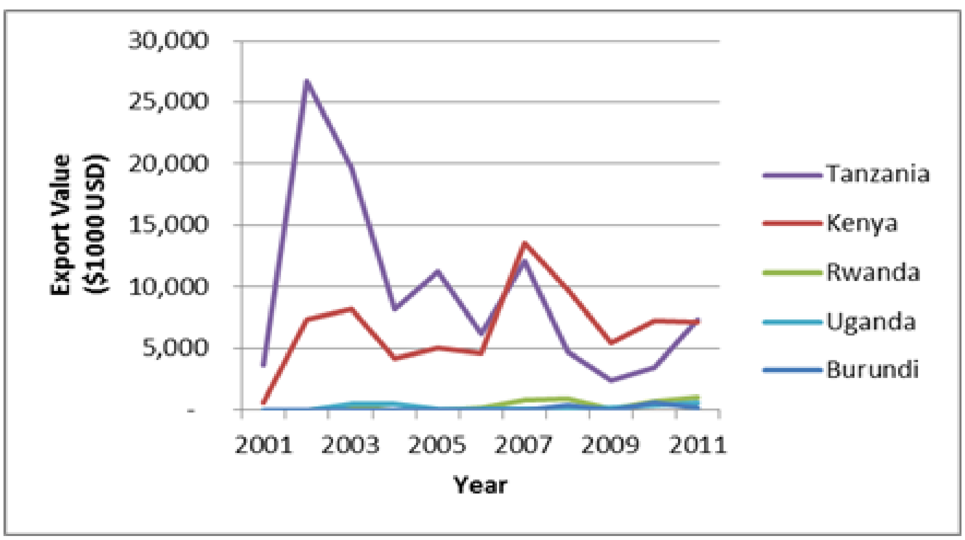
Figure 9 shows export value for these same crops. Once again, between 2009 and 2011, the value generally rose (partially reflecting the run-up in global commodity prices after the 2008 food price crisis began). The value of rice exports rose most precipitously, with maize and sorghum showing increases as well, but the export value of pulses (less subject to global volatility) also remained high. There was virtually no export value evident for groundnuts, sweet potato, or cassava.

Considering volume and value together, once again the export trends alone would seem to suggest that priority be given to rice, pulses, maize, and sorghum. However, since rice is relatively less susceptible to aflatoxin contamination in its tradable form, really only pulses, maize, and sorghum warrant attention at the EAC level from this optic.



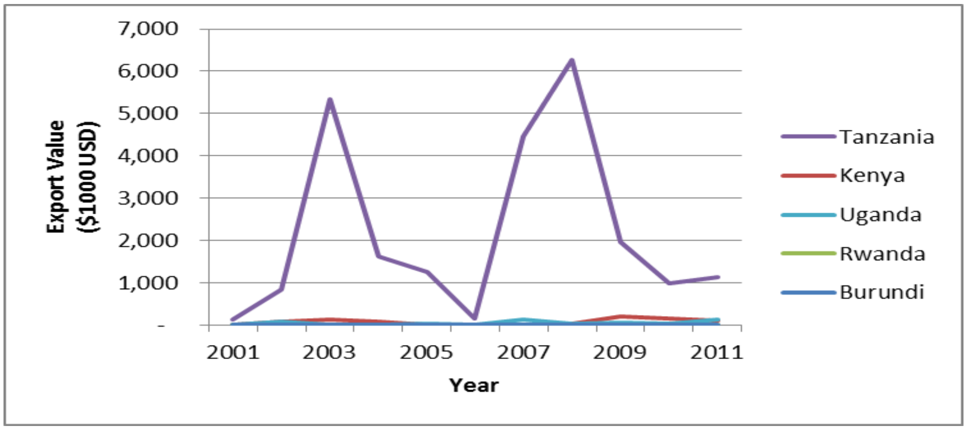
Source: FAOSTAT 2014 *Figure 9: Total value of EAC exports for selected crops.*

However, the extent to which any one EAC partner state depends on or benefits from exports of a susceptible product is another way to look at it. For example, Figure 10 shows EAC country participation in maize export value. While no partner country exports more than $10 million worth of maize annually, Tanzania and Kenya both export more than the other three countries and for that reason should probably be more concerned about aflatoxin contamination of maize than the other countries.



Source: FAOSTAT 2014 *Figure 10: Total value of maize exports for EAC partner states.*

In the case of groundnuts, as Figure 11 shows, only Tanzania has had significant export value. Whether or not the volatility over time is in fact related to aflatoxin contamination warrants further analysis.



Source: FAOSTAT 2014 *Figure 11: Total value of groundnut exports for EAC partner states.*

Consumption of Susceptible Crops

The third risk factor for aflatoxin as a public health problem is extent of exposure through dietary intake by humans and animals. In order to compare apparent consumption of highly susceptible crops, Narayan et al. (2014) used Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA) data from Tanzania and FAO Food Balance Sheet data for the other four countries. Not surprisingly, given the area planted and total production shown in the figures above, Tanzania had the highest maize consumption by far, at 349 g/p/day, followed by Kenya with 211, Burundi with 155, Uganda with 112, and Rwanda with 39. Even though Kenya has much less area under maize production, and produces much less in absolute terms, it also imports maize when necessary, often from its neighbors, presumably driven by high demand. Narayan et al. also focused on groundnuts, in recognition of its well-known risk profile, and found that groundnut consumption for all EAC countries was much lower: Tanzania at 15 g/p/day, Uganda at 12.6, Burundi at 6.3, Rwanda at 2.5, and Kenya at 1.1. They did not consider the other crops being examined here.

Separately, for more than a decade, WHO's Global Environment Monitoring System/ Food Contamination Monitoring and Assessment Program has endeavored to group countries for analytical purposes. GEMS/FOOD uses FAO Supply Utilization Account data for estimated per capita consumption of 415 primary or semi-processed food products. In its initial typology, Burundi, Rwanda, and Uganda were placed in Cluster A, which is characterized by high consumption of roots/tubers (especially cassava and sweet potato) and fruits (especially bananas and plantains), while Kenya and Tanzania were placed in Cluster I, which is characterized by high consumption of cereal grains (especially maize). These groupings generally reflect the same finding for area planted and production presented in earlier figures. In the view of GEMS/FOOD, Burundi and Rwanda are somewhat similar in consumption patterns, and so are Tanzania and Kenya. Uganda has characteristics of both but is seen as close historically to Burundi and Rwanda due to high consumption of bananas and plantains.

Postharvest Loss Management and Mitigation in the EAC

Although many studies have been carried out in the past 25 years of PHL in sub-Saharan Africa associated with major cereal crops such as maize and rice, fewer studies have been carried out with respect to groundnuts, sweet potato, pulses, and cassava. Similarly, even where multiple PHL studies do exist for a given crop, typically such studies focus on losses for a single country, or in the case of very large countries, a single source area. To the best of our knowledge, no studies of losses associated with any of these crops exist across all five EAC partner countries, and certainly none exists for all crops and all countries.

Another factor that complicates analysis is the reality that nearly all studies of relevance are limited to quantitative loss, often with just a passing nod to qualitative losses. Yet the different main categories of loss both matter, and interact in complex ways. When there is excess supply, for example, after a bumper harvest, for a source area as a whole, it can actually be beneficial to have less volume flow to market, even if deliberate culling is required which might seem to cause a loss. Conversely, when supply is short, challenges of quality and condition are typically viewed as less important by traders, processors, and even consumers and unit prices may be much higher than for the same quality/condition during peak harvest.

For East Africa, indeed for most of sub-Saharan Africa, the best recurring source of loss information has been the African Postharvest Loss Information System (APHLIS), which was established with funding principally from the European Union (EU). While the initial funding source has been exhausted, several private foundations are considering providing further support, subject to certain conditions, one of which is expansion beyond cereals and the other is inclusion of price/value data.

In its present form, APHLIS covers only selected grains: maize, wheat, rice, sorghum, barley, oats, millets, and teff. While some data for some crops is available for all EAC countries, and often goes down to the province level within them, there are spatial gaps. Moreover, there is usually a lag of one year at least. Explanatory material regarding major events, such as droughts, is not consistently provided. As suggested previously, APHLIS divides losses by step in the supply chain, although it aspires to capture a shorter segment than suggested above, and subdivides the supply chain into fewer steps. Notwithstanding those limitations, APHLIS remains interesting and useful for analytical purposes.

Metal storage containers offer advantages in terms of durable protection against serious pests such as bats, rodents, and the Large Grain Borer, and allow for gradual removal of product. They still require drying to appropriate moisture levels before products are stored, often require use of agrochemicals against other insect pests and disease, and are not hermetic enough to arrest growth of Aspergillus *that can produce aflatoxins. IITA.*

Yet for the seven crops of concern to this study, more detailed information is needed, ideally based on in-depth analysis of local growing conditions and agricultural practices. To the extent data is available, studies of a single crop and a single producing area should be used. Often they arise from the Consultative Group centers in cooperation within the respective National Agricultural Research Organization (NARO), sometimes from centers of excellence associated with universities, and other times from donor-funded projects. Important technical papers have been produced within the region with detailed analyses of where exactly aflatoxin originates most in a given supply chain, and by implication, where it is most important to intervene.

On the other hand, for all crops of interest, a dilemma arises with respect to whether it is preferable to single out discrete interventions (for example, ultrahermetic storage solutions) that target hotpots of loss or to promote more complex strategies that intervene at multiple points along the supply chain.

A middle ground approach has been developed by a research team under the guidance of F. Waliyar (2013) of the International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT). The team divided its strategy for groundnuts into two portions. As they saw things, *preharvest enabling factors* for aflatoxin contamination included: use of susceptible cultivars; end-of-season moisture stress to the crop for more than 20 days; mean soil temperatures of 28-31°C in the pod zone; cracks and mechanical injury to the pod; insect damage to pods by termites or pod borers; death caused by diseases (stem, root, and pod rots) at pod maturity stage; and nematode damage to the pod. *Preharvest mitigation measures* recommended by Waliyar include: use of aflatoxin-resistant groundnut varieties; selection of sound seed; treatment with Dithane (Mancozeb @ 3g/kg) before planting; application of farm yard manure/compost @ 5-10 tons/ha; application of trichoderma @ 1kg/ha; maintaining optimal plant population in the field (33/m^2); application of gypsum (@ 400-500 kg/ha) at flowering; avoiding end-of-season drought with irrigation, if possible; controlling foliar disease using Kavach insecticide with 1-2 sprays; removing dead plants from the field before harvest; and harvesting the crop at the right maturity. In their view, PHL enablers include: harvesting an overly mature crop; mechanical damage to the pod at the time of harvest; stacking the harvest when pod moisture is more than 10 percent or under high humidity conditions; damage to the pod by insects during storage; storing haulms with immature or small pods, which tend to contain more aflatoxins; gleaning pods from the soil after harvest; and rewetting of stored pods due to factors such as ground moisture or roof leakage. In response, postharvest mitigation measures recommended include: avoiding mechanical damage to the pod by inserting the blade or plow below the pod zone; drying the harvested produce for 3-5 days using the inverted wind row drying method; making sure pod moisture goes below 8 percent; stripping or threshing the pod immediately after drying; and avoiding stacking. Also, when using mechanical threshers, use appropriate sieves based on pod size so that immature pods are blown off; removing mechanical- and insect-damaged pods; separate the fully mature large pods (to be used for raw consumption) from the remaining produce (used for oil extraction); not mixing the gleaned pod with the main produce; if necessary, drying the stripped/threshed pod once again to maintain seed moisture below 8 percent ; stacking the pod-filled gunny bags on a wooden plank and storing them in well-aerated, waterproof storage; preventing insect damage to the pods in storage.

A fully integrated strategy seeks to address challenges continuously from pre-production through to storage. Another team led by Waliyar, this time in Mali, faced a situation in which 74 percent of groundnut seed sampled and 94 percent of the paste samples revealed more than 4 ppb; while 60percent of the groundnut seed sampled and 87percent of the paste more than 10 ppb. Some samples displayed levels as high as 2,400 ppb. Knowing the complexity of the etiology of *Aspergillus* spp. and its mechanisms for generating aflatoxins, they concluded that managing a single factor would not be effective, but rather demanded a series of measures to prevent infection all along the process. Their Integrated Management Strategy combines genetic, cultural, and biological control to suppress the fungal infection and aflatoxin contamination, with simultaneous emphasis on technology transfer and awareness creation.

Drying groundnuts on the ground in open air. Since Aspergillus originates in the soil, simply avoiding unnecessary contamination by drying crops on platforms can help. IITA

In order to reduce the effect of drought at the end of cropping season, they worked to avoid conditions that favor fungal invasion and growth by using: a) deep summer plough; b) seed treatment with fungicides and insecticides; c) farmyard manure (compost, bacteria); d) optimum plant population; e) control of crop diseases and pests. They also employed biocontrol agents to reduce contamination, including *Trichoderma viridae* and compost enriched with *Pseudomonas aeruginosa* strain CDB35 (5 t/ha), in combination with gypsum (500 kg/ha) and cereal crop residues (5 t/ha). Instead of traditional field drying heaped on the ground in the field, they tried raising the heap off the ground and making sure the pods faced the sun. They also developed an improved granary at the household level using local earthen block construction, which raised the temperature, was dryer, and also benefitted from kitchen smoke. These measures, separately and together, did substantially reduce the growth of *Aspergillus* spp. and the formation of aflatoxins.

Either way, in order to reach large numbers of farmers, especially through a network of lead farmers or extension agents, whatever works best for a particular crop in a certain context needs to be formally written down and perfected. The Groundnut Production Guide for Uganda: Recommended Practices for Farmers developed by the National Agricultural Research Organization (NARO) of Uganda is a good example. NARO's interventions span the production process from start to finish, including detailed recommendations for harvest, postharvest handling, and storage.

As EAC moves forward, a concerted effort is needed to 1) further perfect such guides for single crops that are susceptible to make sure they sufficiently address aflatoxin contamination as well as PHL reduction; 2) share approaches and technologies that work well across partner states; 3) find ways to more completely diffuse such innovations so that they reach a much larger number of small producers; 4) link continuous improvement in good or even best practices to policy and regulatory reforms that will provide official stimulus for adoption; 5) work closely with market-makers to ensure that their level of awareness rises apace, along with market-oriented incentives to reduce contamination; and 6) continue to build human capital in centers of excellence, food safety regulatory bodies, and the agrifood system, so that higher levels of compliance will occur naturally.

Policy Recommendations

Based on the analysis conducted here, as well as the results of the meeting of regional experts from the EAC, we recommend that the EAC partner states take steps to implement the following policy recommendations and transition these recommendations into programs and practices:

1. In the interest of regional food security and the public health, give immediate attention and prioritized resource allocation to addressing PHL for aflatoxin prone staple food crops.
2. Give the greatest urgency to maize, groundnuts, and milk, but also devote adequate attention to sorghum, sweet potato, and pulses wherever they are widely grown, consumed, and/or traded.
3. Within the priority commodity systems, take a comprehensive approach that begins with good agricultural practices (GAPs), extends through good handling practices (GHPs), and continues along the value chain through good manufacturing practices (GMPs).
4. For postharvest management, broadly defined, focus interventions on locally adapted and validated best practices for harvesting, drying, sorting, and storing to reduce PHL.
5. To guide policy and program development for postharvest interventions at the household, farm, marketing, and processing levels, further qualitative and qualitative analysis should be undertaken on key crops and best practices for aflatoxin abatement.
6. The EAC should play a leadership role in a region-wide initiative to inform farmers, aggregators, and traders of the breadth of issues related to aflatoxin and PHL, while also providing them with affordable options for improvement.
7. Establish monitoring, reporting, and information systems, beginning with the known aflatoxin “hotspots,” and utilizing existing tools, such as APHLIS and FEWSNET, to create baseline information, and assess progress. Expand the breadth and depth of these systems as resources allow.

8. For prevention purposes, support and expand the use of proven biological control methods such as AflaSafe, but also explore others such as *Trichoderma viridae* and compost-enriched with *Pseudomonas aeruginosa*.

9. Take steps to identify, describe, and address aflatoxin issues related to gender, climate change, HIV/AIDS, and other cross-cutting issues.

10. Reduce EAC and COMESA tariff schedules to increase economic access to modernized postharvest handling, storage, and testing equipment, and encourage the rapid inflow of other aflatoxin control tools and technologies.

11. Invest in behavioral change and communications (BCC) programs that are customized by gender, language and literacy levels to:

- Raise the level of awareness among small farmers, rural households, vulnerable groups, actors within affected value chains, and providers of technology generation and transfer services
- Launch a national campaign to reduce aflatoxin contamination that would involve all major stakeholders in the public and private sector, civil society and the academic community.

12. Actively support the PACA to serve as the lead knowledge platform for aflatoxin control across the region.

List of Abbreviations and Definitions

Term	Definition
ADI	Average daily intake
ADMI	ADM Institute for Reduction of Postharvest Losses
AFB1	Aflatoxin B1
AflaSafe™	A biological control product
AFT	Total aflatoxins
AGRA	Alliance for a Green Revolution in Africa
ALOP	Acceptable level of protection
APHLIS	African Postharvest Losses Information System
ARS	Agricultural Research Service (of USDA)
BGYF	Bright-green-yellow fluorescence
BMGF	Bill and Melinda Gates Foundation
CDC	Centers for Disease Control (of the United States)
CIMMYT	International Maize and Wheat Improvement Center
Codex	Codex Alimentarius Commission
CAADP	Comprehensive Africa Agriculture Development Program
CONTAM	(EU) Panel on Contaminants in the Food Chain
DON	deoxynivalenol
EAC	East African Community
EFSA	European Food Safety Authority
ELISA	Enzyme-linked immunosorbent assay
EU	European Union
FAO	United Nations Food & Agricultural Organization
FDA	Food and Drug Administration (of the United States)
GAP	Good Agricultural Practice
GEMS	Global Environment Monitoring System/ Food Contamination Monitoring and Assessment Program
GFSP	Global Food Safety Partnership
GHP	Good Handling Practices
GLP	Good Laboratory Practices
GMP	Good Manufacturing Practices

Term	Definition
ha	Hectare
HACCP	Hazard Analysis and Critical Control Points
HCC	Hepatocellular cancer
IARC	International Agency for Research on Cancer
ICARDA	International Center for Agriculture Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid-Tropics
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
IRRI	International Rice Research Institute
ISM	International Society for Mycotoxicology
JECFA	Joint (FAO/WHO) Expert Committee on Food Additives
Kenya MoA	Ministry of Agriculture, Livestock, and Fisheries (of Kenya)
LACCP	Loss Analysis and Critical Control Points
LSMS-ISA	Living Standards Measurement Survey Integrated Survey on Agriculture
MAAIF	Ministry of Agriculture, Animal Industry, and Fisheries (of Uganda)
MAFC	Ministry of Agriculture, Food Security and Cooperatives (of Tanzania)
MINAGRI	Ministry of Agriculture and Animal Resources (of Rwanda)
MINAGRIE	Ministry of Agriculture and Livestock (of Burundi)
MRL	Maximum residue limit
MT	Metric tons
MycoRed	EU-supported global network interested in mycotoxin reduction
NARO	National Agricultural Research Organization (of Uganda)
NFDA	National Food and Drug Authority (of Uganda)
NRI	Natural Resources Institute
NTB	Non-tariff trade barrier
PACA	Partnership for Aflatoxin Control in Africa
pH	Scale for measuring level of acidity
PHL	Postharvest loss
ppb	Parts per billion
RA	Risk assessment

Term	Definition
RF	Rockefeller Foundation
SOP	Standard operating procedures
SPS	Sanitary and Phytosanitary Measures
TDI	Tolerable daily intake
TDS	Total diet study
TFDA	Tanzania Food and Drugs Authority
USDA	United States Department of Agriculture
WB	World Bank
WHO	World Health Organization
WRI	World Resources Institute
WTO	World Trade Organization

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