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Effective Control of Aflatoxin Contamination in Staple Maize Food Crop in Sub-Saharan Africa: A Review of Current Pre- and Postharvest Low-Cost Technologies and Perspectives

Benoit Gbemenou Joselin Gnonlonfin[1], Alain Sy Traore[2] and Seydou Samake[3]

1. Department of Industry and Private Sector Promotion & Directorate of Agriculture and Rural Development, ECOWAS Commission, 101, Yakubu Gowon Crescent-Aoskoro, PMB 401, Abuja FCT, Nigeria

2. Directorate of Agriculture and Rural Development, ECOWAS Commission, 101, Yakubu Gowon Crescent-Aoskoro, PMB 401, Abuja FCT, Nigeria

3. Embassy of the United States of America in Accra, 24 Fourth Circular Rd, Accra, Ghana

Abstract: Mycotoxins/aflatoxins contaminations in some food commodities seriously impact human and animal health and reduce the commercial value of crops. Mycotoxins are toxic secondary metabolites produced by fungi that colonize agricultural commodities. Pre- and postharvest contamination of aflatoxin is a major health concern in Africa where maize production and consumption have increased significantly over the years. Efforts to reduce aflatoxin in maize through various strategies such as breeding for resistance, improved agronomic practices, cultural harvesting and postharvest handling practices, and the use of bio-control agents are available. Some of these control practices are not well known by smallholder farmers. Important pre- and postharvest practices, in addition to the stringent food safety regulations and monitoring, are not undertaken as a result of various factors such as a lack of awareness and training, and the high cost of awareness and sensitization drives. The climate changes scenarios including El Nino are also factors to be considered. However, continued use of sustainable and effective low-cost management practices by small scale farmers are possible ways of reducing the risk of aflatoxin contamination. This review attempts to highlight low-cost, affordable and practical management options at pre- and postharvest in maize. Sound low-cost management practices are possible ways of reducing the risk for fungal infection and aflatoxin contamination that are relevant to the Africa context. This review would be useful and guided prioritization of development activities, continuous awareness creation and training and future research.

Key words: Aflatoxins, *Aspergillus flavus*, climate change, low-cost technology, awareness, training.

1. Introduction

In developing world, many individuals are not only food insecure, but also are chronically exposed to high levels of mycotoxins in their diet. Food security exits when all people at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life [1]. Food safety results when microbial contaminants and chemical toxicants are present below acceptable limit in the food. Aflatoxin, a mycotoxin, compromises food security in the most vulnerable groups of people in Africa, especially in Kenya. *Aspergillus flavus*, *A. parasiticus* and to some extent *A. nomius* produce aflatoxins as secondary metabolites in feed and food crops prone to fungal infection. Aflatoxin B1 (AFB1) is the most powerful natural mutant. Aflatoxins cause liver cancer, suppressed immune systems, and retarded growth and development by contributing to malnutrition. Children are the most sensitive to the effects of

Corresponding author: Benoit Gbemenou Joselin Gnonlonfin, Ph.D., research fields: sanitary and phytosanitary (SPS).

aflatoxin-contaminated food. Chronic exposure (state of continuous or recurring contact with any toxic substances or radioactive materials over a long period of time, three months or more) to aflatoxins is more common in Africa, but acute toxicity (adverse effects of a substance that result either from a single exposure or from multiple exposures in a short period of time, usually less than 24 h). For acute toxicity, the adverse effects should occur within 14 d of the administration of the substance, leading to death of humans, which also has been reported [2]. Some of the highest and most recurrent human death were due to aflatoxin contamination in Kenya where significant numbers of people death were reported with up to 125 deaths in the year 2004 (Fig. 1) with a general morbidity of 41.5% cases fatality [3]. Maize consumption is an important source of aflatoxin for these populations [3].

Toxigenic fungi also cause economic losses by spoiling grain. Animals fed aflatoxin-contaminated grain have lower productivity, slower growth and impact on their welfare. Aflatoxin-contaminated commodities have a lower market value and often are consumed locally since they cannot be exported. Regulations on maximum levels of mycotoxins in feed and food in developed world have been lowered, which can result in lowered export earnings by developing countries that cannot comply with the stricter regulations. Overall costs for mycotoxin management and monitoring are very high, e.g., the United States is estimated over $1.5 billion for aflatoxin in maize and peanut [4].

In many parts of Africa maize has become the preferred cereal for food, feed and industrial use, displacing traditional cereals such as sorghum and millet. Maize is a food crop that is part of the staple diet in many sub-Saharan African countries; it is consumed at a level of about 400 g per person per day [4]. In some families maize may be consumed twice daily. However, maize is vulnerable to infestation by mycotoxigenic fungi. Maize production in sub-Saharan Africa tripled from the early 1960s to late 2000 because of an increase in area under cultivation for about 2-fold and an increase in productivity greater than 40% [5]. Consequently, maize consumption is very high especially in the urban areas with an average consumption of 85 kg per annum per person [6]. Maize is one of the cereals most susceptible to aflatoxin contamination. Aflatoxin contamination can occur at any stages, from production, harvesting, postharvest handling, processing, storage and distribution

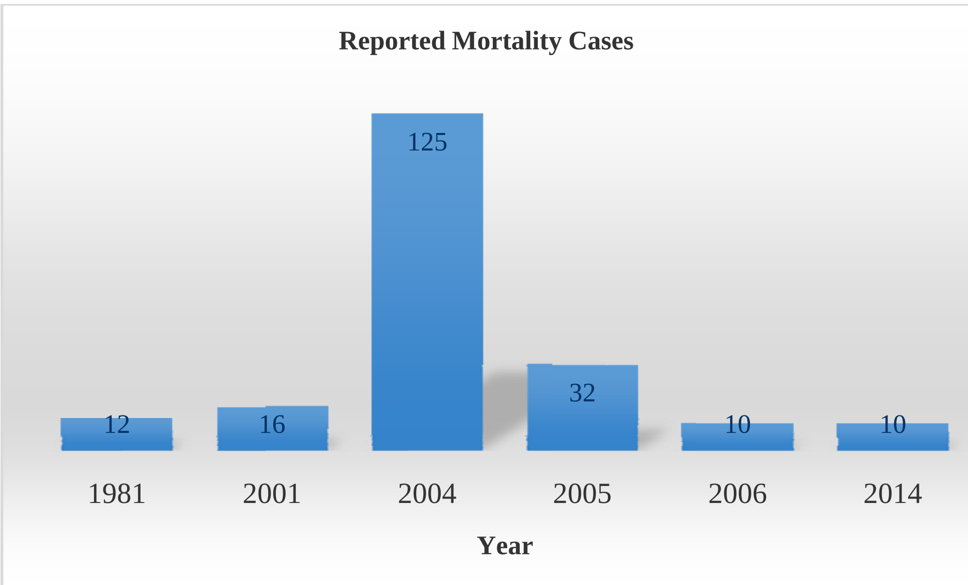


Fig. 1 Case study of reported mortality cases due to acute aflatoxicosis in Kenya, East Africa, caused by consumption of aflatoxin-contaminated maize.

Source: author's drawing based on available data in the literature.

and is highly dependent on environmental conditions, especially temperature and water activity and certain characteristics of smallholder production practices, e.g., nature of certain food production systems like subsistence farming, a decline in available farm land, making crop rotation impossible, harvested maize heaped in the field for drying, lack of resource, technology, and infrastructure for proper drying and storage practices are considered to be predisposing factors to aflatoxin accumulation in natural settings. In addition, the socio-economic status of smallholder farmers force them to sale the maize to aggregators while still in the field. This results in some cases to a premature harvest or high moist maize at harvesting.

Although there have been efforts to reduce aflatoxin in maize through various strategies including breeding for resistance, improved agronomic practices, cultural, harvesting and postharvest handling practices, and the use of bio-control agents, more could still be done. Some of these control practices are not well known hence not in practice by smallholder farmers. Important pre- and postharvest practices, in addition to the stringent food safety regulations and monitoring, are not undertaken due to various factors including culture, inexistence of awareness and training, and high cost. While the development and scaling up of aflatoxin control practices are essential to reduce exposure to aflatoxins by consumers and producers who depend on maize for income generation, it is also paramount to adapt low-cost, effective and efficient technologies. This review attempts to briefly describe the prevalence and distribution of aflatoxins in sub-Saharan Africa and different low-cost management strategies that can be used by smallholder farmers. It also recommends those that can be potentially adapted to the African contexts and adopted by relevant stakeholders as well as the future research activities with the ultimate goal of reducing aflatoxin contamination in maize hence reducing exposure, which are in line with the ECOWAP/CAADP orientations.

2. Prevalence, Distribution of Aflatoxins in Sub-Saharan Africa with Reference to the Kenyan Case

The presence of significant levels of aflatoxins has been reported in groundnut and maize as well as in other crops. Reports on contamination levels in Africa have been reviewed by Wagacha and Muthomi [7]. Data are reviewed from potential highest exposure risks to commodities with lower exposure risk in sub-Saharan African populations (Table 1). These data show that there is a need for systematic investigations along many priority food value chains that are staple in sub-Saharan Africa. For instance, Wareing *et al.* [8], in their study on dried cassava product in Ghana, reported that fungal growth and mycotoxin development were positively correlated with drying time. A positive correlation was also observed between fungal growth, mycotoxin production and growing season [8].

Aflatoxin production depends on factors such as water stress, high temperature (> 32 °C) stress, insect damage to the host plant, susceptible crop growth stages, poor soil fertility, high crop density, weed competition [9]. Thus, the extent of aflatoxin contamination varies with geographic location, agricultural and agronomic practices, and the susceptibility of germplasms to fungal invasion during field production, storage and/or processing.

The presence of detectable concentration of aflatoxins has been reported in maize, groundnut and other crops. Data are reviewed for high-risk commodities including maize. In 2004, it was estimated that the annual loss of all food exported is USD 450 million due to aflatoxin contamination, which made agricultural products unfit for both human and animal consumption as well as for trade [10]. This was the loss to the smallholder farmers who depend on the crop for food and income. Recent studies have found high aflatoxin levels that are above the acceptable limit of 10 μg/kg in maize samples

Table 1 Principal food commodity and aflatoxin level.

Food commodity	Country	No. samples	Mean level (μg/kg)	Range (μg/kg)	References
Groundnut cake	Nigeria	-	-	20-455	[11]
Dry roasted groundnut	Nigeria	106	52.4	-	[12]
Peanut	Botswana	-	-	12-329	[13]
	Cameroon	41	161.4	31-950	[14]
	Kenya	-	-	0-7,525	[15]
Maize	Nigeria	-	125.6	-	[16]
	Benin	300	-	2-2,500	[17]
	Zambia	-	-	0.7-108.74	[18]
	Ghana	-	-	20-355	[19]
	Kenya	350	-	1-46,400	[20]
	Cameroon	77	1.0	2-42	[14]
	Tanzania and Republic of Congo	-	-	0.04-120	[21]
Fermented maize dough	Ghana	-	-	0.7-313	[19]
Edible tubers “tiger nuts”	Nigeria	25	454	-	[22]
	Nigeria	-	-	10-120	[23]
Sorghum	Nigeria	-	-	10-80	[24]
Dried yam	Nigeria	-	27.1	-	[25]
	Benin	-	14	2.2-220	[26]
Dried cassava	Tanzania	-	nd	nd	[27]
	Ghana	-	nd	nd	[8]
	Benin	236	nd	nd	[28, 29]
	Tanzania and Republic of Congo	-	-	0.1-13.0	[21]
Cassava products	Tanzania and Republic of Congo	-	-	0.3-4.4	[21]
Cowpea	Benin	-	nd	nd	[30]
	Tanzania	-	-	487.4-1,888.7	[31]
Dried okra	Benin, Mali and Togo	30	6.0	-	[32]
Dried hot pepper	Benin, Mali and Togo	30	3.2	-	[32]

nd = not detectable; source: adapted from Ref. [33].

collected from different counties in Kenya including Kitale, Kitui, Makueni, Nakuru and Nandi [34]. Similarly, contamination by aflatoxin with levels exceeding the acceptable limit of 20 μg/kg [35] and 4 μg/kg [36] was reported in maize from Benin [17], Burkina Faso [37], Uganda [38] and Tanzania [39].

Contamination by aflatoxin in staple foods such as groundnut with levels above the Kenyan acceptable limit of 10 μg/kg was reported as well [40]. Earlier report from Uganda has shown high levels of aflatoxin in groundnut [38] and locally manufactured baby foods (including baby soya, rice porridge) [41] with levels beyond East African Community (EAC) limit of 10 μg/kg, and United States and European Union limit of 20 μg/kg and 4 μg/kg, respectively. More investigation is needed to reduce and control the contamination of these staples. Further, there are no maximum limits for West Africa member states, this calls for more work to set the maximum limit in that region.

Animal consuming feeds contaminated by AFB1 can lead to the occurrence of aflatoxin M1 in milk and milk products. Lanyasunya *et al.* [42] reported the risk of aflatoxin contamination of dairy feed and milk on smallholder dairy farms in Kenya. Some promising intervention could be the development of biological binders. Investigations are ongoing to assess the extent of the problem and interventions to minimize the risk of exposure among the vulnerable population.

3. Fungal Population Structure with Focus on S-Strain Isolates and Subsequent Aflatoxin Biosynthesis

The internal mycobiota associated with maize, groundnut and other crops has been investigated. In Kenya, the lethal aflatoxicosis of human that occurred in 2004 was associated with high infection of maize by S-strain isolates of *A. flavus*. Further investigation has shown that the deadly strains of Kenyan *Aspergillus* are distinct from other aflatoxin producers as the molecular characterization of these S-strain isolates resolved into a clade distinct from the S-strain isolates from the United States, Asia and Australia [43]. Research works on the toxigenic profile of *Aspergillus* species infecting maize in Kenya and Tanzania have shown high incidence of toxigenic strains with S-type (produces larger amount of aflatoxin) being more prevalent as oppose to L-type [34]. These findings were in accordance with the frequent aflatoxicosis outbreaks as the maize samples were collected from the affected regions in Kenya. More investigation is needed to understand the fungal pathosystem and distribution as aflatoxicosis outbreaks are being reported from new regions.

In light of the above reports it is essential to document the low-cost technologies to reduce aflatoxin contamination and that could be affordable, potentially adapted and adopted by smallholder farmers in sub-Saharan region with potential scaling up to other developing region and beyond.

4. Low-Cost Technologies for Aflatoxin Management in Sub-Saharan African Region

Exposure to aflatoxin risks in human population is growing and it is alarming. Many developing countries have realized that reducing aflatoxin concentration in foods will not only reduce financial burden on health care but also confer regional and international trade advantages such as exports to the attractive more lucrative markets. The maximum limits set by the European Union and other countries are bottlenecks to export as shown in a report from the European Food Safety Authority [44].

To ensure that foods have the lowest aflatoxins concentration possible, prevention of fungal invasion is required. Good practices during production, harvesting, appropriate postharvest handling (sorting, cleaning, drying, insect management, good packaging, application of hygiene, use of appropriate storage systems, appropriate transportation means), and marketing, need to be observed. Cultural practices during production including crop rotation, use of resistant and/or tolerant varieties, tillage, choice of planting date, and management of irrigation and fertilization can limit infection and subsequent aflatoxin accumulation [45]. Awareness and sensitization campaigns, training, monitoring and backstopping activities are needed to ensure adoption, dissemination and sustainability of the low-cost aflatoxin management strategies/technologies.

4.1 Pre-harvest Maize Management Practices

Prevention is better than cure. Developing low-cost technologies for the prevention of aflatoxin requires a good understanding of the factors that influence the infection process as well as conditions that influence toxin production. Soil type, condition and availability of viable spores are important factors [3]. Environmental factors that favor *A. flavus* infection in the field include high soil and/or air temperature, drought stress, nitrogen stress, crowding of plants and conditions that facilitate the dispersal of conidia during maize silking [46]. Factors that influence the incidence of fungal infection include the presence of lepidoptera larvae, adult and other invertebrate vectors, grain damage, oxygen and carbon dioxide levels in stores, inoculum load, substrate composition, fungal infection levels, prevalence of toxigenic strains and microbiological interactions [47]. In West Africa, investigations by the International Institute of Tropical Agriculture (IITA) have concluded the efficiency and efficacy of crop rotation (Fig. 2 and Table 2) [48]. Therefore, crop rotation and management of crop residues also are important in controlling *A. flavus* infection in the field. Because of lack of sufficient land and financial resource, there could be some challenge for the application of this low-cost management strategy. However, it could be recommended to farmers rotation of crops other than maize included pigeon pea, beans, cowpea, sweet potato and maybe roots and tubers in the context of West Africa.

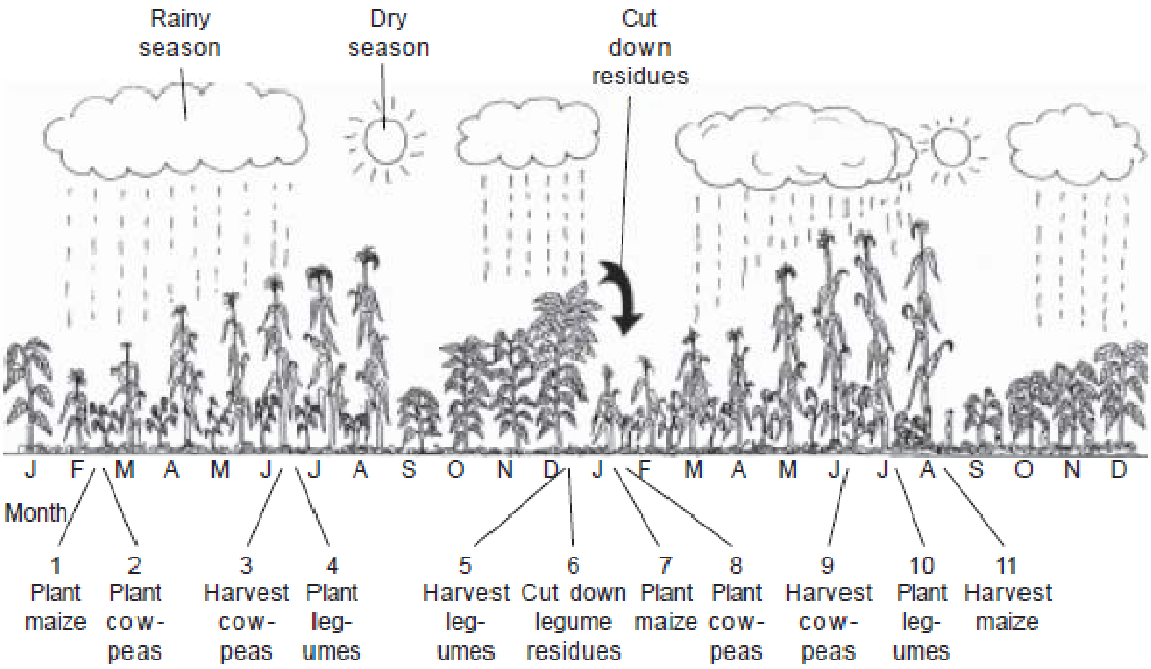


Fig. 2 Example of 2-year rotation of cereals, cowpeas and legumes.
Source: Ref. [49].

Table 2 Farming practices contributing to high and low level of aflatoxin in stored maize in West and East Africa.

Lower aflatoxin levels	Higher aflatoxin levels
Production practices	
Crop rotation	Maize mono cropping
Maize in mixed cropping	Cowpea, peanut or cassava intercrop
Farmers aware of incomplete husk cover	Maize is damaged in the field
Diammonium phosphate fertilizer	No fertilizer
Harvest practices	
Harvest at crop maturity	Delayed harvest
Harvest of maize with the husk	Harvest maize in heaps: cobs shelled later
Sun drying on platform	“Field” drying on the plant
Drying of maize without the husk	Delayed drying
Immediate removal of damaged cobs (sorting)	No sorting at harvest
Storage practices	
Cleaning of the storage structure	No preparation of the storage structure
Maize stored for 3-5 months	Maize stored for 8-10 months
Smoke or insecticide use	No insect control
Maize stored in aerated stores	Maize stored in poorly aerated stores

Source: adapted from Refs. [48, 50].

Tillage practices, crop rotation, weed control, late season rainfall, irrigation, fertilizer application, wind and pest vectors all can affect the source and level of fungal inoculum maintaining the disease cycle in maize. When maize was intercropped with cowpea the likelihood of aflatoxin contamination increased [48]. In most African countries crops are cultivated under rain fed conditions, with low levels of fertilizer and little or no pesticides application. These conditions promote *Aspergillus* infection, and any actions taken to reduce the probability of silk and kernel infection will reduce aflatoxin contamination. Maize in mixed cropping may be recommended (Fig. 3 and Table 1). Example of mixed cropping is shown in Fig. 3.

Insects could vector fungi and cause damage that allows fungal access to grain and other crop tissues thereby increasing the aflatoxin contamination [51]. The prevalence of the insect borer *Mussidia nigrivenela* was positively and significantly correlated with aflatoxin accumulation in maize in Benin. When loose-husked maize hybrids or traditional varieties are used the chance of insect damage and aflatoxin contamination increased. Promoting the use of completed-husked maize hybrids and traditional variety may be recommended. It is observed that completed-husked traditional maize is scare, this calls for more investigation in genetic conservation. In addition, some of these traits could be used in the breeding program.

Harvesting crops when they are not properly dry can promote and increase aflatoxin contamination during storage. A survey conducted in Kenya showed that an average of 10% of the respondents are aware of the impact of this practice on aflatoxin contamination [50]. Such knowledge is important in prompting farmers to design and adopt appropriate strategies for the management of aflatoxin contamination. As indicated earlier, training, awareness and sensitization activities are needed for the dissemination of such knowledge.

Biological control strategies have been developed, such as atoxigenic fungi, which out-compete their closely related strains/species, thus reducing the levels of aflatoxin in the crops. This technology has been used in the United States to reduce aflatoxin contamination of peanut [52] and maize [53]. A similar

Fig. 3 Mixed cropping with alternate rows of maize, beans.
Source: crops and cropping systems [49].

approach is being used and promoted in Burkina Faso, Ghana, Kenya, Malawi, Mozambique, Nigeria, Tanzania, Zambia using locally identified atoxigenic *A. flavus* strains [54]. Investigations are underway in the Eastern and Western Africa regions and new atoxigenic strains are being investigated for use and the development of a regional biological product. Further, the environmental safety dimension and potential recombination of the strains are being investigated to ensure complete safety. In addition, research work on the use of alternative appropriate carrier for practicability and sustainability is underway.

Breeding for resistance is one of the most promising long-term strategies for aflatoxin management in Africa. Potential biochemical and genetic resistance markers have been identified in food crops, especially maize and groundnut which are being utilized as selectable markers in breeding for resistance of aflatoxin contamination. Maize genotypes with aflatoxin resistance have been identified in West and Central Africa [55]. These potential sources of resistance are being used in breeding program by Bioscience eastern and central Africa (BecA), International Livestock Research Institute (ILRI), International Maize and Wheat Improvement Center (CIMMYT) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to develop aflatoxin-resistant, high-yielding cultivars adapted to tropical regions. As stated earlier it is observed that completed-husked traditional maize has potential for resistance to aflatoxin accumulation, however the completed-husked maize varieties are scare, this calls for more investigation in genetic conservation. In addition, some of these traits could be incorporated in the breeding program. It could be recommended to farmers the use of completed-husked maize during production.

Double prolonged approach involving genetic engineering was employed to develop a groundnut variety free from aflatoxins [56]. This finding could reduce fungi infected crops being discarded every year or being consumed with unacceptable levels of aflatoxin. By producing small proteins called defensins, groundnuts can stop the fungus from propagating and infecting it. Defensins are produced as immune responses to pathogens by some plants (not usually groundnut), animals and humans [57]. The second approach, Host-Induced Gene Silencing (HIGS), uses a naturally occurring biological mechanism where plants and pathogens often exchange small nucleic acid molecules (RNAi) during the infection process. Groundnut seeds emit gene-silencing RNA molecules to help shut down the synthesis of aflatoxin by the fungus. Scientists from the Donald Danforth Plant Science Center, ICRISAT in Hyderabad, India, US Department of Agriculture (USDA) and Louisiana State University are behind the work. They are planning future field trials for further development of aflatoxin resistant groundnut. Genetic engineering could be the future approach and low-cost technology in the fight for aflatoxin control and management.

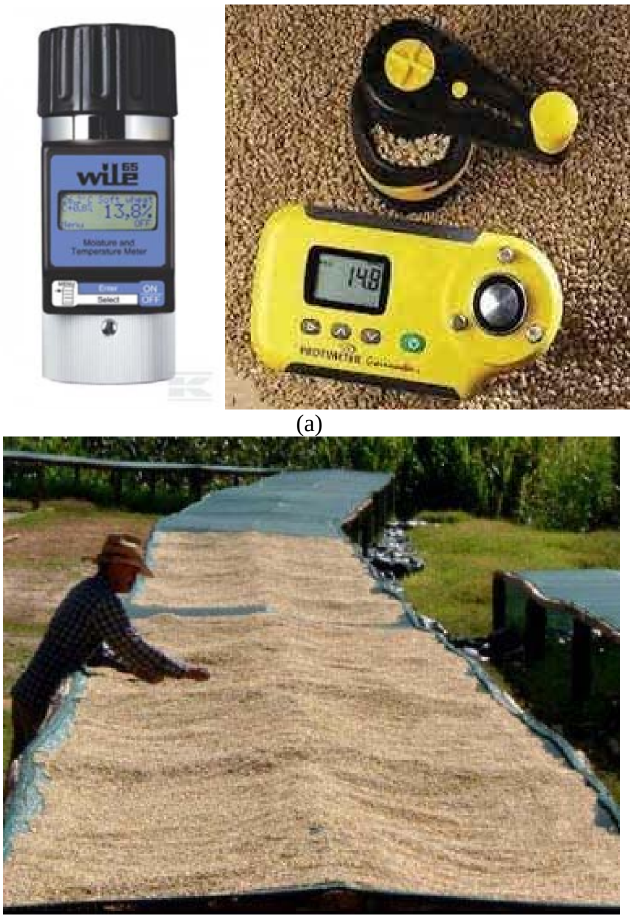
4.2 Harvest and Drying Practices

Harvesting on time affects the extent of aflatoxin contamination. Extended field drying of maize increased insect infestation and fungal contamination. Delayed harvest increased mould incidence, insect damage and aflatoxin accumulation [41]. Aflatoxin levels increased 4-fold and more than 7-fold when maize harvest was delayed by three weeks and four weeks, respectively, after maturity [41]. Moisture content was reduced when harvest was delayed, but the grain did not dry to the required safe storage moisture content of 13%. Delayed harvest of maize in Kenya is a common practice that promotes fungal growth and aflatoxin production which can occur within a few days if the grain is not properly dried and cooled before storage.

Rapid drying of agricultural products in order to lower the moisture level is critical as it creates unfavourable conditions for fungal growth and proliferation, reduces insect infestation and contributes to safe storage over longer periods [42]. Aflatoxin contamination can increase 10-fold in 3 d if maize grain is not dried properly [58]. A recommendation is that harvested crops should be dried as quickly as possible to safe moisture levels of 10%-13% for cereals and 7%-8% for oil seeds. Studies have demonstrated that drying harvested maize to a moisture level of 15.5% or lower within 24-48 h reduces the risk of fungal growth and subsequent aflatoxin biosynthesis [59].

In their intervention trial in Guinea, West Africa focused on thorough drying system in subsistence farm village and achieved a 60% reduction in aflatoxin levels. Farmers are also advised to dry grain outside the field and off the ground/soil (preferably a platform) to reduce fungal spore contamination during storage. During drying the cob or grains should be turned-over so that all surfaces received the sun [60]. Examples of platform and calibrated moisture meter that could be used for drying and for checking/monitoring the moisture content (Figs. 4 and 5) are given below. Similar drying platforms are being promoted in Bolivia for the same purpose (https://www.youtube.com/watch?v=N59Txku_bV0).

Drying grains keep longer, are rarely attacked by insects, and do not support mould growth, since the free water required for their development is not



(a)

(b)

Fig. 4 Calibrated moisture meter (a) and improved platforms for better drying (b).

Raised platform for drying. Grain sorting and monitoring for moisture content can be done during drying process.

Note on drying: During drying sorting can be done to remove moulded, insect damaged grains. A centralized drying platform could be an approach where appropriate.

Fig. 5 Improved drying clay and traditional sun drying using tarpaulin.
Note on hygiene: If traditional drying has to be sued, tarpaulin should be washed and disinfected using 10% bleach solution after the drying period or after a shift. Make sure the tarpaulin is dried before putting the produce for drying. The feet of the person on top of the tarpaulin should be disinfected using 10% bleach solution and that person should remain on the tarpaulin until the spreading of the produce to be dried is completed. Alternatively, a mixing palette could be used instead.

available. Drying in Africa usually is solar-based, and often takes longer to reach a safe moisture level. When high rainfall occurs at harvest, farmers may stack cobs with the stalk to shield the products from rain, heap the entire maize plant in the field for drying, pile grains in a home yard under cover, dry grains over a kitchen fire, or mix moist and dry grains. Drying the grain on a raised platform often reduces contamination by toxigenic fungi (Table 3). Farmers should be advised to dry the harvested maize using raised platform. Sometimes, in traditional conditions, drying is not completed before storage. During storage, transportation and marketing, low moisture content should be maintained by avoiding leaking roofs and condensation arising from inadequate ventilation [7, 28]. Aggregators are advised to further dry the maize grain before packaging and storage. Hygiene conditions should be observed as well (e.g., clean tarpaulin) and both farmers and aggregator should not leave the product on the drying area overnight. The dew and accidental rain may increase the moisture level. In Benin, drying for 3-6 d during the driest part of the year, e.g., humidity as low as 20%, resulted in whole yam tuber and cassava root chips with a moisture content of 20%. Thus, drying was not complete, but most farmers were unaware of this problem [26, 61]. Simple device should be developed and farmers and aggregators trained on the use so that they can assess if their products have reached a safe moisture level. Where appropriate, agricultural extension service staff should be trained to ensure implementation and monitoring. On-going research

Table 3 Incidence (%) of most common toxigenic fungal species in maize following 7 d of drying with the indicated drying method.

Drying method	*Aspergillus*	*Fusarium*	*Penicillium*
Cobs on stalk in the field	4.7 ab[1]	99 a	41.7
Sun drying: cobs on the ground	21 a	95 a	44 a
Sun drying: cobs on a platform	2.0 b	86 b	4.7 b
Sun drying: cobs on a plastic sheet	18.0 a	33 c	9.7 b

[1] Means data within a column followed by the same letter are not significantly different based on the student-Newman Keuls test ($p < 0.05$). There were 12 replications per treatment.
Source: Adapted from Ref. [48].

project AflaStop, being marshalled in the region by the Center for Disease Control and Prevention (CDC) aims at the development of low-cost drying technology that will help to manage aflatoxin contamination at farm level [54].

4.3 Postharvest Management Practices

Aflatoxin contamination in Africa is compounded by excessive heat, high humidity, lack of aeration in the storage area, and insect and rodent damage. Firstly, to reduce aflatoxin levels is to sort during harvest cobs that are damaged, insect infested, have an incomplete husk cover, or contain moldy grain from the rest of the grain. This grain should be consumed last, if consumed at all, and kept apart from the grain to be stored for long period. Furthermore, the distribution of aflatoxin on a maize cob or grain is very heterogeneous with high level of the toxin in just a few or a small percentage of grain [62]. The highest concentrations of aflatoxin usually are found in heavily moulded and/or damaged grains. Sorting is an efficient technique to reduce aflatoxin levels in stored maize, although the percentage of cobs or grain stored out varies widely by farmers, and may depend on both personal judgment and economic status. Studies have demonstrated that proper sorting out physically damaged and infected grains based on their coloration, odd shapes, shriveled and reduced size can reduce aflatoxin level by 40%-80% [63]. Sorting and winnowing combined with maize grain can significantly reduce aflatoxin level up to 80% [64]. In Malawi, the effectiveness of hand sorting was investigated and also showed greatest reduction on the naturally occurring aflatoxin [65]. Similarly, determining aflatoxin in peanuts showed that a significant proportion (80%) of the toxin is often associated with the small and shriveled seeds [66] and mouldy and stained peanuts, which can be removed by proper sorting [60]. Farmers and aggregators are advised to practice and allocate time and resource for sorting. In addition, awareness and training on proper sorting should be conducted. On the other hand, a simple grain sorter equipment should be developed and farmers and aggregators trained on the use so that they can be able to implement this practice.

The safe management and/or value addition to the sorted grain or "waste material" is another challenge. Simple and cost effective alternative utilization, safe disposal methods of sorted material need to be reviewed and could be tested.

To reduce aflatoxin contamination after sorting, maize cobs or grain should be stored in a well ventilated drying bin. From time to time the grain quality must be checked and insect infestation controlled if stored for long period (more than six weeks). In the case of high insect infestation, then the maize cob should be shelled, the bad grain removed and the good grain put in bag, preferably bag made of jute. Farmers in Africa increasingly store grains in polypropylene bags, but the poor aeration in these bags may encourage fungal growth and aflatoxin accumulation, in grains not dried to a safe level [17]. Farmers and other actors are unaware of this scenario.

As earlier mentioned, on-going research project AflaStop, being implemented in the region by the CDC aims at the development of low-cost hermetic storage containers that will help to manage aflatoxin contamination at the farm level.

The storage form (cobs or shelled grain) of maize influences the incidence of toxigenic fungi. Higher levels of aflatoxigenic fungi were found in maize that was shelled immediately after harvest than in maize kernels that were left on the cob through proper drying [67]. Shelling maize by beating cobs in a bag with a stick injures the grains and facilitates fungal infection and growth. Damaged maize grains are prone to high aflatoxin contamination, as are maize cobs that are threshed with mechanical sheller [68]. Farmers should be advised on hand shelling. In contrary, a sheller equipment should be developed and aggregators and other actors trained on the use.

The type of storage also influences aflatoxin levels, and the types of storage structures and their placement vary across the agroecological zones in Africa. In West and Central Africa, traditional storage methods are: temporary storage, used primarily for drying and long-term storage structures made from plant materials (wood, bamboo or thatch), clay or polypropylene bags [69]. Maize stored as grain had the highest incidence of *A. flavus* both in bags and clay stores after four months. The incidence of *A. flavus* in maize stored on the cob was low and < 1.3% irrespective of the storage structure [17]. In East temporary storage, used primarily for drying is also often used as “long-term” storage mostly in the field and long-term storage structures made from plant materials (wood), living room, roof and above fireplace. Similar use of improved granary and store of maize in shelled form reduced aflatoxin contamination [38]. Sanitation measures including removal and destruction of debris from previous harvest, cleaning stores before loading new produce and application of first-in-first-out principle should be observed as these have shown to be correlated with aflatoxin reduction [17].

Finally, aflatoxin levels can be reduced by processing methods such as wet milling, roasting, baking, and dehulling and sorting. Studies have demonstrated that maize dehulling decreased aflatoxin levels by 46.6% [70]. Substantial amounts of aflatoxins can be removed from grains by immersing them in water and removing the upper floating fraction, as contaminated grains generally have a lower density. Likewise, sorting and removal of small, broken and visibly contaminated grains during processing can significantly reduce toxins levels [64]. Dietary strategies can also prevent ingestion or absorption of mycotoxin/aflatoxin in the prepared food and feed. To contain the toxic effects as well as the prevention the synthesis of mycotoxin/aflatoxin antioxidant compounds (vitamin, provitamins), food components (phenolic compounds, coumarins and its derivatives, fructose), medicinal herbs and plants extract and biological binding agents (hydrated sodium calcium aluminosilicate, activated carbons, bacteria, yeast) can be used [71].

Many of the above-mentioned strategies as a package of technologies could be applicable in the context of sub-Saharan African region as these are simple and do not imply additional cost. There is need to review the existing training modules to take into consideration the biological control such as “AflaSafe” technology, use and application. Further, trainings and awareness and sensitization campaigns are critical to inform farmers, traders, processors, policy-makers, extension service officers, consumers as well as the general public about the risk of toxin contamination and such campaigns have been successfully implemented in West Africa [72].

5. Conclusions and Recommendations

Aflatoxins appear to be much more pervasive than previously thought, with a large percentage of agricultural commodities and high percentage of the population in Africa affected. The harmful effects of chronic exposure of aflatoxin on human health and nutrition and on animal productivity and welfare have been overlooked even though it has serious effects on the vulnerable population especially children impacting on their growth and development. Prevention through integrated pre- and postharvest control could have a significant effect on public health especially in low-income countries and deserve special attention. As such the proposed integrated package of low-cost management methods could contribute to overcoming this problem. Component technologies and practices in this package effectively lower aflatoxin level and are accessible and affordable to small scale farmers. Key components in this integrated package are mixed cropping, timely application of biocontrol agent such as "AflaSafe", timely harvest, minimizing crop contact with the ground, proper drying on raised platform prior to storage/sale, use of thermometer to monitor and check the moisture content, sorting, insect control from the field through the end of storage, use of appropriate storage structure and packaging to avoid insect infestation and grain rewetting and sanitation/hygiene (Fig. 6). This would be possible through structured sensitization and awareness campaigns and trainings. Farmers, traders, processors, consumers and other stakeholders have to become aware of the risk that mycotoxins/aflatoxins pose to their production chain. Again, public awareness, capacity strengthening of farmers on the good agricultural and good management practices and monitoring are keys actions.

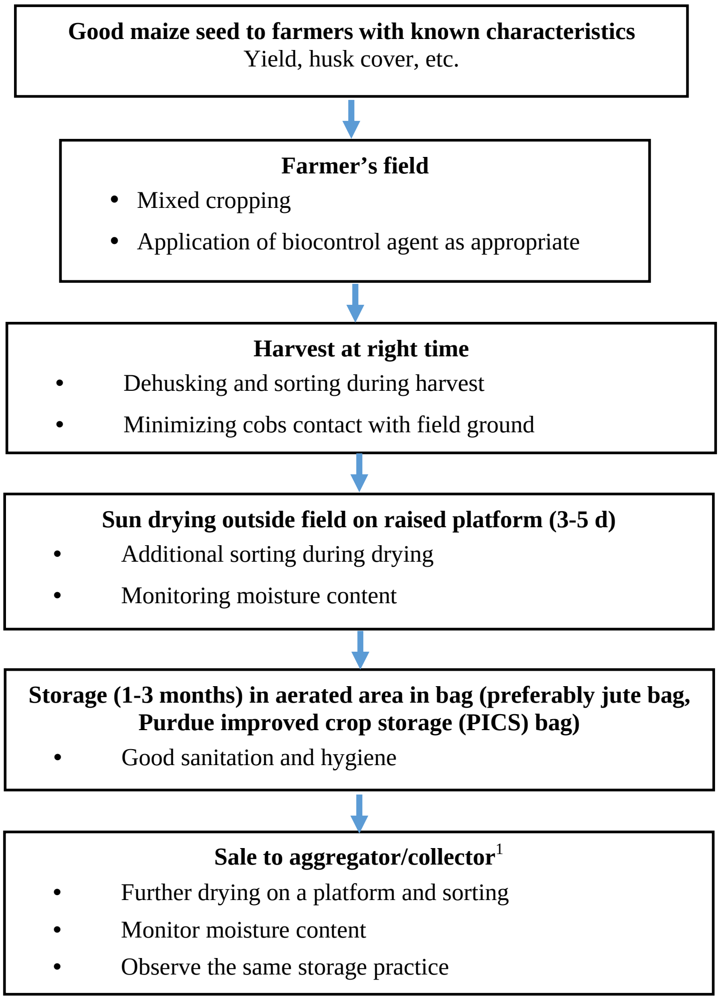


Fig. 6 Proposed package of low-cost methods for aflatoxin control at farm and aggregator level.

[1] Aggregator/collectors shall check for aflatoxin level before storing or trading.

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