Chapter 6

Aflatoxin Management Strategies in Sub-Saharan Africa

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Additional information is available at the end of the chapter

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Abstract

Aflatoxins are natural poisons produced by some members of the *Aspergillus* section *Flavi* group. Their control is critical in sub-Saharan Africa as in other parts of the world because of the health and economic dangers that aflatoxins cause. Aflatoxin management requires a pipeline approach (from production to consumption) that addresses the pre-disposing factors to aflatoxin contamination. These strategies will involve strategies at the pre-harvest, peri-harvest and post-harvest stages to prevent contamination. Post-contamination practices are also relevant in situations where avoidance of contamination is not possible. Strategies that inform producers, handlers, consumers of what aflatoxins are, how they can be prevented from contaminating produce or managed are important for aflatoxin management. Additionally, the engagement public and private sectors, regional bodies and community associations are critical for effective aflatoxin management as they have the capacity to influence behavior changes and modulate practices that predispose food and feed to aflatoxin contamination. Furthermore, the role of research and academic institutions to provide factual information and effectively communicate technical information for aflatoxin management is crucial to avoid misinformation and application of improper practices.

Keywords: aflatoxin, management, Africa, *Aspergillus*, mycotoxins

1. Introduction

1.1. Aflatoxins and their impact on sub-Saharan Africa

Most parts of sub-Saharan Africa fall within the region of high perennial risk to mycotoxin contamination. This region is within 40°N and 40°S of the equator with warm and humid environmental conditions [1]. Under these favorable conditions of humidity and temperature, fungal prevalence is rife. Unfortunately, some fungi, as part of their metabolic processes, synthesize mycotoxins (fungal toxins), that contaminate crops intended for human and animal consumption [2]. Ingestion of contaminated crops results in morbidity and mortality where tolerable levels are exceeded in food and feed [3, 4]. Associated health dysfunctions caused by aflatoxin ingestion include liver carcinoma and other hepatic dysfunctions, stunting in children and associated cognitive deficiencies, reduced immunity, and ailments associated with nutrient malabsorption due to disruption to villi architecture [5–7]. Acute aflatoxin ingestion can result in death. In livestock, including poultry, swine and fishes, listlessness, poor feed conversion ratio, reduced productivity are additional signs of aflatoxin ingestion [8, 9].

In addition to the negative health impacts caused by aflatoxins, aflatoxins also limit income generation. This is because the import of aflatoxin-contaminated produce above regulatory limits of importing countries is prohibited. Therefore, aflatoxin contamination has been responsible for depriving the sub-Saharan region of trade opportunities. Also, trading relationships have been marred by notifications of consistent aflatoxin contamination such as through the rapid alert system of the European Union (https://ec.europa.eu/food/safety/rasff_en). Moreover, economies of households within the sub-Saharan region are negatively affected because household income is diverted in addressing morbidity caused by aflatoxicosis (illness caused by ingestion of aflatoxins) termed disability adjusted life years (DALYs) [10]. This reduces availability of income for more economically advantageous ventures. Therefore, aflatoxin management is critical for the health and economy of sub-Saharan Africa However, it is reported that countries build social networks of trading relationships based on achievable mycotoxin limits [11]. For example, France is a trading partner with the UK, Spain and Netherlands (among others) which have similar total aflatoxin standards of 4 ng/g. Similarly, the USA is a trading partner with Mexico, Colombia, Dominican Republic (and others) which have similar total aflatoxin standards of 20 ng/g in maize.

Aflatoxin management is critical also because in addition to environmental reasons for aflatoxin exposure, infrastructural deficits, informal market structures and improper cultural habits can introduce additional aflatoxin-exposure risks [12]. Management strategies therefore, of necessity requires multi-dimensional approaches that mitigate risks from multiple sources such as contamination risks during crop development, during harvesting and post-harvest. This chapter discusses the approaches that are necessary for aflatoxin mitigation, and those that have been used for the management of aflatoxins in sub-Saharan Africa and progress made so far. Brief mention is also made of emerging strategies for aflatoxin management.

1.2. Incidences of aflatoxicosis in sub-Saharan Africa

Aflatoxicosis may be broadly classified into **acute and chronic aflatoxicosis**. Acute aflatoxicosis refers to aflatoxin poisoning caused by ingestion of large doses of dietary aflatoxins. Chronic aflatoxicosis refers to aflatoxin poisoning caused by the ingestion of smaller amounts over extensive periods of time. Acute aflatoxicosis is severe often results in immediate fatalities. However, with chronic exposure the effects of exposure are cumulative, so exposure may be undetected in early stages because of its subsymptomatic nature. In sub-Saharan Africa, aflatoxin contamination has been reported by technical experts in academic journal and reports and by some news media outlets. Technical research has disclosed the prevalence and exposure levels in crops (e.g. maize, groundnuts, melon seeds (*egusi*), chillies, dried fish, local spices) [13–15]; in addition to biomarkers (e.g. those present in breastmilk of nursing mothers, blood serum and urine) [16, 17]. A comprehensive report of incidences have been reviewed [18]. These have revealed the presence of aflatoxins in food crops as an indicator of dietary exposure. These scientific studies have been conducted as part of academic programs, and developmental efforts in collaboration with national systems to establish exposure levels. They have majorly been for chronic exposures, and to provide empirical evidence for outbreaks caused by acute exposure. Incidences of chronic exposure are not as momentous as those for acute exposure, but they could be lifelong starting early in life. This is especially because exposure can precede birth, from foetal exposure through umbilical cord, to aflatoxin exposure very early in life (from the first 1000 days of life), via mothers' breastmilk (where the nursing mother has had dietary aflatoxin exposure), and through weaning foods made using contaminated food products [19]. Furthermore, in many parts of sub-Saharan Africa, staple food consumption is frequent and forms a constant source of dietary exposure to consumers. Limited diversity in the meals consumed increases exposure risk, especially if the food consumed is contaminated by these harmful toxins. Aside from the consumption of foods for dietary needs, recreational consumption of locally brewed beers is another risk factor contaminated cereals could form the stock material from which the brews are made from [20].

Converse to reports majorly on chronic exposure by technical experts, news media/communication expert reports are often based on acute exposure. Acute outbreaks have caused national alarm (such as those recorded in 1980, 2004 and 2012 in Kenya; and 2016 in Tanzania). These outbreaks of acute aflatoxicosis occurred due to the ingestion of unsuspectingly high levels of aflatoxins in maize consumed as a staple food Outbreaks were first reported as 'mysterious illness' or caused by 'toxic' or 'poisonous' food. This is due to the clandestine nature of aflatoxins. This bears similarity to the foremost global report of aflatoxicosis in 1960 called the "Turkey X' disease, where 'X' was the mysterious unknown [21]. The covert nature of aflatoxins is primarily because sensual perception of aflatoxins is nearly impossible since the toxins are invisible, tasteless and odorless when present in food crops. Management of aflatoxins during these times have called for crisis response actions that immediately forestall continued exposure.

2. Aflatoxin management strategies

Aflatoxin management requires multiple strategies including the following which are further discussed in details hereafter: Awareness of aflatoxins, Pre-harvest aflatoxin prevention/reduction, Peri-harvest aflatoxin prevention/reduction, Post-harvest aflatoxin prevention/reduction and Post-contamination aflatoxin management.

2.1. Awareness of aflatoxins

Awareness of aflatoxins is critical to its management because information is the basis for initiating and sustaining measures to control aflatoxin exposure and associated health and economic implications. Awareness is a result of access to available information. This knowledge helps to inform the general public, health care practitioners, social workers, policy makers and other stakeholders on the risks of mycotoxins and control strategies necessary for prevention of aflatoxicosis and post-contamination management of contaminated crops, where prevention of contamination is not possible. There are different schools of thought regarding the way awareness creation is most effective [22, 23]. One school of thought suggests that the focus should be a top-bottom approach in terms of awareness creation about the problems of and solutions to aflatoxins without a bottom-up approach. The argument for this is that all that is required by the general public is to understand that there are differences in food quality, rather than the technical details of aflatoxins. This system will require that a food grading system is in place that enables the lay buyer to make financial decisions based on product differentiation. Furthermore, this may be more effective in a more organized market system where product differentiation on price and quality attributes are easily discernable. Another school of thought suggests that awareness creation should be a combination of top-down and bottom-up approaches. The argument for this is that education of the lay person on the risks associated with aflatoxicosis is necessary for behavioral changes towards crop management practices. This is important given the informal systems of trading that occur at the rural levels. Furthermore, as the systems of crop management are varied and so may require specific changes in practices suited to the customs of the regions.

2.1.1. Multi-faceted aflatoxin-management strategies

Current efforts made on aflatoxin awareness have been via multiple channels including policy briefs, regional reports, traditional media and social media reports, and word-of-mouth by various bodies such as regional government bodies and government institutions, private-sector and commercial organizations, extension services and farmers groups/community societies, and academic and research institutions among others.

2.1.1.1. Regional governments and government institutions awareness

The most notable regional bodies in sub-Saharan Africa regarding aflatoxin management is the Partnership for Aflatoxin Control in Africa (PACA), established under the Africa Union at the 7th Comprehensive Africa Agriculture Development Program (CAADP). PACA has raised awareness at regional and national levels through programs such as Pan-African workshops (these workshops have brought together scientific experts, lay people, policy makers, farmers and industries), policy briefs, coordination of sensitization and surveillance exercises at regional and national levels (http://aflatoxinpartnership.org). Through PACA's efforts, which are often in partnership with key organizations involved in aflatoxin management/mitigation, policies requiring the control of aflatoxins in foods is becoming mainstream. In recent years (from 2014), PACA has implemented the Africa Aflatoxin Information Management System) (AfricaAIMS) in pilot countries (including Senegal, The Gambia, Malawi, Nigeria, Tanzania and Uganda) to collate and harmonize data on aflatoxins [24]. This has been useful for assisting countries to make definitive and coordinated efforts in aflatoxin surveillance and discussions for aflatoxin management.

So far, technical reports form many of the reports on aflatoxins and aflatoxin management. There are concerns that these reports are too technical and so the dire messages of aflatoxin exposure, and beneficial information on relevant interventions for aflatoxin management may not reach all stakeholders. Infographics and short documentations via policy briefs such as those by PACA and the International Food Policy Research Institute (IFPRI) are being developed. These are deliberate measures that that have been taken for technical information to be readily grasped by lay readers/audiences and policy makers.

Other regionals communities involved with raising awareness on aflatoxin management in the sub-Saharan African region include Permanent Interstate Committee for Drought Control in the Sahel/Comité permanent inter-État de lutte contre la sécheresse au Sahel (CILSS), Common Market for Eastern and Southern Africa (COMESA) and Economic Community of West African States (ECOWAS). Regional governments and government institutions communities assist with the development of regulatory schemes and their enforcement, aflatoxin testing, development of infrastructure and trade relationships, coordinating the access to appropriate technologies and infrastructure and establishment of trade relationships. Awareness within the communities is also important for proper decision-making. This is done through workshops and meetings wherein technical experts can communicate the technical details in simpler terms and respond to queries to clear doubts.

2.1.1.2. Private-sector/commercial organizations

Private sector participation is key for aflatoxin management in the sub-Saharan Africa. This is particularly important because the private sector through demand-driven approach can influence the behaviors of growers, aggregators and important stakeholders towards adoption of aflatoxin management techniques. However, where there is no financial incentive or social incentive to change, growers' inertia to change can be high. The positive influence of the private sector in changing behaviors that promote aflatoxin accumulation have been demonstrated. A few examples are discussed here.

Example 1 – The World Food Program (WFP).

Through a scheme, Pay for Performance (P4P), the WFP provided food relief in danger and conflict prone-regions of the world and aided those economies in improving crop quality and reducing aflatoxin contamination [25]. P4P requires grains for food relief. Due to the need to procure high quality food materials for disaster relief and a desire to promote crop production and so aid the economies within such regions, WFP influenced growers' behaviors for reduced aflatoxin contamination. This improved grain quality in the market and introduced grading systems. Examples of countries where this project covered include Zambia, Tanzania, Ghana, Burkina Faso, Democratic Republic of Congo, Ethiopia. The project was implemented between 2008 and 2013 [25].

P4P operated via grassroot and growers' education on aflatoxin mitigation and measurement. Aflatoxin measurement in crops was done by using the blue box that contained aflatoxin test kits, moisture meter, sieves, in addition to other items. Due to the P4P scheme/initiative, WFP rejections of grains in market outlets decreased. WFP also paid a premium price above the prevailing market price to farmers who invested in behavior change as part of P4P. This percentage reduction demonstrated the power of influence that the private sector or those with high purchasing power can have on the market. A more detailed information on this program can be found at http://www1.wfp.org/purchase-for-progress. As part of the program under P4P, producers were trained on crop management practices at post-harvest such as rapid drying of grains to below 14% moisture content, grain sorting, proper sampling techniques for aflatoxin measurement, aflatoxin testing and sample grading. WFP purchased products from the farmers were possible and linked the farmers to markets for grains that they were unable to take up.

Example 2 – Nestlé Foods.

Mycotoxin screening, including screening for aflatoxins forms a critical component of Nestlé's quality assessment of raw materials. Like WFP, Nestlé has embarked on capacity development initiatives from farmers in out-grower schemes that they work with. This was the Grains Quality Improvement Project. Through training on crop management practices, including post-harvest management, Nestlé markedly reduced their rejection rate from 96 to 4% (between 2007 and 2017) in sub-Saharan countries such as Ghana where this concept has been applied [26]. The Grain Quality Improvement Project (2009) was conducted with the International Institute of Tropical Agriculture in Ghana, Nigeria and Côte D'Ivoire [27, 28]. This kind of initiative was imperative for an International Food Brand Nestlé. Additionally, it helped the company to continue to buy locally and at the desired quality. The social impact of this project was perhaps important for Nestle's cooperate social responsibility goals and for the brand to retain its competitive advantage while not reneging on the strict quality standards for its food grains.

Example 3 – AgResults Nigeria Aflasafe™ Pilot Program.

The private sector involvement via the AgResults Nigeria Aflasafe™ Pilot program was designed to incentivize the use of technologies and implement practices that reduce aflatoxin incidence in crop (http://agresults.org/en/283/). Aflasafe™ is a biological control technology that favors the proliferation of naturally occurring populations of non-aflatoxigenic *Aspergillus* strains through competitive exclusion of toxin-producing aflatoxigenic *Aspergilli* [29]. The AgResults Nigeria Aflasafe™ Pilot Program introduced in Nigeria in 2013 encourages private businesses, called (Aflasafe) Implementers, involved in coordinating farmers and aggregating farmers' produce to reduce aflatoxin prevalence in crops by providing the necessary skills and technical information for Implementers to do so via training workshops and linking them to markets seeking premium quality grains (via Innovation Platforms) [30]. The AgResults program operates in Nigeria and is specifically targeted at promoting the use of Aflasafe™ as an inclusion to the good agricultural practices provided in the training package.

The private sector's involvement via this pilot program is two-fold. (1) The farmers' grain purchase coordination through Implementers (private businesses that coordinate the training of aflatoxin management including the use of Aflasafe™) ensures that demand for high quality grains are accessible; and (2) Purchase of high quality grains by the food and feed industries (especially the poultry industry) drive the demand for high quality grains. These

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food and feed industries pay a premium price for the high-quality grains. Additionally, the implementers gain a premium for proper implementation of the aflatoxin-management practice [31]. Due to the sustained demand for high quality grain by the food and feed industries, the implementers maintain the demand for the use of Aflasafe as part of aflatoxin management practices. As such, with the modulation of *Aspergillus* populations through repeated use of Aflasafe demand for maize with safe levels of aflatoxins in maize grains where the market demands are met with a price incentive as a driver in a pull-mechanism for the implementation of aflatoxin management techniques and technologies.

2.1.1.3. Extension services and farmers groups/community societies

In many parts of sub-Saharan Africa, farmers rely on and trust extension officers as accurate and reliable sources of agricultural advice. Therefore, extension agents are a powerful source of knowledge dissemination and awareness creation. However, due to the limitations in budgetary allocations, extension officers do not always have the financial power to reach out to many farmers in the farming communities with up-to-date knowledge on skills and technologies. Additionally, budgetary constraint also limits the ability of the extension officers to regularly receive training required to update their knowledge, skills and practices.

Farming communities have started organizing themselves into community groups with leadership structures that help in information dissemination [32]. When training is received by leaders in these groups within a central location, they are then able to disseminate the information in their local chapters. Information about aflatoxin management in many occasions has reached farmers this way. Through these organizational structures, groups are also able to organize field days or famers field schools. Field days where demonstration plots are displayed to farmers also constitute a form of training regularly done. However, this is difficult for aflatoxin control demonstrations, since the chemical toxin is not perceptible with the senses.

2.1.1.4. Academic and research institutions

Academic and research institutions play a key role in creating awareness of the control strategies for aflatoxin and aflatoxicosis prevalence. It is important for them to share accurate information about the management of aflatoxins. Distorted or inaccurate information about aflatoxin management is detrimental to awareness creation efforts made towards aflatoxin mitigation. Academic and research institutions have contributed to raising awareness through the publication of technical reports, discussions at technical meetings and contributions to non-technical writings and reports. They also contribute by organizing training meetings for important stakeholder groups such as extension practitioners, farmers groups, the private sector, regulatory organizations, and other important stakeholders to attend. It is also important for educational institutions and research organizations to partner in training students on aflatoxin management and other phytopathology concerns. This may ensure continuity in capacity development for the management of aflatoxigenic fungi, their toxins and other food security and food safety threats.

2.1.1.5. Other awareness platforms

Online documentation (e.g. websites, blogs, social networks), field extension services, commercial organizations and word of mouth are also important avenues of awareness creation. Dissemination of information via traditional media such as newspaper publications, radio broadcasts and discussions are also important for ensuring that the population gets the required information and to gauge the level of awareness/responses to the sensitization efforts. It is important that these efforts continue where already in place and make-up concerted efforts that are contributory to awareness creation as an important aflatoxin management strategy.

2.2. Aflatoxin management

2.2.1. Pre-harvest aflatoxin prevention/reduction

Although pre-, peri, and post-harvest aflatoxin management strategies; have been itemized as different from awareness creation, knowledge of these strategies is important for awareness. For pre-harvest aflatoxin management to receive contextual appreciation it is important to understand how aflatoxin contamination occurs. Natural contamination of food by aflatoxins requires contamination by aflatoxigenic strains of *Aspergilli.* Aflatoxin-producing strains of the *Aspergillus* section *Flavi* group such as *Aspergillus flavus, A. parasiticus, A. nominus* and S strains are responsible for contamination. Recently, a novel aflatoxin producer called *A. korhogoensis* (defined as a "*a novel cryptic species within the A. flavus clade*" was identified in Côte d'Ivoire [33]. Route of contamination is typically one by which the spores of these strains can enter the grains. Fungal spores reside on crop debris, in soils and can be air-borne when dispersed by wind. Spores can also be carried by insects and birds directly to the grains and thereby contaminate them [34–36].

To this end, methods that serve as barriers in preventing aflatoxigenic fungi from gaining entrance into the crop are critical for the control of aflatoxin contamination. For the maize during crop development, spores can enter grains via the silk channel (each silk thread leads to a kernel of maize), through cracks in the kernel because of abiotic stress such as heat or drought, and biotic stresses such as insects or birds [34, 37]. Furthermore, reducing the populations of the aflatoxin-producers in the environment can also reduce the risk of human exposure to aflatoxin. Pre-harvest management of aflatoxin contamination therefore comprises:

- Breeding efforts that increase the barriers to aflatoxigenic fungi [38]. These have been explored through increased tightness of husk cover and increased hardness of grains. These reduce the possibility of fungal entry into the grain and therefore aflatoxin contamination. However, flint grains (very hard grains) are difficult to process and because of that, farmers are not always willing to grow these varieties. Gene silencing as a method for aflatoxin management was recently developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) [39]. However, acceptance of genetic modification of foods in and for sub-Saharan Africa has not received wide acceptance.

- Insect and pest control reduces the populations of pests that pre-dispose the crop to aflatoxin contamination. Insect control is particularly very important because of the strong correlation between mycotoxin contamination and insect damage. Using pest control can significantly reduce the risk of associated mycotoxins. With the growing inclinations for organic farming globally, the use of non-synthetic pesticides is preferable. Bird scare to prevent damage to the crop is also important. These practices do not only address the risk of contamination but are also important for maintaining optimum yields.
- Biological control of aflatoxin is another pre-harvest control strategy that is being adopted in sub-Saharan Africa. Aflasafe as reviewed earlier is a biocontrol measure. It involves the use of non-toxin producing strains to compete with aflatoxin-producing strains on the field as a naturally occurring displacement strategy implemented about a fortnight before crop flowering. Native strains are isolated from regions where the product is to be applied to the most suited/adapted non-toxin producing strains to that environment through rigorous research efforts for isolate selection. The technology has been commercialized under the trade name Aflasafe in a few African countries with continuing research efforts [29].

While mold contamination is known in many parts of sub-Saharan Africa because of their visual presentation and bitter taste, the aflatoxins that they produce are frequently unknown because they lack sensory attributes. Therefore, moldy grains would attract lesser value, while grains without visible mold, are not necessarily without aflatoxin contamination. Therefore, it is not uncommon for these grains to be used in the processing of food or feed material in which mold appearance is masked. This is for instance, in the processing of peanut butter, groundnut cake, poultry feed and fermentation for beers [40–43]. However, this is not a good management technique for aflatoxins as these poor-quality grains enter the food chain as alternative food products and the processing techniques may either minimally reduce the aflatoxins or concentrate the aflatoxins. However, visual signs of mold are not the only indicators of fungal infestation. It is possible for strains that produce high levels of aflatoxins to mildly infected grains, resulting in high aflatoxin levels. Also, grains contaminated with aflatoxins that have been washed and dried after infection, may no longer have visible mold growth but still contain the aflatoxins. This is because aflatoxins are only very mildly soluble in water at 10 mg/ml and are heat stable up to 150°C, after which they are only mildly detoxified [44].

2.2.2. Peri-harvest aflatoxin prevention/reduction

During harvest, exposure to aflatoxin contamination can occur due to practices that expose the crop to aflatoxigenic fungi as it is harvested. These could include harvesting during the rains or during high moisture conditions that encourage fungal proliferation; harvesting into recycled or contaminated containers such as bags, and carts that harbor the toxigenic mold or insects, or directly onto uncovered ground surfaces, threshing during harvest in a way that damages the grains. Preventing these would therefore involve the use of clean surfaces or containers for placement of harvested grains and rapid drying after harvest to avoid incubation of the fungus and subsequent accumulation of the toxin.

2.2.3. Post-harvest aflatoxin prevention/reduction

Post-harvest practices occur immediately after harvesting grain produce. These practices are inclusive of practices undertaken such as transportation, storage and processing of the harvested agricultural produce. As with peri-harvest practices, it is important to prevent predisposing factors such as pest infestation, re-contamination from re-used bags or improperly sanitized vessels or vehicles. It is therefore critical to ensure proper pest control, good aeration by placing stored grains in dry and well aerated storehouses. The use of wooden pallets, and away from walls, rather than placing bags in direct contact with floor surfaces and walls limits aflatoxin accumulation in hot spots. Other important post-harvest practices for reducing contamination include winnowing and sorting of grains to remove low density materials and grains that tend to harbor high proportions of the contaminated material [45].

2.2.4. Post-contamination aflatoxin management

Post-contamination management strategies are implemented when all attempts of reducing aflatoxin levels to permissible limits have failed. It is not recommended as a strategy without attempts to prevent contamination. There are controversies surrounding the implementation of some of these practices for the management of aflatoxins. Some of the practices include dilution with non-contaminated grains to reduce bulk contamination, ammoniation [46], binding of aflatoxins using adsorbents or aflatoxin-binders used for animal feed [47], nixtamalization [48], grain fermentation, radiation (including solar radiation) [49], grading to allow higher levels for non-dairy ruminants up to permissible levels, or use as alternative non-food uses such as production of bio-ethanol.

2.3. Conclusion

Aflatoxin management, including continuous public awareness and monitoring is required both on-farm and off-farm. Awareness is a critical stage of management and covers pre-harvest, peri-harvest, post-harvest stages of crop production. Post-contamination options are the last alternative to aflatoxin management and is the least preferred method for aflatoxin management in food and feed grains due to other associated risks of contaminant fate. The most preferred method is to prevent entry of aflatoxin-producing fungal strains, then limiting the ability of contaminating aflatoxin-producing strains from synthesizing and accumulating the harmful toxins in food grains. With proper aflatoxin-management, health and income improvement will increase in sub-Saharan Africa – a region with a high perennial risk of aflatoxin exposure, thus boosting the health of the people within the region.

Conflict of interest

The author declares no conflict of interest. Replace the entirety of this text with the ‘conflict of interest’ declaration.

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