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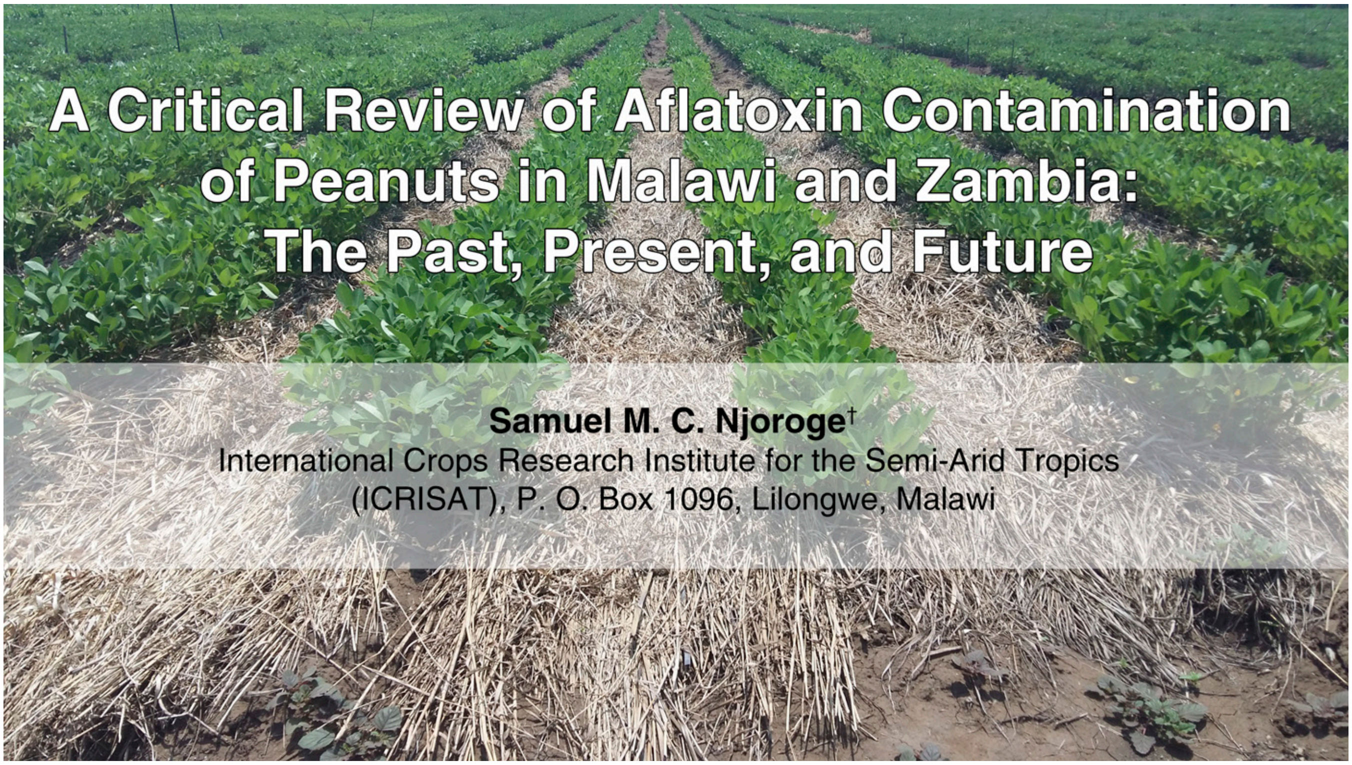

A Critical Review of Aflatoxin Contamination of Peanuts in Malawi and Zambia: The Past, Present, and Future

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Peanut (*Arachis hypogaea* L.), also known as groundnut, is an important crop in Malawi and Zambia, which is grown mostly by smallholder farmers who account for more than 90% of the total production (Derlagen and Phiri 2012; Mofya-Mukuka and Shipekeza 2013). The importance of the crop is anchored in its utility to improve soil fertility in cereal-based cropping systems, to enhance the livelihoods of farming households who consume it as part of their diet and also sell it for cash, and to earn foreign exchange when exported. In Africa, 4.2% of the total area under peanut production comes from Malawi (373,925 ha) and Zambia (237,423 ha), and within the continent, these countries are ranked 14th and 17th, respectively (FAOSTAT 2017).

Research and development efforts have resulted in an increase in both the area under peanut production and productivity. Compared with 20 years ago (1994 to 2014), the productivity of the crop (kg/ha shelled) has improved from 240 to 595 in Malawi, and 307 to 454 in Zambia (FAOSTAT 2017). However, despite the increase, productivity is still considered low. Yields are limited from reaching their potential under rain-fed production of more than 2,000 kg/ha by poor agronomic practices (e.g., delayed planting at the onset of the rainy season, low plant populations per ha, poor weed management, intercropping, and delayed harvesting), poor to no disease and insect pest management, drought stress, and growing low yielding local varieties (Mpiri 1994; Ngulube et al. 2001; Siambi et al. 2007; Subrahmanyam and Hildebrand 1994; Waterworth 1994).

Technologies for improving productivity are available. However, a key challenge that still needs to be solved in these countries is how to produce peanuts with acceptable levels of aflatoxin contamination—for formal markets that are increasingly being regulated, and perhaps more importantly, for under-regulated informal markets and for home consumption from subsistence farming (Matumba et al. 2016; Monyo et al. 2012; Njoroge et al. 2013, 2016b, 2017; Seetha et al. 2017). Aflatoxin contamination, discovered over 50 years ago, is a major impediment to the safe use of peanuts, a nutritious crop valued for its oil, protein, amino acids, and micronutrients. Aflatoxins reduce the absorption of nutrients in the alimentary canal (Wild 2007), and children may become stunted when they are chronically exposed to aflatoxin contamination at an early age (Gong et al. 2002, 2003; Magoha et al. 2014). For more information on the effects of aflatoxin on human health, Williams et al. (2004) and Wild (2007) provide good overviews.

In this review, I begin by presenting data on the occurrence of aflatoxin contamination in peanuts. This data will show that aflatoxin continues to be a problem in both formal and informal trade. I also focus on the impacts that aflatoxin contamination continues to have on the peanut trade, illustrating that unlike 30 years ago, most of the peanut trade has now shifted to domestic and regional markets that do not restrict the sale of aflatoxin-contaminated peanuts. Regional markets are, however, also beginning to enforce standards on aflatoxin, which will further impact the peanut trade.

Whereas we can show the impacts of aflatoxin on formal export trade, we don't really know the full cost burden of aflatoxin contamination. Hidden costs would include costs associated with managing aflatoxin contamination, both prevention and remediation or reprocessing, costs of rejected produce, costs of reduced value, and, ultimately, costs associated with the health burden of exposure. The impacts on health are not particularly well documented and research in this area is still in the formative stage both in Malawi and Zambia.

However, for regional countries, important in trading peanuts with Malawi and Zambia, aflatoxin exposure health studies have been published. Therefore, from increased awareness of the negative impacts of aflatoxin on health, these importing countries may become

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more restrictive to aflatoxin-contaminated produce in the future. Research to determine aflatoxin exposure in infants and children from Tanzania has been published (Magoha et al. 2014; Shirima et al. 2013) and showed the presence of aflatoxin in breast milk and food consumed by children. Documented evidence on health impacts from Tanzania also includes a recent aflatoxicosis incident that occurred in the Dodoma and Manyara regions, killing 19 people (PACA 2016). In Kenya, numerous studies have been conducted on aflatoxin exposure within the population (Azziz-Baumgartner et al. 2005; Obura 2013). Many outbreaks of aflatoxicosis have been recorded in Kenya, and the most severe resulted in 125 people dying from eating contaminated maize in 2004 (Azziz-Baumgartner et al. 2005; Lewis et al. 2005).

This review addresses available technologies for mitigating aflatoxin contamination, clearly stating their advantages and disadvantages, discussing barriers to their adoption, and identifying gaps still in need of research. Newer technologies are gaining momentum, such as biological control using nontoxigenic strains of *Aspergillus flavus* (Bandyopadhyay and Cotty 2013; Bandyopadhyay et al. 2016; Cotty 1990; Dorner 2009; Dorner et al. 2003; Fravel 2005). The biocontrol approach is being presented to farmers in Africa as an anchor technology that other aflatoxin mitigation efforts should complement (Bandyopadhyay et al. 2016). The efficacy and potential pitfalls associated with this approach are also discussed.

On the other hand, an integrated approach that includes genetic resistance, agronomic and cultural techniques, and postharvest handling and processing, has long been promoted as the solution to solving the aflatoxin problem (Siambi et al. 2007; Turner et al. 2005; Waliyar et al. 2003, 2007, 2013, 2015). However, aflatoxin is still a problem and a common contaminant in peanuts and products processed from it (Matumba et al. 2015a, b; Monyo et al. 2012; Njoroge et al. 2013, 2016b, 2017). The persistent issues associated with aflatoxin contamination results in questions about whether these technologies are being implemented or their effectiveness.

A lot of effort and money continues to be invested in Malawi and Zambia, and in other African countries, into mitigating aflatoxin contamination, but evidence of long-term success is limited. Is it because farmers and processors are not being offered the right incentives to adopt aflatoxin mitigation strategies? This section concludes by asking who should pay for aflatoxin control. In developed countries like the U.S.A., farmers do not bear the full cost of controlling aflatoxin—buyers and shellers of the raw nuts from farmers bear the majority of the cost (Wu 2014). Are smallholder farmers in Malawi and Zambia able to bear the costs of controlling aflatoxin?

Finally, based on past and current initiatives, the prospects of eliminating aflatoxin in the near future at the household level and in trade are not promising. For change to occur, an economic value must be found for poor quality peanuts that can be channeled into safe alternative end-uses, as the incentive needed to remove contaminated peanuts from the human food chain. The private sector has to play its role in providing incentives to farmers for better quality harvests and to create economically viable alternative end-use options for peanuts of lower quality, all within a supportive environment facilitated by revised and implemented government policies. Solutions must be amenable for implementation by smallholder farmers who are the majority producers of peanuts, and by actors in the under-regulated and regulated peanut trade.

Occurrence of Aflatoxin Contamination

Aflatoxins are toxic chemical compounds produced by *A. flavus* and *A. parasiticus* (Amaike and Keller 2011; Craufurd et al. 2006; Diener et al. 1987; Horn 2003; Klich 2007; Monyo et al. 2012; Njoroge et al. 2016b; Okoth et al. 2012) and are common contaminants of oilseed crops, e.g., peanut, corn, cottonseed, and sunflower, and other crops such as sorghum, rice, paprika, etc. (Amaike and Keller 2011; Diener et al. 1987; Hendrickse 1997; Horn et al. 1995; Matumba et al. 2015a; Mutegi et al. 2009; Njoroge et al. 2013, 2016b, 2017; Okoth et al. 2012; Seetha et al. 2017; Siambi et al. 2007). Aflatoxins were first identified in the early 1960s after more than 100,000 turkey poults died after being fed contaminated peanut meal, which was later found to contain aflatoxins. Aflatoxins were later shown to also negatively impact human health and, therefore, it is a regulated hazard in food (Azziz-Baumgartner et al. 2005; Cardwell and Henry 2004; Groopman et al. 2008; Hendrickse 1997; Lewis et al. 2005; Lu 2003; Wild 2007; Wild et al. 2015; Williams et al. 2004; Wu 2014). More than 100 countries have set standards for allowable aflatoxin limits (Wu 2014).

Data on the prevalence of aflatoxin contamination is essential for applied research into their impact on health and for effective mitigation (Wild et al. 2015). Information on the prevalence of aflatoxin contamination in peanuts and its products along the value chain in Malawi and Zambia, and the regional market destinations of DR Congo, Kenya, Tanzania, and South Africa, continues to be published (Table 1). From the published reports, it is evident that aflatoxin contamination continues to be a major problem along the peanut value chain despite sustained efforts through research and development to mitigate it.

Initial reports published on the occurrence of aflatoxin contamination focused on documenting losses from export trades (Babu et al. 1994). These were then followed by reports on interventions along the value chain against aflatoxin contamination. Siambi et al. (2007) reported on interventions against aflatoxin contamination that enabled farmers from Malawi to regain access to the European Union markets. It was not until much later that reports started to focus more on domestic consumption of contaminated products (Bumbangi et al. 2016; Kachapulula et al. 2017; Monyo et al. 2012; Njoroge et al. 2013, 2016b, 2017; Seetha et al. 2017), the lack of awareness among both the farmers and the public on aflatoxin contamination (Matumba et al. 2016; Monyo et al. 2012), and the ineffectiveness of regulations for limiting aflatoxin in human food (Matumba et al. 2017; Njoroge et al. 2016b, 2017).

The shift to focus deliberately on local levels of aflatoxin contamination along the value chain was probably triggered by the 2004 aflatoxicosis case in Kenya, where over 125 people died from eating contaminated maize (Lewis et al. 2005). Since then, many studies have been published showing current levels of aflatoxin contamination. In addition, studies looking at the occurrence of aflatoxin contamination from different agroecologies, markets, sample types, and across seasons have also been published recently (Bumbangi et al. 2016; Kachapulula et al. 2017; Monyo et al. 2012; Njoroge et al. 2016b, 2017; Seetha et al. 2017). Fewer studies have published data on the prevalence of human exposure to aflatoxins in Kenya, Malawi, and Tanzania (Azziz-Baumgartner et al. 2005; Magoha et al. 2014; Obura 2013; Seetha et al. 2018; Shirima et al. 2013). Prevalence data on animal exposure to aflatoxins have not been published.

Impacts of Aflatoxin Contamination

Trade: a shift to less restrictive export markets and poorly regulated domestic markets. Peanut is currently an important export crop in Malawi and Tanzania, whereas Zambia used to export significant amounts 40 to 50 years ago (Fig. 1). Among these three countries, Malawi generally exports more peanuts than Tanzania and Zambia, and also generates significantly more earned foreign exchange (Fig. 2). Therefore, reduced access to export markets would be felt more by Malawi than by the other two countries. At present, 40 to 60% of total production in Malawi is marketed, of which 35% is processed into peanut cake, oil, and peanut butter, and the rest is exported (Derlagen and Phiri 2012; Emmott 2013). The amount currently exported from Malawi has steadily increased to surpass levels exported before the market crashed during the early 1990s (Fig. 1). No peanuts were formally exported from Malawi during the early 1990s market collapse, mostly because of aflatoxin contamination, and also due to farmers shifting from growing peanut to tobacco as their main cash crop (Babu et al. 1994; Derlagen and Phiri 2012).

Until 1987, the Agricultural Development and Marketing Corporation (ADMARC), a state parastatal body in Malawi, was the sole trader of peanuts. As a sole trader, ADMARC enforced quality and tested for aflatoxin contamination (Babu et al. 1994) with the aim of supplying quality peanuts to the export markets. ADMARC would only export peanuts when aflatoxin contamination was less than 5 ppb. ADMARC successfully marketed peanuts to the European Union until the late 1980s, when aflatoxin contamination became a problem or standards were more strictly enforced. Currently, marketing of peanuts is liberalized and is mostly driven by the private sector. However, the problem of aflatoxin contamination has continued to persist as determined by the levels of aflatoxin contamination both in products marketed locally and nonaccess to aflatoxin-restrictive export markets (European Union Trade Helpdesk 2017; Magamba et al. 2017; Matumba et al. 2015b; Monyo et al. 2012; Njoroge et al. 2016b).

As a result of aflatoxin contamination, peanuts from Malawi and Zambia cannot consistently access more restrictive markets such as those in the EU. A recent article in the Daily Press in Malawi put the losses due to lack of market access from aflatoxin contamination at US $11 million, but included maize and other grains together with peanuts (Jimu 2017). To address this problem, many projects have been funded to mitigate aflatoxin contamination and to 'restore' market access. Some interventions in Malawi and Zambia aimed at reducing aflatoxin contamination in peanuts for export to the EU and South Africa have been successful in increasing exports into niche markets (Siambi et al. 2007; Njoroge et al. unpublished). However, such interventions are not sustainable in the long run if their sole aim is to reestablish access to export markets.

Malawi last exported peanuts to the UK in 2009. Since 2010, it exported only a small amount to the EU, specifically to the Netherlands, 47,000 kg in 2010, and the last export was 19,000 kg in 2014 (European Union Trade Helpdesk 2017). Zambia also stopped accessing EU markets and last exported to the Netherlands, 14,000 kg in 2006 (European Union Trade Helpdesk 2017). However, peanuts from Malawi and Zambia still find markets in neighboring African countries whose markets are comparatively less restrictive on the maximum allowable aflatoxin contamination than the EU or are poorly enforced with minimal to no testing done to determine aflatoxin contamination. For example, in 2005, 56% of the total peanuts export value was exported to South Africa, followed by 20% to Zimbabwe, 9% to Zambia, and 15% to other countries (Derlagen and Phiri 2012). Compared to Malawi, Zambia and Tanzania are becoming more important regional markets for peanuts (Fig. 3). Data from 2010 shows a shift in the regional market destination of peanut from Malawi where 49% of total export value was exported to Tanzania, 29% to Kenya, 11% to South Africa, and 10% to Zimbabwe (Derlagen and Phiri 2012). Peanuts are also exported informally to neighboring countries, and it is hard to capture this data. Informal exports are not tested for aflatoxin contamination and in 2014, 19,000 metric tons, about a third of all peanuts exported from Malawi, occurred informally (Elderman and Aberman 2014).

The change in access to export markets can partially explain the reduced value per ton of peanuts exported. In the early 1960s to 1981, the price per ton of peanuts exported from Malawi steadily increased and reached US $1,000 per ton. However, the value per ton of peanuts exported from Malawi thereafter declined during the 1980s and has not yet reached US $1,000 per ton. Furthermore, despite the current increase of exports of peanuts from Malawi (Fig. 1), the value obtained per ton fell to less than US $100 per ton during 2012 and 2013 (Fig. 4). In contrast, the value of peanuts exported from Zambia previously was higher than those from Malawi and Tanzania (Fig. 4) (FAOSTAT 2017), implying that until 2001, Zambia was able to access better markets. However, since 2001, the value per ton of the export from Zambia has been similar to those from Tanzania and Malawi (Fig. 4). It is therefore apparent that the success of the peanut sector should not just be measured by countries being able to export, but also on the value of the exports, which is tied in part to low aflatoxin contamination.

Access to some markets within Africa are also changing as tighter enforcement of aflatoxin standards is implemented, and this regulation is affecting exports from countries like Malawi. For example, exports to South Africa from Malawi are in decline. Both South Africa and the European Union accounted for just 7% of all peanuts exported formally from Malawi in 2013 and 4% in 2014 (Elderman and Aberman 2014). Regional African markets that are currently not

Table 1. Documentation of aflatoxin contamination levels in peanut or peanut products sourced from farms and retail markets in the Democratic Republic of Congo, Kenya, Malawi, South Africa, Tanzania, and Zambia, and in peanuts exported from Malawi

Country	Year	Sample source	Product	N[s]	Aflatoxin range (µg/kg)	Reference
DR Congo[t]	2010–2011	Retail	Kernels	20	2–1,258 AFB_{1+2} + AFG_{1+2}[u]	Kamika et al. 2014
Kenya	2006	Farm	Kernels	769	0–7,525 AFB_1[v]	Mutegi et al. 2009
	–[w]	Retail	Kernels	82	ND[x]–2,377	Ndung'u et al. 2013
	2010	Retail	Peanut butter	12	>10–<600 AFB_{1+2} + AFG_{1+2}	Filbert and Brown 2012
Malawi	1980–1991	ADMARC[y]	Kernels	11,422	–[z]	Babu et al. 1994
	2003–2004	Farm	Kernels	1,484	ND	Siambi et al. 2007
	2003–2004	Farm	Kernels	1,864	2.1–4 ppb AFB_1	Siambi et al. 2007
	2003–2004	Farm	Kernels	457	>4 ppb AFB_1	Siambi et al. 2007
	2008–2009	Farm, Retail	Kernels	1,397	ND–3,240 AFB_1	Monyo et al. 2012
	2013	Retail	Peanut butter	14	34.3–115.6 AFB_{1+2} + AFG_{1+2}	Matumba et al. 2014
South Africa	2010–2011	Retail	Kernels	20	ND–73 AFB_{1+2} + AFG_{1+2}	Kamika et al. 2014
Tanzania	2014–2015	Farm	Kernels	275	ND–1,000 AFB_1	Seetha et al. 2017
Zambia	2012–2015	Farm	Kernels	399	ND–4,980 AFB_1	Njoroge et al. 2013
	2012–2015	Retail	Peanut butter	954	ND–10,70 AFB_1	Njoroge et al. 2016b
	2012–2015	Retail	Kernels	163	ND–11,100 AFB_1	Njoroge et al. 2017
	2012–2015	Retail	Peanut powder	39	ND–3,000 AFB_1	Njoroge et al. 2017
	2015	Retail	Kernels	92	0–49 AFB_{1+2} + AFG_{1+2}	Bumbangi et al. 2016
	2013	Farm	Kernels	12	>100 AFB_{1+2} + AFG_{1+2}	Kachapulula et al. 2017
	2013	Farm	Kernels	83	>4 AFB_{1+2} + AFG_{1+2}	Kachapulula et al. 2017
	2013	Farm	Kernels	68	>4 AFB_{1+2} + AFG_{1+2}	Kachapulula et al. 2017

[s] Number of samples tested for aflatoxin contamination.
[t] Democratic Republic of Congo.
[u] Total aflatoxin contamination. Aflatoxin B_1 + aflatoxin B_2 + aflatoxin G_1 + aflatoxin G_2.
[v] Aflatoxin B_1.
[w] Year of sample collection or analysis is not stated in the article.
[x] Aflatoxin contamination was below the limit of detection.
[y] Agricultural Development and marketing corporation. In Malawi, before the export market of peanut was liberalized in the 1990, ADMARC had the sole monopoly to export peanuts.
[z] Aflatoxin levels not reported. However, ADMARC tested peanuts for aflatoxin contamination and only exported when aflatoxin contamination was lower than 5 ppb.

enforcing aflatoxin standards will likely change in the future and move toward monitoring and regulating imports for compliance, posing a great risk to the future of peanut exports (Elderman and Aberman 2014). For example, in 2016, the Zambia Bureau of Standards confiscated over 11,000 peanut butter containers imported from Zimbabwe that exceeded the limits on aflatoxin (Lusaka Times 2016).

Therefore, within the regional peanut value chain, trade in peanut butter will probably be the first to be impacted from enforcement of aflatoxin standards, because it is traded in more formalized retail and commercial channels than those of peanut kernels. In Zambia, a recent three-year study by Njoroge et al. (2016b) on aflatoxin contamination in local and imported peanut butter brands revealed that more than 50% of these were contaminated with more than 20 ppb AFB_1. Further, the study showed that of the eight brands tested repeatedly across the three-year period, none consistently averaged less than 20 ppb. Of importance is the fact that the peanut butter brands sampled in the study were from Malawi, South Africa, Zambia, and Zimbabwe showing the extent of the aflatoxin problem in the subregion. Therefore, for these countries to continue to sustain access to such markets, they would have to start complying with the aflatoxin standards that the Zambia Bureau of Standards is beginning to enforce.

Whereas the recent case of enforcement in Zambia shows that there is movement toward surveillance, domestic markets within Malawi, Tanzania, and even Zambia, are still not well regulated for aflatoxin contamination. Most peanuts consumed locally are sold in poorly regulated markets with no monitoring or testing for aflatoxin contamination (Elderman and Aberman 2014; Magamba et al. 2017; Njoroge et al. 2016b, 2017). Current regulatory limits for maximum allowable aflatoxin limits within these countries are probably too ambitious. In Malawi, for example, the allowable limit for total aflatoxin is set at 3 ppb in peanut butter, but this regulatory standard is currently under review, and likely to be harmonized with the regional standards. The challenge is however far greater than setting limits to 10 or 20 ppb because the resources needed to enforce and conduct surveillance are mostly lacking.

Aflatoxin Mitigation

Preharvest management. A lot of research has been conducted globally to understand how aflatoxin contamination occurs in the field and how to control it. This information was recently reviewed (Jordan et al. 2018; Wild et al. 2015) with a focus on technologies being implemented in Africa. The 2016 working report from the International Agency on Research on Cancer (Wild et al. 2015) reviewed aflatoxin mitigation technologies from a health perspective, by taking into account proven health benefits at a community level and also those suitable for implementation in rural Africa. The IARC review placed 15 interventions into four categories: (i) sufficient evidence for implementation, (ii) needs more field evaluation, (iii) needs formative research, and (iv) no evidence or ineffective. However, of these 15 interventions, genetic resistance (grouped together with agronomic practices) and biological control were the only preharvest management options discussed. Notably, agronomic practices were not evaluated or discussed as a standalone intervention (Wild et al. 2015). In the review chapter by Jordan et al. (2018), new information was presented from recent studies of aflatoxin mitigation in Ghana, Haiti, Malawi, Mozambique, Uganda, and Zambia under the USAID Feed the Future Peanut and Mycotoxin Innovation Laboratory (PMIL) projects. Jordan et al. (2018) discussed eight preharvest management options for minimizing aflatoxin contamination, but not all with examples of efficacy in Africa.

Generally, preharvest aflatoxin contamination occurs when toxigenic *A. flavus* or *A. parasiticus* infects the peanut kernels of plants stressed by drought (Fig. 5) and high temperature, and produces aflatoxins at conducive temperatures. Therefore, preharvest management of aflatoxin contamination is directed toward reducing predisposing factors based on the assumption that aflatoxigenic fungi are present and the knowledge that the plant is not immune to infection. During field production, peanuts are susceptible to aflatoxin contamination when the plant is stressed by drought and high temperature (Jordan et al. 2018). Aflatoxigenic fungi reside in the soil as conidia, sclerotia, and hyphae, which act as primary inoculum for directly infecting peanuts (Horn 2003). Peanut kernels can be infected with *A. flavus*, which is primarily responsible for aflatoxin contamination

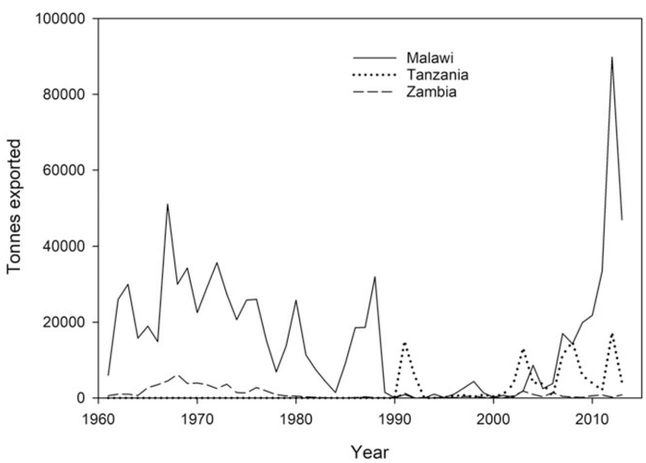

Fig. 1. Peanut exports (metric tons) from Malawi (solid line), Tanzania (small dashed line), and Zambia (long-dashed lines) from 1961 to 2013 (source: FAOSTAT 2017).

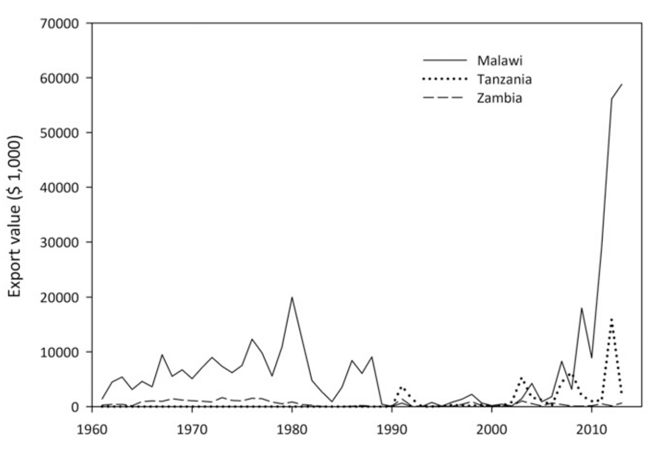

Fig. 2. Value (US$) of shelled peanut exported from Malawi (solid line), Tanzania (small dashed line), and Zambia (long-dashed lines) from 1961 to 2013 (source: FAOSTAT 2017).

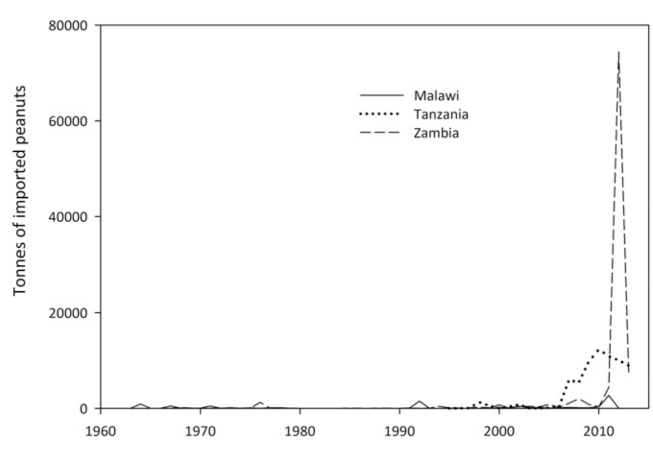

Fig. 3. Peanut imports (metric tons) from Malawi (solid line), Tanzania (small dashed line), and Zambia (long-dashed lines) from 1961 to 2013 (source: FAOSTAT 2017).

in these countries and is present in all the cultivated soils (Kachapulula et al. 2017; Monyo et al. 2012; Njoroge et al. 2016a; Seetha et al. 2017). *A. parasiticus*, the other aflatoxigenic fungus, has also been isolated in Zambia but in lower frequencies than *A. flavus* (Njoroge et al. 2016a). Interventions are therefore aimed at minimizing the interaction of the host, toxigenic fungi, and the environmental factors (high temperature, drought, poor soil fertility, and soils infested with nematodes and termites).

For Malawi, aflatoxin contamination is usually higher in the hotter and lower altitudes of the lakeshore of Lake Malawi and Shire Valley, compared with the cooler and higher altitudes of Mchinji, Kasungu, and Lilongwe plateau (Monyo et al. 2012). The study by Monyo et al. (2012) showed that populations of aflatoxigenic fungi were higher in the hotter regions of Malawi. These results were unlike those in Zambia, where Njoroge et al. (2016a) reported higher populations from the cooler plateau regions compared populations from the hot Luangwa Valley. Prior to the soils being sampled in the Luangwa Valley, floods had occurred, and Njoroge et al. (2016a) discussed that this could have affected the population densities in Luangwa Valley. *Aspergillus* spp. are aerobic fungi found in the upper profiles of the soil (Horn 2003); therefore, populations could have been reduced by waterlogging or deposition of alluvial soils from the floods (Njoroge et al. 2016a).

This section focuses on a critique of the literature of preharvest technologies that are currently being promoted, or actively being researched for mitigating aflatoxin contamination in Malawi and Zambia. These fall under cultural and agronomic practices and biological control. Initially, the status of breeding peanut plants for resistance to aflatoxin contamination is reviewed since efforts to breed and screen for resistance is still a major activity in the peanut improvement programs of both countries.

Plant resistance. Efforts to breed peanut plants though conventional techniques for resistance to aflatoxin contamination have not been successful. To date, no cultivated peanut has been reported with the desired combination of stable high levels of resistance to aflatoxin production and good agronomic characteristics (Nigam et al. 2009; Wu et al. 2008). Whereas cultivars with some resistance to *A. flavus* infection have been developed, the combined interactions of genetics, environment, and management have not consistently reduced aflatoxin contamination to safe levels (Jordan et al. 2018; Nigam et al. 2009). However, Waliyar et al. (2013) reports that despite a high variation in *A. flavus* infection and subsequent aflatoxin incidence, significant improvement in the level of varietal resistance—less than 20 ppb—is possible, compared with susceptible varieties that are contaminated with more than 2,000 ppb. Under the present circumstances, genetic resistance alone cannot eliminate the problem of aflatoxin contamination unless it is used in combination with other management practices such as cultural management practices, biocontrol, etc. (Nigam et al. 2009).

With continued advancement in biotechnology, the pursuit of developing transgenic aflatoxin-resistant peanut plants will open up a new frontier in the management of aflatoxin contamination. Complete prevention of aflatoxin contamination will require introducing a combination of resistance genes through binary vector constructs for the expression of two or more antifungal genes (Rajasekaran et al. 2006). Progress has been made and peanut plants have successfully been transformed and tested for resistance to aflatoxin contamination or infection by *A. flavus* (Arias et al. 2015; Niu et al. 2009; Rajasekaran et al. 2006; Sharma et al. 2017). However, it will take time before farmers can access and grow transgenic peanuts in Malawi and Zambia. Currently, most African countries do not accept genetically modified (GM) crops, and only Burkina Faso, South Africa, and Sudan are growing GM maize or cotton.

Agronomic and cultural practices. During field production of peanuts, aflatoxin contamination occurs when plants, stressed by drought and high temperature, are infected by aflatoxigenic fungi. Implementing agronomic and cultural practices that would reduce the crop's exposure to high temperature and drought—often toward the end of the season—would in theory also reduce the risk of preharvest aflatoxin contamination.

Delayed planting significantly increases the risk of aflatoxin contamination if the rains ends before the crop is mature, and, therefore, timely planting at the onset of the rains is important. In Malawi and Zambia, farmers usually practice mixed farming that is characterized by diversifying crops planted during the rainy season. At the onset of the rainy season, farmers usually prioritize the sowing of maize (a food security crop) and tobacco (a cash crop) over peanuts, which may be planted up to 2 weeks or more after the onset of the rainy season. In both Zambia and Malawi, labor is also a limiting factor that contributes to the late planting of crops. As a result, the late planted crop does not benefit from the full rainy season, which could terminate before the crop matures, exposing it to drought stress.

Experiments to determine the effect of time of planting on aflatoxin contamination have been carried out in Zambia. Results from these experiments, conducted at Msekera Research Station during the 2013 and 2014 seasons, indicates that peanuts planted 2 weeks after the onset of the rains were significantly more contaminated than those planted early, at the onset of the rains or 1 week later (Fig. 6 and 7). In the review by Jordan et al. (2018), similar results were reported from studies also conducted in Zambia. Increased productivity is another benefit of timely planting. However, most farmers find it difficult to plant peanuts with the first rains because of labor scarcity and the prioritization of the crops to be planted.

In-field water management during crop production is also important for aflatoxin mitigation. Farmers can control aflatoxin by

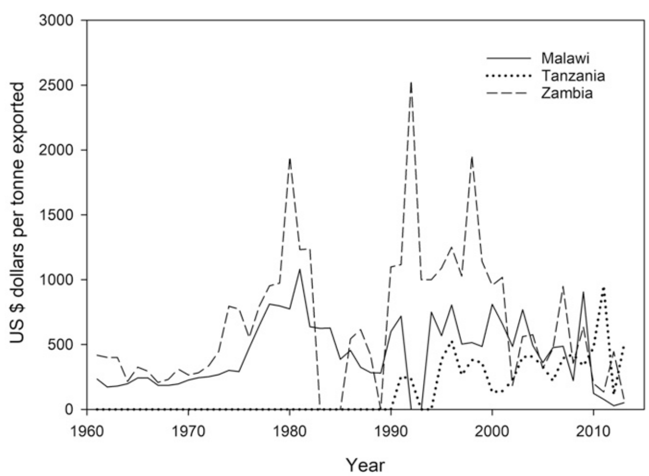

Fig. 4. Export value (US$/t) for peanut exported from Malawi (solid line), Tanzania (small dashed line), and Zambia (long-dashed lines) from 1961 to 2013. (source: FAOSTAT 2017).

Fig. 5. Drought stressed peanut crop in Zambia. Photo credit – Sam Njoroge.

irrigating at critical times, when rainfall is erratic or inadequate, and prevent drought stress, which predisposes peanuts to aflatoxin contamination. However, most subsistent farmers cannot afford to irrigate, and cheaper techniques are needed in situ to both harvest rainfall water and also to minimize moisture loss from the soil through evaporation. At Msekera Research Station in Zambia, the efficacy of water management techniques on reducing aflatoxin contamination in peanuts was tested during the 2013 and 2014 growing seasons. These included tied-ridges, also known as diking, to harvest runoff rain water between the planting rows (Fig. 8), mulching with dry grass straw (Fig. 9), and a bare soil control. Aflatoxin contamination in diked plots (applied 45 days after planting) or mulched plots (applied 45 days after planting) were all significantly lower than contamination in control plots, which had AFB_1 levels of 9 ppb in 2013 and more than 20 ppb in 2014 (Fig. 6 and 7). In all years, aflatoxin contamination in mulched and diked plots were less than 20 ppb. Tied-ridges is a good technology but also greatly depends on the seasonal distribution of rainfall at critical periods as the crop matures. On the other hand, mulching has multiple benefits of reducing runoff water, improving water percolation, and lowering soil temperature and evaporation. However, the limitation with this technology is the challenge of getting enough grass straw, especially for larger land sizes. In addition, during the season, mulch decomposes and can be fed on by insects such as termites, necessitating remulching or spraying the straw with insecticides, which are added expenses and labor intensive.

Can these water-saving technologies be upscaled for adoption? Conservation agriculture offers the route for these technologies to be taken up by farmers. Mulching for reducing water loss is compatible with conservation agriculture, which encourages farmers to retain crop residue on the soil surface. Long-term studies would therefore need to be conducted to test the effect of mulching with the previous seasons crop residues on aflatoxin contamination. At present, conservation farming is being promoted for adoption by farmers in Malawi and Zambia. On the other hand, diking involves soil movement and is not compatible with conservation farming. To address this problem within conservation agriculture, farmers practicing conservation farming can plant peanuts in permanent sunken planting basins that would also serve as water harvesting stations during rainfall events.

Soil fertility management is another important factor in peanut production. Application of gypsum is recommended to improve seed-set and quality of large-seeded peanuts, and it also reduces aflatoxin contamination (Mixon et al. 1984; Turner et al. 2005; Wilson 1995). Mixon et al. (1984) tested the application of pentachloronitrobenzene (PCNB), carbofuran, carboxin, *Trichorderma*, and gypsum, singly or in combination, on *A. flavus* seed colonization and aflatoxin contamination. They reported that in one out of the two years tested, PCNB or carbofuran reduced colonization, and in the other year, only carboxin was effective. No aflatoxin contamination was found in kernels from plants grown in soils amended with gypsum, but rather, kernels from plants in the nontreated control were contaminated. This was the first demonstration that soil applications of gypsum may reduce colonization of peanut seed by *A. flavus* and subsequent aflatoxin contamination. Waliyar et al. (2007) also showed that amending soil with gypsum reduced aflatoxin contamination in West Africa. However, the efficacy of calcium amendment is also dependent on the amount of rainfall received post-application (Wilson 1995).

The efficacy of application of manure to improve yield and reduce aflatoxin contamination has been shown (Chalwe et al. 2016; Waliyar et al. 2007). From experiments in Zambia, Chalwe et al. (2016) added different rates of manure, equivalent to 0, 1, 1.5, 2, 2.5, and 3% of the soil organic matter. They reported that manure application, at the 3% amendment level, significantly reduced aflatoxin contamination compared with the 0% amendment level. However, aflatoxin contamination in all the treatments of the study by Chalwe et al. (2016) was minimal, with none having more than 5 ppb total contamination. More meaningful reductions of aflatoxin contamination were obtained from on-station experiments in Zambia, conducted during the 2013 and 2014 growing season (Fig. 6 and 7). In particular, for 2014, the control treatment had more than 20 ppb AFB_1, significantly higher than treatments amended with 2.5 or 3.5 t/ha of manure, which had about 10 and less than 4 ppb AFB_1, respectively (Fig. 7). The challenge for application of manure is its availability in areas where farmers do not practice animal farming.

Biological control. Biological control is the use of non-aflatoxin producing strains of *A. flavus* or *A. parasiticus* to reduce aflatoxin contamination by displacing or competitively excluding aflatoxin producing strains of the same fungi. Biocontrol using nontoxigenic strains is a technology that has been in use since the 1990s in the U.S.A. and more recently in Africa and the strategy of identifying country-specific or regionally specific, nontoxigenic *A. flavus* strains to be used. This technology is currently being developed for both Malawi and Zambia to mitigate aflatoxin production on maize and peanut crops. In advocating for the use of biological control, Bandyopadhyay and Cotty (2013) state that the effects of

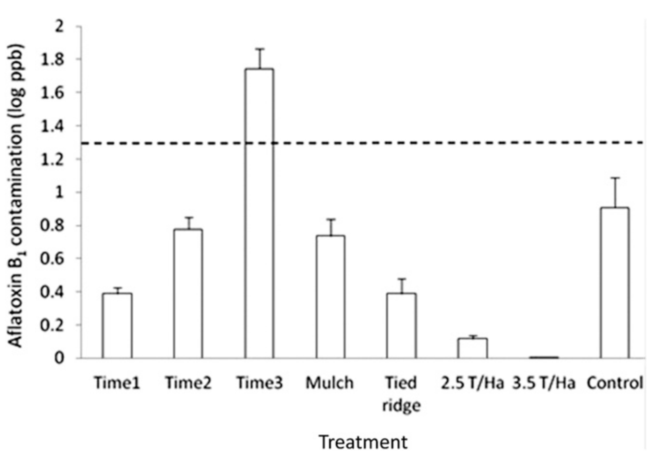

Fig. 6. Aflatoxin B_1 (log ppb) contamination from time of planting treatments at the onset of the rainy season. Time1 is at the onset, Time2 is a week later, and Time3 is 2 weeks after. Mulching or diking was 45 days after planting, manure application at 2.5 or 3.5 t/ha, and an overall control treatment was the famers' usual practice. Trials were conducted in Zambia at Msekera Research Station in 2013. Dashed line represents aflatoxin B_1 contamination of 20 ppb. Error bars represent one standard error of the mean.

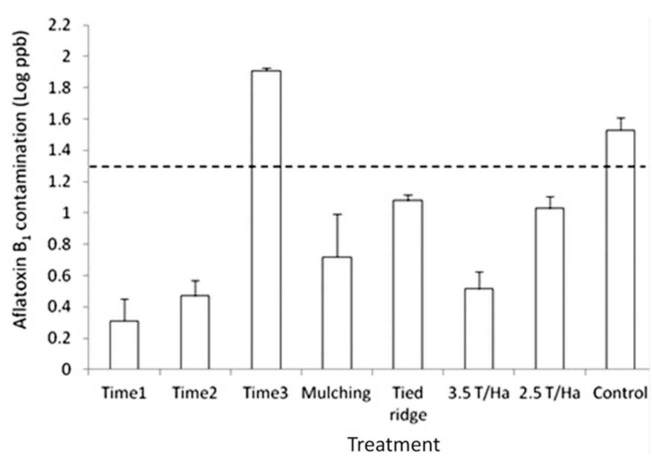

Fig. 7. Aflatoxin B_1 (log ppb) contamination from time of planting treatments at the onset of the rainy season. Time1 is at the onset, Time2 is a week later, and Time3 is 2 weeks after. Mulching or diking was 45 days after planting, manure application at 2.5 or 3.5 t/ha, and an overall control treatment was the famers' usual practice. Trials were conducted in Zambia at Msekera Research Station in 2014. Dashed line represents aflatoxin B_1 contamination of 20 ppb. Error bars represent one standard error of the mean.

non-biocontrol preharvest and postharvest interventions have thus far proved to be inconsistent, continuing to leave farmers vulnerable to contamination. They further discuss that when non-aflatoxigenic strains are used for biocontrol, aflatoxin contamination is reduced by 80 to 90%, and even up to 99%, both at harvest and after poor storage.

Other published results from biocontrol studies indicate that biocontrol significantly reduces aflatoxin contamination (Dorner 2009). However, it is also apparent from these published results that aflatoxin reduction using biocontrol may leave farmers with a harvest that is still contaminated at a level above the regulatory requirements. Dorner (2009), one of the scientists behind the biocontrol product Afla-Guard (nontoxigenic strain of *A. flavus* NRRL 21882), published summarized results from a study on the development of the Afla-Guard biocontrol. The results presented reveal that in areas where biocontrol was tested that had little to no drought, aflatoxin was very low in both the control and the treated peanuts. Interestingly, at another test site, aflatoxin contamination in biocontrol treated plots was 49 ppb compared with 319 ppb in the control. Aflatoxin contamination was significantly lower in the biocontrol treated plots but still significantly higher than the World Health Organization's advisory levels of 20 ppb, which is also above the cutoff in the U.S.A. for human consumption. This is likely one reason why peanut farmers in the U.S.A. do not use biocontrol to manage aflatoxin contamination. Further, Dorner (2009) published data showing aflatoxin levels in the different graded fractions of biocontrol treated peanuts.

The data from Dorner (2009) revealed that aflatoxin levels were high in inedible kernels (oil stock and damaged kernels). In both Malawi and Zambia, inedible and damaged kernels would still be eaten, so it is still imperative to sort, even after treating with biocontrol. Data from Nigeria, one of the countries in Africa where AflaSafe (a combination of four nontoxigenic strains of *A. flavus*) was developed and commercialized, also shows significant reduction in aflatoxin contamination when the AflaSafe was applied to corn fields. However, in the study by Atehnkeng et al. (2014), biocontrol-treated plots had 12 to 23 ppb at harvest and 66 to 105 ppb during storage, the preharvest reduction equating to 57 to 99% and the postharvest reduction was 93 to 95% less than the nontreated control. Like in the previous example, significant reduction was achieved but not always below regulatory limits.

Currently, biocontrol is being promoted, in the African countries where it is being developed, as the anchor technology for aflatoxin control. Other non-biocontrol technologies for managing aflatoxin, when used in combination with biocontrol, may augment further reduction in contamination. However, no data has been published to show the efficacy of biocontrol in combination or compared alongside other technologies. This, therefore, is a gap and research needs to be conducted.

One of the possible reasons why the efficacy of biocontrol may not be good in certain locations or seasons can partially be its mechanism for activity. Biocontrol using non-aflatoxigenic strains should be applied 60 to 80 days after planting when the soil water activity is high or rain is forecast to fall soon, and when the canopy is well developed—all to protect the fungus as it grows and sporulates (Dorner 2009). Addressing the concerns about its efficacy under low humidity or during drought, Bandyopadhyay et al. (2016) state that AflaSafe applications are timed to coincide with frequent rainfall and high soil moisture, and when drought conditions prevail after application, the active ingredient fungi will remain alive on the carrier grain and sporulate when conditions are conducive. However, the window for protecting the developing kernels against infection and aflatoxin contamination is most critical during periods of drought. In cases where there is no rainfall during this critical window, toxigenic fungi already present and active in the soil are likely to have an advantage and cause contamination. Further, if there is sufficient rain or soil moisture to active the biocontrol fungi, shouldn't there also be enough moisture to reduce aflatoxin contamination without biocontrol? More research is needed before firm recommendations can be made to farmers and other users for adoption.

Recently, Ehrlich (2014) examined the advantages and disadvantages of using non-aflatoxigenic *A. flavus* to prevent aflatoxin contamination in crops. He lists many potential pitfalls on biocontrol that should be studied. These include understanding the natural diversity of *A. flavus* in agricultural soils, the effects of climate change both on this diversity and on plant susceptibility, the ability of introduced biocontrol strains to outcross with aflatoxin-producing *A. flavus*, the adaptation of certain *A. flavus* isolates for predominant growth on the plant rather than on the soil, the difficulty in timing its application or controlling the stability of the inoculum, how the introduction of the biocontrol strain affects the soil microenvironment, the potential damage to the plant by the introduced strain, and the need to better understand the entire *A. flavus* toxin burden that may result from *A. flavus* contamination beyond that of aflatoxin.

Moore (2014) also discussed concerns about sexual reproduction and recombination in aflatoxigenic *Aspergilli*. He states that in field populations where aflatoxigenic strains are present, sex may yield toxigenic progeny. Whenever biocontrol is applied, non-toxigenic strains reduce in proportion after a season and reapplication is usually recommended after two years. Moore (2014) suggests that if applied biocontrol strains aren't detectable after a few seasons, then perhaps recombination is to blame. Moore (2014) concludes by stating further that these fungi are and have long been sexually active. Their ability to evolve new phenotypes and genotypes via sexual recombination is a fact that cannot be ignored.

In Malawi and Zambia, farmers and other participants along the value chain have been sensitized about sorting out and discarding moldy grain, which are at a higher risk of being contaminated with aflatoxins. Whereas the application of biocontrol does not increase the total fungal load, a shift occurs, in the short term, toward having more atoxigenic strains in the treated soil, which carry over on pods and kernels in storage. Is it not possible that under bad storage or handling, atoxigenic strains would still grow and mold on pods and

Fig. 8. Water harvesting using dikes, also referred to as tied-ridges, at Chitedze Research Station in Malawi. Photo credit – Sam Njoroge.

Fig. 9. Mulched and nonmulched peanut at Chitedze Research Station in Malawi. Photo credit – Sam Njoroge.

grain? It is difficult for farmers and other participants along the value chain to distinguish between atoxigenic and toxigenic strains, because morphologically, the strains look the same.

Lastly, when a farmer's field is treated, the spores of the atoxigenic strains will eventually drift into neighboring fields that were not targeted for treatment. Fields in Africa are small and fragmented and it's usually impossible to treat only one field in the middle of a village. Farmers in neighboring fields would have to give consent and allow for their fields to be treated.

In conclusion, after review of the literature, I encourage the adoption of the view taken by the IARC report on biocontrol (Wild et al. 2015). They concluded that biocontrol using atoxigenic strains will require an investment to optimize, adapt, and deploy the technology in a sustainable manner.

Postharvest management. Compared with preharvest aflatoxin mitigation research, there isn't much published work on postharvest aflatoxin mitigation of peanuts in either Malawi or Zambia. From literature published elsewhere, timely harvesting of peanuts is a critical step that can prevent aflatoxin contamination, followed by drying the kernels to about 8% moisture content, sorting high aflatoxin risk kernels out from the lot, and good storage. Currently, research on evaluating appropriate storage technologies is ongoing. However, postharvest research remains a major gap in aflatoxin mitigation.

Harvesting and drying. Delayed harvesting, after peanuts have attained physiological maturity, resulting in harvesting over mature kernels, is a major risk factor for aflatoxin contamination. In both Malawi and Zambia, farmers usually harvest late, often using the shedding of the plant leaves (which is partly due to foliar diseases) as an indicator for harvest maturity. There is ongoing research work in Malawi under Feed the Future Peanut and Mycotoxin Research Laboratory to determine the effect of delayed harvesting on aflatoxin contamination.

When peanuts are harvested late, some of the pods detach as the plant is dug up and remain in the soil. In experiments conducted in Mozambique, Zuza et al. (2017) showed that groundnuts harvested 10 days after attaining physiological maturity had up to 40% lower pod yield compared with those harvested at physiological maturity. Farmers in Malawi and Zambia usually try to recover detached pods from the soil, and even a few weeks after harvest, communities living around large farms are "allowed" to glean peanuts that have remained in the soil. From research conducted in Malawi by ICRISAT, gleaned peanuts are usually contaminated with aflatoxin (data not presented). The practice of gleaning peanuts from the soil should be strongly discouraged, and all stakeholders should be educated on the increased risk of aflatoxin exposure from eating kernels gleaned from the soil.

Drying peanuts to 8% moisture content helps mitigate increased aflatoxin contamination during postharvest handling and storage. Farmers utilize several methods to dry the peanuts in the field (Fig. 10 and 11). Immediately after harvest, some farmers strip peanut pods from the plant, and either dry the pods on the soil or on mats. Other farmers collect the plants with the pods still attached, and invert them to air dry, for a week to a month, with the pods not in contact with the soil.

A modified stalked-pole technique, called the Mandela cork in southern Africa, and also referred to as ventilated stalking, is also increasingly being used by farmers to dry peanuts in the field. The stalked pole method originated in the United States, where farmers used this method for curing peanuts in the early part of the 20th century before the use of drying wagons was introduced. When properly constructed, the method allows for air movement through the central part of the stalk or cone, facilitating slow curing of the peanuts. The Mandela cork method, although not officially released as a drying technology in both countries, is being promoted for adoption by farmers, while researchers are gathering data on its effectiveness to reduce aflatoxin contamination. There is contradictory information on the efficacy of Mandela corks in reducing aflatoxin contamination, which is probably due to nonstandardized construction and the fact that it is not constructed around a raised platform to facilitate better air movement. Optimal construction needs further research.

Shelling. Shelling peanuts is a major constraint to increasing production and profitability of peanut farming and can also be a risk factor for aflatoxin contamination. Shelling by machine is 10 times faster than shelling by hand and thus significantly reduces labor (Emmott 2013). Apart from the benefit of saving labor, shelling by machine encourages farmers not to rewet the unshelled pods, usually done to make shelling by hand easier, by softening the pods. Emmott (2013) suggests that the use of moisture meters at buying points could be an indicator for aflatoxin risk.

The availability and affordability of sheller machines is, however, a barrier to its widespread adoption and use, coupled with higher breakage loss of kernels compared with hand-shelling. Research is ongoing to develop better small-scale shelling machines that are more affordable and cause less brakeage of the kernels.

Sorting and storage. Sorting of ungraded peanuts is an effective way of significantly reducing aflatoxin contamination. The IARC rated sorting as an effective technology, but stated that commercial optical sorting equipment would be required for peanuts in Africa, for both small and large scale operations (Wild et al. 2015). In Malawi and Zambia, farmers do not have optical sorting machines.

In the absence of optical sorting machines, visual sorting can also significantly reduce aflatoxin contamination. Removing kernels that are shriveled, undersized, insect damaged, broken, or moldy helps to reduce aflatoxin contamination. In Zambia, as part of research on aflatoxin mitigation during the 2013 growing season, we tested the efficacy of visual sorting on reducing aflatoxin contamination (Table 2). From 256 farmers who were given certified seed, we collected 5 kg of in-shell peanuts at harvest, sun dried them on tarpaulin,

Fig. 10. Stripped peanut pods being dried on bare ground. Photo credit – Sam Njoroge.

Fig. 11. Other common ways of drying peanuts include Mandela Cork, also known as stalked pole, inverted, and on tarpaulin (not shown). Photo credit – Norah Machinjiri.

hand shelled the peanuts, and visually sorted them into two categories: i) graded, i.e., undamaged mature plump kernels, and or ii) grade-outs, i.e., damaged, shriveled, moldy, immature, and undersized kernels. We then analyzed the aflatoxin content of each of the different categories (Table 2). By sorting, a larger proportion (91%) of the graded kernels fell within 0 to 20 ppb AFB_1 compared with the proportion of grade-outs (47%) within 0 to 20 ppb. Grade-outs were more contaminated and had a larger proportion fall in the proportion with aflatoxin B_1 greater than 20 ppb (57%) compared with graded kernels (8%).

In another example, also in Zambia, the Eastern Province Farmers' Cooperative Limited (EPFC), a farmers' organization, received an order to export peanuts to South Africa. Initial aflatoxin tests in the unsorted lots showed that aflatoxin B_1 contamination was more than 100 ppb and would not meet the aflatoxin standards in South Africa. ICRISAT, working in collaboration with Zambia Agriculture Research Institute, trained workers at EPFC on how to visually sort the peanuts, and coupled this with aflatoxin testing in the laboratory. Graded peanuts had significantly lower aflatoxin levels, more than 90% reduction (Fig. 12). By visually sorting and selecting good kernels, EPFC were able to successfully export 120 MT of peanuts to South Africa in 2013, where the acceptable aflatoxin limit is 10 ppb.

Visual sorting is effective, but as can be seen in Table 2, some sorted-out kernels have acceptable aflatoxin levels, whereas some

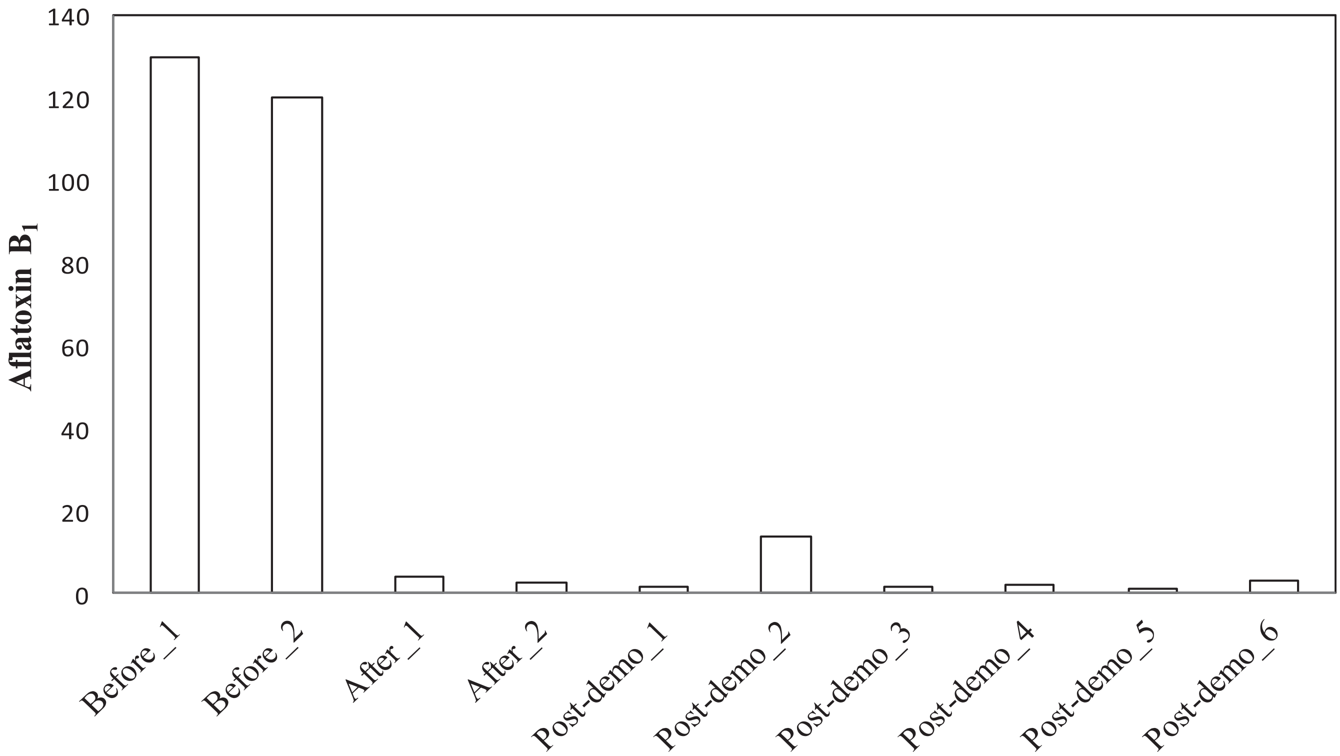

Fig. 12. Effect of grading peanut kernels on aflatoxin B_1 contamination at the Eastern Province Farmers' Cooperative (EPFC), Zambia, in 2012. Before 1 and Before 2 represent aflatoxin values in the bulk sample before visual sorting. After 1 and After 2 are the aflatoxin values in the sorted kernels obtained by removing shriveled, undersized, damaged, and moldy kernels from the initial bulk samples. Post-demo 1 to 6 are values of other bulk lots sorted using the demonstrated method. By visually sorting, EPFC were able meet aflatoxin standards to export to South Africa, 120 MT peanuts.

Table 2. Effect of visual grading[u] on aflatoxin B_1 (AFB_1) contamination[v] in peanuts collected at harvest from farmers' fields in Chipata, Katete, and Mambwe districts of eastern province, Zambia.[w]

	Graded			Grade-outs		
AFB_1 (ppb)[x]	Chipata	Katete	Mambwe	Chipata	Katete	Mambwe
0–4	93[y]	8	64	30	2	34
>4–20	41	3	24	40	3	11
>20–100	5	1	6	28	3	18
>100–1,000	9	1	1	43	3	39
>1,000	0	0	0	7	2	3
N	148	13	95	148	13	95
Maximum AFB_1 (ppb)	407	506	200	3,235	1,039	1,900
Geometric mean AFB_1 (ppb)[z]	4	5	3	40	60	22

[u] At the beginning of the season, farmers in eastern Zambia were given certified seed to plant and manage the crop using farmers practice. At harvest, we collected 5 kg of peanuts from the net plots, air dried them to 9% moisture content, and hand-shelled. Kernels were then visually sorted into two categories, i) graded, i.e., undamaged plump kernels, and ii) grade-outs, i.e., damaged, shriveled, moldy, or undersized kernels.
[v] Aflatoxin contamination was determined with ELISA using methods described in Monyo et al. (2012). The limit of detection was 1 ppb.
[w] Eastern Province of Zambia is where most of the groundnut crop in Zambia is cultivated.
[x] Parts per billion.
[y] Each sample was analyzed from six analytical subsamples and means were calculated to determine the range of contamination.
[z] To normalize the data, aflatoxin values were transformed (log [X + 1]) before calculating the mean.

kernels that are deemed as acceptable still have high aflatoxin levels (Table 2). Therefore, this technique also has limitations, but in the absence of other more effective technologies, it would be effective in reducing aflatoxin contamination. Another issue with sorting is the fate of the higher risk kernels sorted out. Discarded kernels can end up in the human food chain at lower prices, increasing aflatoxin exposure of poor people who would purchase these products (Bandyopadhyay et al. 2016). However, in Malawi and Zambia, there is no published information on the fate of such sort-outs, and research needs to be conducted to ascertain this.

In the U.S.A., farmers' stock peanuts are usually sorted into segregation I, II, or III on the basis of damage and the visual detection of *A. flavus* (36). Edible grade peanuts, also called segregation I, are peanuts with less than 2.5% damage and no visible *A. flavus*. Segregation II are peanuts with greater than 2.5% damage but no visible *A. flavus*. Segregation II peanuts are usually crushed for oil, and allowed into the food market if market shortages exist. Segregation III peanuts are those with detectable *A. flavus* during grading and are not allowed to enter into the edible market and must be crushed for oil or can also be used as seed. However, *Aspergillus* is a seed pathogen and therefore, use of contaminated kernels as seed is not advisable. A similar system should also be adopted in Malawi and Zambia.

Work has been published showing that aflatoxin contamination can increase during storage (Monyo et al. 2012; Seetha et al. 2017). However, little work has been published on the effects of different methods of storage on aflatoxin contamination. This remains a major data gap.

Cost of Aflatoxin Control

Who should pay for aflatoxin control, and what is the cost of aflatoxin control? Should consumers and processors pay a premium for peanuts that are within the regulatory aflatoxin limits? Would a higher price for quality peanuts incentivize farmers to adopt technologies that reduce aflatoxin contamination and also accept that not all that they produce will be bought if the crop fails the aflatoxin quality standards test? Costs for aflatoxin control would include costs for implementing new mitigation technologies against aflatoxin contamination during field production and postharvest handling, costs of testing for aflatoxin contamination, costs of rejected produce because of high aflatoxin contamination, costs of alternative uses, costs to animal health and productivity, and costs to human health.

We can attempt to assign costs associated with aflatoxin control, but more work is still needed. Not much information is available on the economic impact of aflatoxin contamination. Babu et al. (1994) calculated the economic impact of aflatoxin contamination in the peanut export and trade balance in Malawi. They reported that the mean yearly loss due to aflatoxin contamination, from 1985 to 1989, was US $0.6 million. At present, it is estimated that Malawi loses about US $11 million due to aflatoxin contamination (Jimu 2017).

In the U.S.A., attempts have also been made to quantify costs associated with aflatoxin control to the industry. Lamb and Sternitzke (2001) quantified the net economic cost of aflatoxin to the farmer, buying point, and sheller segments of the southeast United States peanut industry. Also in the U.S.A., Wu et al. (2008) looked at the cost effectiveness of aflatoxin control methods and reported findings on three commodities usually affected by aflatoxins. On the issue of the cost of control, they found that within a commodity there is a mismatch in economic incentives, such that different actors bear the brunt of aflatoxin control costs at disproportionate rates. For example, maize and cottonseed growers bear most of the cost of aflatoxin control, whereas for peanuts and tree nuts, the shellers and handlers incur the costs of aflatoxin control (Lamb and Sternitzke 2001; Wu et al. 2008).

The economic incentives to control aflatoxins can be complicated. If a cost effective method could be found that would always lower costs over benefits, this would be useful to the peanut industry on a yearly basis (Wu et al. 2008). However, the reality of aflatoxin contamination is that it is hard to predict how problematic aflatoxin contamination will be in a given year, within a region, or even within a given field (Wu et al. 2008). Therefore, the economic incentive is not enough to sway the value chain actors to adopt current methods of control. Coupled with the economic argument is the burden of disease and loss of productivity when people are exposed to both chronic and acute levels of aflatoxins in developing countries like Malawi.

In conclusion, the cost of aflatoxin control in Malawi and other parts of the world remain largely unknown. In Malawi, all actors along the value chain take up the cost of aflatoxin control, but the predominant cost is probably borne by farmers who must accept low prices because of a lack of alternative end use markets and non-differentiated pricing of the commodity based on aflatoxin levels.

Incentives, Alternative Options, and Regulation

Aflatoxin contamination is still a problem along the value chain despite years of research and money invested, both by private sector and the government, to mitigate it. In a recent article, Elderman and Aberman (2014) agrees with Babu et al. (1994) and Emmott (2013) that price incentives in Malawi are needed to reduce aflatoxin levels in peanuts. Elderman and Aberman (2014), however, further argue that without a price incentive, farmers are not likely to adopt peanut planting, harvest, handling, and storage techniques designed to mitigate the risk of aflatoxins, especially if additional costs are incurred by the farmer, even if they are sufficiently trained in these practices and are aware of the health implications associated with aflatoxins. Currently, there is limited quality grading or price differential for peanuts sold on Malawi's markets (Emmott 2013).

In Malawi, traders and processors, whose aim is to supply markets that seek high quality plus low aflatoxin peanuts, already operate. However, given a choice, farmers still opt to sell shelled nuts to informal traders and aggregators and not engage with the low aflatoxin supply chain (Elderman and Aberman 2014). This is partially because farmers incur the loss of not selling close to 25% of their harvest that is graded out to remove high risk, likely contaminated kernels. Therefore, the price premiums must be large enough to offset these losses (Elderman and Aberman 2014). Alternatively, a market that pays for grade-outs will have to be developed with the capacity to safely utilize the higher aflatoxin-risk peanuts, by keeping them away from direct human consumption by the farmer or being offered for sale to local domestic markets. This is not currently the case, as evidenced by the lack of access to premium markets and prevalent occurrence of aflatoxin contamination within the domestic market. Therefore, Emmott (2013) advocates for a market-led approach to reduce aflatoxins and innovative market mechanisms to pull aflatoxins out of human value chains.

A market structure for quality control needs to be established. As previously discussed, prior to liberalization of the peanut trade, ADMARC was the sole trader of peanuts in Malawi. ADMARC would sort and export most of the peanuts purchased, after determining that aflatoxin levels were less than 5 ppb (Babu et al. 1994). The rest of the peanuts would be crushed for oil or used for local consumption, albeit without being tested for aflatoxin contamination (Babu et al. 1994). From Babu et al. (1994), it is apparent that external markets were the primary concern during the ADMARC era, and the health of the local consumers might not have been considered. Peanuts in Malawi are still sold on poorly regulated local or regional markets, exposing populations to high levels of the toxin and undermining food security and nutritional interventions.

Risk assessment should be the guiding factor in developing aflatoxin policy (Grace and Unnevehr 2013). For aflatoxins, it is accepted that it is a widespread hazard, therefore, zero risk is an unrealistic goal (Grace and Unnevehr 2013). Ultimately, the enforcement of risk-based food law is critical to the public health and economic viability and drives the development and sustained use of intervention technologies (Wild et al. 2015).

In Malawi, enforcement of standards on aflatoxin levels in food consumed in the country is under the mandate of the Ministry of Health, while for exported produce, the Bureau of Standards in the Ministry of Tourism, Trade, and Industry is responsible for certification. Whereas government has a major role in food regulation, the role of the private sector to self-regulate and protect local consumers needs to be improved. For example, market surveys for aflatoxin contamination have continued to show that certain peanut butter brands produced in Malawi are contaminated with aflatoxins. The peanut butter processors continue to sell products with minimal or no tests done to comply with the aflatoxin limits set by the bureau of standards.

Future

Because of the importance of the aflatoxin problem in Africa, the Partnership for Aflatoxin Control in Africa (PACA) was established at the 7th Comprehensive Africa Agriculture Development Program (CAADP) in 2011, and it became operational in October 2013. PACA, housed in the African Union Commission, has the role of providing leadership and coordination for Africa's aflatoxin control efforts. In 2014, five pilot countries—The Gambia, Senegal, Uganda, Tanzania, and Malawi—were selected to implement aflatoxin control work under PACA and the Regional Economic Communities. Each pilot country is to conduct an aflatoxin situation analysis to document the prevalence of aflatoxin contamination, and to audit the legislative, policy and regulation, management practices, and other control mechanisms that can effectively inform interventions (PACA 2014). One intended outcome of the situation analysis is to develop a national aflatoxin mitigation strategy with prioritized intervention areas that will be mainstreamed into the National Agriculture and Food Security Investment Plans (PACA 2014). Currently, both Tanzania and Malawi have conducted the situation analysis and are implementing activities for reducing aflatoxin contamination. It is still too early to assess the successes of these initiatives, but the continental move toward collectively addressing the aflatoxin contamination is a step in the right direction.

The bottleneck for attaining success is not the lack of technologies suited for farmers in Africa. Technologies are available for mitigating aflatoxin contamination, and research into improving these them continues. Success will be catalyzed by the demands of stakeholders when they are presented with evidence of the full cost burden of aflatoxin contamination, especially when domestic consumers in Africa fully understand the health implications of aflatoxin-contaminated peanuts and begin to make quality demands. It is my opinion that increasing consumer demand, coupled with investments into processing technology that would enable processors make alternative products from contaminated lots and thus put economic value to contaminated produce, are the catalysts needed for change.

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