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Physical Methods for Reduction of Aflatoxins Exposure in Groundnuts in Some Low-Income Countries: A Review

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Abstract

Aflatoxin (AF) is a powerful carcinogen primarily produced by some strains of the fungus Aspergillus flavus and Aspergillus parasiticus, which frequently infest nuts and cereal crops. Groundnuts are among the most widely studied substrates of *Aspergillus spp.*, growth and AF contamination. Aflatoxin contamination is a significant public health concern since chronic exposure is linked to causing carcinogenicity, teratogenicity, hepatotoxicity, estrogenicity, neurotoxicity, childhood growth impairment, and immunotoxicity in humans and animals. Acute exposure to AF contamination is associated with fatal aflatoxicosis due to nausea, vomiting, abdominal pain, and convulsions. Good agricultural practices, control of plant diseases, and favourable storage conditions can limit AF contamination yet do not guarantee complete elimination. Looking for an effective technique to reduce AF to an acceptable regulatory limit has been a great subject among researchers. Physical methods like manual visual sorting, screening, density, roasting, dehulling, winnowing, and decortication can reduce AF contamination while maintaining the quality of the kernel and render the kernels harmless to humans and animals compared to AF degradation by chemicals. Therefore, the present review article found that physical removal/visual sorting efficiently lowered the mean AF content commonly used in low-income countries. We briefly enumerated the effectiveness of various common physical methods in reducing post-harvest AF contamination in groundnuts, particularly their percentage AF reduction and outsort/loss, sufficient AF reduction evidence, feasibility, and scalability. We also highlighted the merits and demerits of these methods and essential information that could be helpful for further investigation.

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Introduction

Aflatoxins (AF) are naturally occurring contaminants synthesized by fungal species, mainly *Aspergillus flavus* and *Aspergillus parasiticus*.[1–4] Four major types of AF can occur in groundnuts, Aflatoxin B_1 (AFB_1), aflatoxin B_2 (AFB_2), aflatoxin G_1 (AFG_1), and aflatoxin G_2 (AFG_2), with AFB_1 being the central toxic, carcinogenic, and most prevalent. Aflatoxin M1 (AFM_1), a hydroxylated metabolite, originates primarily in animal tissues and fluids (meat, milk, eggs, and urine) as a metabolic product of AFB_1.[5-8] Long-term AF exposure is linked to immunosuppression, liver cancer, and developmental retardation in children.[9-11] High-frequency consumption of contaminated groundnut causes children's growth retardation related to high AF-albumin adducts.[12, 13] Severe exposure can cause fatal aflatoxicosis.[14, 18] A rapid epidemiological survey conducted in two districts (Chemba and Kondoa) of Dodoma, Tanzania, in 2016 reported an outbreak of acute aflatoxicosis. Among 68 cases,[20] reportedly died from ingesting AF-contaminated food (stiff maize porridge).[15] In 2004 one of the most severe episodes of human aflatoxicosis in documented history occurred; in Kenya, 126 deaths (39% fatality rate) resulted from ingesting contaminated maize.[14,18] Despite being susceptible, eating groundnuts directly has not yet been reported to cause an outbreak of aflatoxicosis.

The burden of AF is felt not only in human and animal health but also in food security and economic loss due to the failure of the commodity for the export market and huge losses during sorting.[19] Contaminated crops attract lower prices in the feed market, and sellers are sometimes forced to dispose of these crops.[20] Developing countries are in great danger of exposure to AF due to poor technology in handling and controlling mycotoxin.[21–24] About US$ 1.2 billion is an estimated annual loss globally due to AF contamination, of which US$ 450 million is from African economies.[25,26]

More than five billion people, mainly in low-income countries worldwide, are chronically exposed to AF through contaminated foods.[27–30] Maize and groundnut have been reported continuously to contain a high level of AF and a significant source of exposure to humans and animals in low-income settings.[31–33]

Groundnuts are a high-risk commodity for AF contamination since they can be infected by *A. flavus* and *A. parasiticus* in the soil before harvest, during harvest, and in poor storage conditions.[34,35] High temperature and humidity, insect infestation, and mixing old grain residues with new grains accelerate fungal proliferation and aflatoxin production in storage facilities.

In sub-Saharan Africa, groundnuts are locally consumed as an infant and young children complementary food, roasted or boiled kernels, pressed for oil, processed into peanut butter, or ground into a powder that is added to dishes or porridge and also a significant ingredient in ready-to-use.[36,37] High contamination has been reported in groundnut and groundnut products such as peanut butter in Harare, Zimbabwe.[38] Kamika & Takoy found that 70% of 60 samples of peanuts in Congo were contaminated with AFB_1, which exceeds the World Health Organization (WHO) regulatory limit (5 µg/kg) for AFB_1. Elshafie *et al*. reported that 70% of peanut butter (n = 120) procured from the traditionally prepared and local market in Khartoum state had AFB_1 above 10 µg/kg. Moreover, Mupunga *et al*. reported that 91% (10 of 11) of commercial peanut butter samples contaminated with AF ranged from 6.1 to 247 µg/kg (mean, 51 µg/kg), while three of the 18 peanut samples contaminated ranged from 6.6 to 622 µg/kg.

Several countries worldwide have regulations describing the permitted concentration of total AF and AFB_1 levels based on intended use, especially in food and feeds. In the European Union (EU), it ranges from 0.1-12 µg/kg; in the United States, 20 µg/kg, and in China, 5-20 µg/kg, 5 µg/kg AFB_1, and 10 µg/kg total AFB_1 in Tanzania.[42–44] Beyond these tolerable ranges may limit trade and economic opportunities. EU decreased 30% of pistachio and other nuts imports from 2003 to 2004 because of AF contamination.[45] It is more enforced in high-income countries, while in low-income countries highly unregulated.[46]

Successful AF management requires a holistic value chain approach[47,48] that implements mitigation strategies before and after harvest. Potential pre-harvest control strategies comprise good agronomic practice (crop stress reduction), host resistance breeding, chemical control, and biological control. Aflatoxin resistance breeding takes time and is more complicated, making it slow to develop. Likewise, the high cost, the measurable nature of resistance, and the high genotype-by-environment interactions made it challenging to implement.[49,50] Agronomical practices commonly involve all measures to reduce plant stress by supplying adequate water, nutrients, and all necessities for the plant's nourishment, resulting in healthier produce. Low-income countries have a limited capacity to implement good crop management practices.[51,52] Bandyopadhyay *et al*. reported a significant reduction of AF contamination using *A.flavus* toxigenic native strain as a biological control in sub-Saharan Africa.[53] The safety concerns, unfavorable by-products, high cost involved, and marketability challenges have been the major limited success of chemical and some different physical mycotoxin control methods.[54] Chemical control typically leaves residuals that are unsafe enough and not commercially applicable.[55,56] Post-harvest AF control strategies include drying, sorting, and adequate storage.[57,58] High-cost electronic sorting technology (infra-red) effectively reduces AF to an acceptable regulatory limit used in large-scale production in developed countries.[59] Sorting methods like screening, visual sorting, density, winnowing, dehulling/decortication, and milling are less complicated and can be implemented relatively easily

There needs to be more investigation of low-cost, effective technologies to reduce exposure to AF in a low-income context which may involve various combinations of methods for better performance. Combining two or more mitigation methods like size sorting, density/floatation sorting, visual sorting, decortications/dehulling, winnowing, and roasting may further be investigated for efficient AF reduction. Successful interventions should also be time-saving and only remove a reasonable percentage of out-sorts to be scalable and feasible for adoption in low-income settings. This review examines some post-harvest AF mitigation methods in low-income countries and their effectiveness in reducing AF contamination in groundnuts.

Methods Practised in Developing Countries in Reducing Af in Groundnuts

Standard methods practised in developing countries for reducing AF in groundnuts were explored. Their performance, weaknesses, and adoption challenges were reviewed. The common techniques used in low-industrialized countries are roasting, manual visual sorting, size sorting, winnowing, dehulling/decortications, and density sorting.

Thermal Process

Dry Roasting

This refers to applying heat to groundnuts during the dry roasting without using oil or water as a carrier. Groundnuts dry-roasted on a frying pan or a dedicated roaster are constantly stirred to achieve even cooking. Dry roasting alters the chemistry of the food's proteins, improving the groundnut's flavour and aroma. High temperature (160ºC and above) detoxifies AF by breaking its ring chemical structure 60. (Figure 1)

Martins *et al*. (2017) reported significant AF reduction ($p<0.05$) of 62, 84, and 89% when roasting peanuts for 20 minutes at 160, 180, and 200 °C, respectively. A higher AF reduction of 81% was reported in groundnut with a higher initial concentration of AF (695 µg/kg) compared to a 54% reduction at a low concentration of 35 µg/kg.[61] Ogunsanwo *et al*. (2004) reported the decline of AFB_1 and AFG_1 by 59 and 65% % respectively, of AF when peanut seeds were subjected to dry roasting at 140°C for 40 minutes. A similar study further reported that roasting for 30 minutes at 150°C resulted in 70 and 80% reduction in AFB_1 and AFG_1, respectively. Results obtained from the survey conducted by Yazdanpanah *et al*. and Jalili showed a significant decrease of AFB_1 and AFB_2 by dry roasting peanuts at 150 ^{0}C for 15 min without altering the taste of the nut. Moreover, oven or microwave roasting reduces AFB_1 by 30–45% for artificially contaminated peanuts and 48–61% for naturally infected nuts.[63] Emadi *et al*. reported that the roasting method significantly reduced AFB_1, AFB_2, AFG_1, and AFG_2 concentrations by 47%, 31%, 41%, and 26%, respectively.[64] Results from different studies conducted to investigate AFB_1 reduction in peanuts reported a reduction of AFB_1 from 35-85% when subjected to roasting at 80-200 °C 65–68. The degree of reduction (by roasting) in AF contents was the greatest at the highest AF contamination level.

Oil Frying

This refers to the application of heat to groundnuts with the use of oil as a carrier. Oil frying of groundnut at a range of 325-350°F and 250-400°F reduced

AFB_1 and AFG_1 concentration by 45 to 83%, respectively.[69] More reports should be available to report the investigation of aflatoxin concentration of groundnuts subjected to oil frying.

Cooking/boiling and Steaming

This refers to the application of heat to groundnuts with the use of water as a carrier. Cooking and steaming for 1 hour under pressure reduces AF by up to 60%.[65,70] In the investigation of the Nshima (local-specific product made of peanut and maize) processing technique carried out in Zambia villages, Njapau *et al*. reported an 85% reduction of AFB_1 and 81% in AFG_1 ($p<0.001$) by boiling peanut meal. In low-income settings, especially in East Africa, local selling of boiled unshelled groundnut is common. More reports should be available on whether the boiled groundnut may contain less aflatoxin.[71]

Despite showing significant AF reduction by dry roasting, there is limited evidence to prove the ability of AF reduction to below the regulatory limit (<20 µg/kg worldwide range), reinforcing the fact that roasting alone could not be sufficient to reduce AF to the levels that are appropriate for human consumption. Based on the findings, the roasting process should be cautiously observed because no temperature was recorded to capture the fluctuations. Adopting this method in low-income contexts is difficult, especially in achieving 195°C for AF reduction during home cooking. Nevertheless, this method may compromise the nutritional value of proteins and change the nature of groundnut and their sensory attributes. Further investigation, which may involve combining these methods, is necessary for the efficiency of AF reduction to an acceptable range, safe for human and animal consumption.

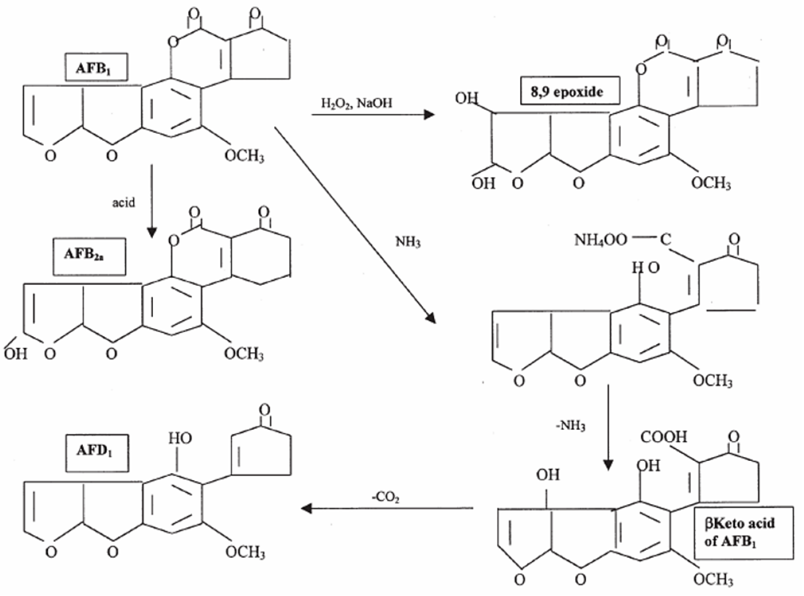

Fig.1: shows a possible pathway for aflatoxin B1 degradation.[72]

Sorting

Manual Visual Sorting

This refers to handpicking in grouping groundnut with similar characteristics and appearance. Visual sorting in groundnut is done to eliminate groundnut with substandard quality (Figure 2). The infected kernels, which comprised shrivelled, mechanically cracked, discolored, deformed, and insect-damaged kernels, had to be visually identified before being manually removed.[70,73–76] The bad-looking kernels, shrivelled and immature, are reported to contain high levels of AF, hence sorting to remove these kernel reduce AF.[77] Park reported 40-80% AF reduction levels by sorting out physically damaged and infected kernels from produce.[75]

Results from the studies on peanut sorting in Kenyan, Haitian, and Gambia showed that performing manual visual sorting on peanuts before storage and before processing can significantly reduce AF concentrations by up to 97%.[78,79] According to Anyebuno *et al*., visual sorting of blanched kernels offers a practical opportunity to reduce AF considerably to below regulatory limits (5 and 10µg/kg in AFB1 and total AF, respectively) regardless of various forms of size sorting. In Accra, Ghana, with percentage removal of 28-29% discoloured and shrivelled kernels.[80]

Visual sorting, carried out by an expert or well-trained personnel, is commonly considered a last line of defence against AF exposure among subsistence consumers (ref). It is suitable in subsistence farming communities due to its straightforwardness and low cost but requires prior sorting education/training to minimize inconsistent findings and maximize efficiency. Visual sorting is commonly practised in developing countries to reduce AF contaminants. However, AF exposure is frequently reported in the region.

Although the method has been reported to significantly reduce AF contamination in peanuts, some setbacks are associated. These include time-consuming, labour-intensive, and tedious for the large AF-contaminated lots, hence making it an unfriendly process to implement in most medium and large-scale food manufacturers worldwide.

Careful sorting of raw kernels before consumption or making a product is essential to minimize the risk of AF contamination. This suggests that training before sorting is necessary for AF reduction, as witnessed by Xu *et al*. Further investigation may provide more information on the efficient complementation of multiple sorting methods like size /screening, winnowing, dehulling, and density sorting, which are faster but still cost-effective.

Fig. 2: Image during manual visual sorting of groundnut at Kibaigwa market, Kongwa district, Tanzania. Graders were given a bag of 100kg each to sort to remove rotten and molded groundnut before getting to the market

Size Sorting

Size sorting refers to screening peanut kernels to obtain large and small ones (Figure 3b). Several findings reported a generally low concentration of AF as the size of the kernel increases. Whitaker *et al*. observed that smaller groundnut kernels tended to have higher concentrations of AF levels than larger kernels; given that microbial growth necessitates using the kernel's resources, it makes sense that fungal colonization affects kernel size. The relationship between toxin and kernel size may indicate that a groundnut's susceptibility to colonization or toxin buildup is influenced by its location on the soil or that early infection may retard kernel growth.[81] At the same time, Davidson *et al*. confirmed that 80% of AF contamination is attributed to small and shrivelled kernels.[82] In screening 17 farmers' stock peanuts, Dowell *et al*. reported a 35%

AF reduction by passing over a belt cleaner. Only loose-shelled kernels of suspected contaminated kernels were removed with a minor loss of 4% of edible peanut. Additional sorting was required to remove other suspect components to lower the AF to an acceptable limit of less than 10 μg/kg globally accepted. In an AF partitioning study that divided groundnuts into various size categories, the initial average AF concentration was reduced from 73.7μg/kg to 42.5 and 66.2 μg/kg in the small and medium-sized categories, respectively.[81] Aoun *et al*. (2020), in a study on low-cost sorting technologies, reported the inefficiency of size sorting (n = 5) to reduce AF in groundnut to an acceptable level. The small sample size involved could not be sufficient proof of its performance. Size sorting increased sorting speed and efficiency in AF reduction when incorporated with visual sorting (Ngure *et al*. 2023 in preparation) while preparing low AF infant porridge flour at Halisi product limited, a small and medium enterprise food processor in Arusha, Tanzania.

Considering all these findings, we did not find sufficient proof of AF reduction below the maximum legal limit by size sorting. One of the challenges of the method is that the large kernels can also be damaged by insects and make them prone to *A. flavus* hence contaminated with AF. Poor management at post-harvest can also expose both large and small grains to mycotoxin contamination, making it challenging to clean by size sorting alone. So far, more needs to be established about the efficiency of size sorting, especially when combined with other affordable sorting technology in low-income settings.

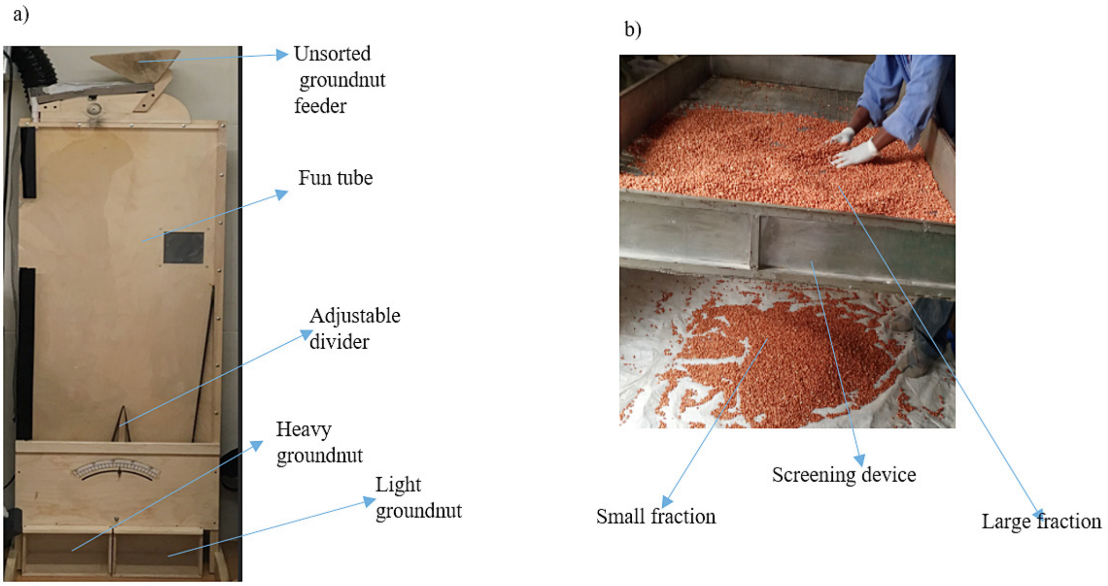

Fig. 3: Image of DropSort used for density sorting (a) and size screening device (b). (Mshanga *et al*., 2023 in preparation)

Density Sorting

Density sorting refers to the segregation between high and less-dense kernels. Highly AF-contaminated groundnut was found to have less dense than medium and low-contaminated ones.[82] Morales reported a negative association between bulk density and fumonisin in maize.[83] Likewise, in 2020, Aoun said a negative correlation between bulk density and AF contamination in groundnut.[31] Air column, pod cleaner, gravity table,[84] and DropSort[85] (figure 3a) are some of the density sorting devices that are capable of grouping the immature (light) and maturity (heavier) pods. Density sorting using a gravity table was the most precise for removing the least dense kernels containing AF contamination compared to air column and pod cleaner.[84] Dorner reported reducing AF for the heavier fraction, with 10.2, 44.5, and 69.6μg/kg in heavy, medium, and light by density sorting.[86] Kirksey *et al*. found the mean AF reduction from 301 μg/kg to 20μg/kg

(88% total AF removal) through a density sorting method involving peanut kernel flotation.[88] Gravity tables and other expensive sorting devices used in industrialized countries might be too expensive, and other lower-cost density sorting options would be helpful in low-income contexts. Simple technology density sorting (DropSort) designed by John Fusch shows efficiency in reducing fumonisin (FUM) in maize by 66% with a percentage loss of 31 [89] (Figure 3). Another study by Aoun *et al*. reported an efficiency reduction of FUM by DropSort, followed by another study by Stafstrom *et al*., who reported 97% Fumonisin reduction efficiency between unsorted and heavy fractions in maize.[31,90] No sufficient information concerns the efficiency of density sorting to remove AF to the acceptable regulatory limit, even though it may involve minimum time to complete the process.

The density sorting method may lack efficiency due to the loss of non-contaminated kernels in the light fraction; however, during a season characterized by an unusually high level of AF contamination, partitioning the most lightweight kernels from the batch can reduce AF. Sufficient testing information on the low-cost density sorting, such as the DropSort and other devices in groundnut, needs to be improved. Complementing the density sorting method with other methods like size, visual, roasting, winnowing, and dehulling is worth further investigation to determine its efficiency in AF reduction.

Winnow and Floatation Sorting

Winnowing is a process of separating light grain /chaff from heavy grain. Typically, this includes flinging the mixture into the air so that the wind will carry the lighter chaff away while the heavier grains fall back to the ground for retrieval. A winnowing fan (a shaped basket shaken to lift the chaff) or instrument (a winnowing fork or shovel) could be used on a mound of harvested grain.

Farmers in rural settings commonly use these methods to separate lighter husk particles from heavier grain seeds.[91] Whitaker *et al*. and Dorner revealed a substantial reduction of mean AF of remaining large, sound kernels after removing small and shrivelled (lighter) peanut kernels. Deduction of 22% of kernel through floatation in water resulted in a 60% reduction in AF in grains.[92] Winnowing effectively achieves significant AF and other mycotoxin removals.[93] It can also remove pests from stored grain.[94] Moreover, it is effective when there is wind [95]; this applies when used manually or by machine.

In addition, reported a relationship between the buoyancy characteristics of peanuts and AF contents in which about 88% total AF reduction by floatation was observed. Seventy-two per cent of the floating kernels had 97+% of the total AF.

There needs to be more information about the efficient performance of winnow sorting, especially in AF removal in groundnut and percentage loss in commonly used sub-Saharan African countries. Theoretically, the help of wind winnowing can remove smaller and lighter groundnuts generally found to contain a higher concentration of AF.

Fig. 4: Winnow sorting practice. Source: https://en.wikipedia.org/wiki/Winnowing

Decortication, Dehulling, and Milling

Decortication and de-hulling are commonly practised in many parts of the world, including East Africa.[98] Several studies published a significant decrease in mycotoxin in the dehulled feed materials.[99] The process involves the removal of the outer covering of beans, grains, and seeds, typically by physical means. The capacity of this method to produce toxin-free final products depends heavily on the initial concentration of toxins in the unmilled foodstuff. According to Castells *et al*., the outer layers of maize kernels contain higher levels of

AF. However, processed products from the inner parts of the grain, such as maize meal and flaking grits, have lower levels of mycotoxins.[100] Siwela *et al*. found that dehulling maize grains reduced AF levels in maize meal by approximately 92%.[101] The subsequent removal of bran and germ further reduced product contamination levels destined for human consumption.[102] Mycotoxins (AF, Fumonisin, B trichothecenes, AOH, HT-2, and T-2) were reduced by 83% in maize using traditional dehulling techniques (wooden mortar and pestle).[99] Adebiyi *et al*. demonstrated that dehulling Bambara groundnut followed by a fermentation process to produce Dawa Dawa (an African fermented condiment produced from Bambara groundnut) can effectively reduce 100% AFB_1, AFG_1, T2-toxin, fumonisin B_1, fumonisin B_2, alpha-zearalenone, Ochratoxin A, and beta-zearalenone in Ga-Matlala village, Limpopo Province, South Africa.[103] The Bambara groundnut tested had mycotoxin below the regulatory limit in the country and elsewhere.[104]

Table 1: Summary of post-harvest mitigation methods and their efficiency in reducing grain aflatoxin

Methods	Grain type / conditions	AF type	Reduction (range)	Outsort /Loss	Reference
Visual sorting	Groundnut	Total AF	40-80%		75,107
Visual sorting	Groundnut	AFB1	97%	2%	79
	Maize	AFB1	reduce< 6%		99
Visual + blanching and dehulling	Peanut	AFB1, B2, G1 and G2	<regulatory limit (Not detected)	28-29%	80
Size sorting (n=17)	Groundnut		35%	4%	108
	Groundnut		73.7 to 42.5µg/kg, small (42%) 73.66 to 66.2µg/kg medium (10%)		81
Density sorting	Groundnut	AF	80%		88
	Groundnut	AF	Mean concentration. 10.2µg/kg heavy 44.5µg/kg Medium 69.6µg/kg light		86
Roasting	Groundnut	Total AF	45-83%		79
	(150˚C for 120min)	AF B_1	>96%		63
	Groundnut	AFB1	85%		71
		AFG1	81%		
	200˚C	AF	89%		61
	180˚C		84%		
	160˚C		62%		
	Peanut 140 ˚C	AFB1	59%		109
		AFG1	65%		
	At 30 min	AFB1	70%		
	Peanut 150 ˚C At 40 min	AFG1	80%		
Winnow or Floatation	Groundnut	AF	60%	22%	92
Decortications /dehulling	Maize		80% 92%		101

Additionally, this is challenging because only a few East African smallholder and subsistence farmers can afford processing facilities that separate bran and germ from the grains. Intervention strategies that prevent a fungal infection from farms to the store are more useful and thus recommended. Moreover, investigation/research and scale-up of low-cost mitigation methods are essential for processing safe food products in low-income settings. As recommended by the Codex Alimentarius Commission (CAC), practices like washing and de-hulling kernels before milling may help manage and control the risk of mycotoxin exposure in staple foods).[105]

So far, there is insufficient published scientific information concerning the dehulling/ decortication and milling done on groundnut to reduce AF. In contrast, they reduce about 92% of AF in other food products, especially cereals.

Combined Sorting Method

This refers to combining multiple methods to reduce aflatoxin from the grains. The method is more common in mechanized countries than in low-income settings. It may be because of insufficient data available for its efficiency. It may be expensive and involve more losses/outsort, which could scare farmers in developing countries. Aoun *et al*. investigated the combination of size and density (Drop Sorting) sorting to reduce AF using a few groundnut and maize samples from Tanzania, which were highly contaminated, and found no clean fraction. Before processing peanuts into desired final goods with small-scale processors in Ghana, manual sorting, which includes presorting and extra sorting after dehulling and blanching, considerably lowers aflatoxin contamination in peanuts.[106] Further combined investigations using a large number of heterogeneous groundnut samples are needed.

Conclusion and Recommendations

Removing AF entirely from the human diet and animal feeds is challenging due to AFs' extreme stability in different conditions. High AF can result from different points along the value chain (pre-harvest, post-harvest, storage) and is toxic in minimal concentrations. It is challenging to reduce AF without time or money costs. No single approach is sufficient to efficiently respond to AF contamination challenges in the food chain. However, integrated management from the field to the consumer is necessary to reduce the impact of AFs. Combining all prevention and control strategies will be the best practice to achieve an acceptable contamination limit for a safe groundnut supply. Post-harvest mitigation procedures described above help produce food products with reduced levels of AF during processing procedures of highly contaminated starting material, considering that AF tends to occur more during post-harvest than pre-harvest.[110] Additional studies to assess the effectiveness of low-cost sorting technology in combination (such as size screening, density (DropSort; The Widget Factory (Ithaca, NY) Grizzly G0710 1 hp blower, flow rate of 537 feet3/ minute (Grizzly Industrial®, Bellingham, WA, USA) (Figure 3a) 90, and spectral sorting) regarding AF reduction efficacy, time used, and percentage outsort could be tested in food and commodities contaminated with AF in low-income contexts.

The adverse health and economic implications of AF contamination could be minimized through more research on affordable and effective mitigation methods to reduce AF in groundnut and other vulnerable commodities, especially in a low-income context.

Meanwhile, stakeholders should support efforts to spread knowledge and awareness to subsistence farmers on AF exposure and scale-up efficient mitigation methods.

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Conflict of Interest

The authors declare no conflicts of interest

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