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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*.<sup>1-4</sup> Four major types of AF can occur in groundnuts, Aflatoxin B<sub>1</sub> (AFB<sub>1</sub>), aflatoxin B<sub>2</sub> (AFB<sub>2</sub>), aflatoxin G<sub>1</sub> (AFG<sub>1</sub>), and aflatoxin G<sub>2</sub> (AFG<sub>2</sub>), with AFB<sub>1</sub> being the central toxic, carcinogenic, and most prevalent. Aflatoxin M1 (AFM<sub>1</sub>), a hydroxylated metabolite, originates primarily in animal tissues and fluids (meat, milk, eggs, and urine) as a metabolic product of AFB<sub>1</sub>.<sup>5-8</sup> Long-term AF exposure is linked to immunosuppression, liver cancer, and developmental retardation in children.<sup>9-11</sup> High-frequency consumption of contaminated groundnut causes children's growth retardation related to high AF-albumin adducts.<sup>12, 13</sup> Severe exposure can cause fatal aflatoxicosis.<sup>14, 18</sup> 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,<sup>20</sup> reportedly died from ingesting AF-contaminated food (stiff maize porridge).<sup>15</sup> 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.<sup>14, 18</sup> 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.<sup>19</sup> Contaminated crops attract lower prices in the feed market, and sellers are sometimes forced to dispose of these crops.<sup>20</sup> Developing countries are in great danger of exposure to AF due to poor technology in handling and controlling mycotoxin.<sup>21-24</sup> About US\$ 1.2 billion is an estimated annual loss globally due to AF contamination, of which US\$ 450 million is from African economies.<sup>25, 26</sup>

More than five billion people, mainly in low-income countries worldwide, are chronically exposed to AF through contaminated foods.<sup>27-30</sup> 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.<sup>31-33</sup>

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.<sup>34, 35</sup> 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.<sup>36, 37</sup> High contamination has been reported in groundnut and groundnut products such as peanut butter in Harare, Zimbabwe.<sup>38</sup> Kamika & Takoy found that 70% of 60 samples of peanuts in Congo were contaminated with AFB<sub>1</sub>, which exceeds the World Health Organization (WHO) regulatory limit (5 µg/kg) for AFB<sub>1</sub>. Elshafie *et al.* reported that 70% of peanut butter (n = 120) procured from the traditionally prepared and local market in Khartoum state had AFB<sub>1</sub> 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<sub>1</sub> 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<sub>1</sub>, and 10 µg/kg total AFB<sub>1</sub> in Tanzania.<sup>42-44</sup> 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.<sup>45</sup> It is more enforced in high-income countries, while in low-income countries highly unregulated.<sup>46</sup>

Successful AF management requires a holistic value chain approach<sup>47, 48</sup> 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.<sup>49,50</sup> 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.<sup>51,52</sup> Bandyopadhyay *et al.* reported a significant reduction of AF contamination using *A. flavus* toxigenic native strain as a biological control in sub-Saharan Africa.<sup>53</sup> 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.<sup>54</sup> Chemical control typically leaves residuals that are unsafe enough and not commercially applicable.<sup>55,56</sup> Post-harvest AF control strategies include drying, sorting, and adequate storage.<sup>57,58</sup> High-cost electronic sorting technology (infra-red) effectively reduces AF to an acceptable regulatory limit used in large-scale production in developed countries.<sup>59</sup> 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 (160°C 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.<sup>61</sup> Ogunsanwo *et al.* (2004) reported the decline of AFB<sub>1</sub> and AFG<sub>1</sub> 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<sub>1</sub> and AFG<sub>1</sub>, respectively. Results obtained from the survey conducted by Yazdanpanah *et al.* and Jalili showed a significant decrease of AFB<sub>1</sub> and AFB<sub>2</sub> by dry roasting peanuts at 150 °C for 15 min without altering the taste of the nut. Moreover, oven or microwave roasting reduces AFB<sub>1</sub> by 30–45% for artificially contaminated peanuts and 48–61% for naturally infected nuts.<sup>63</sup> Emadi *et al.* reported that the roasting method significantly reduced AFB<sub>1</sub>, AFB<sub>2</sub>, AFG<sub>1</sub>, and AFG<sub>2</sub> concentrations by 47%, 31%, 41%, and 26%, respectively.<sup>64</sup> Results from different studies conducted to investigate AFB<sub>1</sub> reduction in peanuts reported a reduction of AFB<sub>1</sub> 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<sub>1</sub> and AFG<sub>1</sub> concentration by 45 to 83%, respectively.<sup>69</sup> 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%.<sup>65,70</sup> 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<sub>1</sub> and 81% in AFG<sub>1</sub> ( $p < 0.001$ ) 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.<sup>71</sup>

Despite showing significant AF reduction by dry roasting, there is limited evidence to prove the ability of AF reduction to below the regulatory limit ( $< 20 \mu\text{g}/\text{kg}$  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  $195^\circ\text{C}$  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.

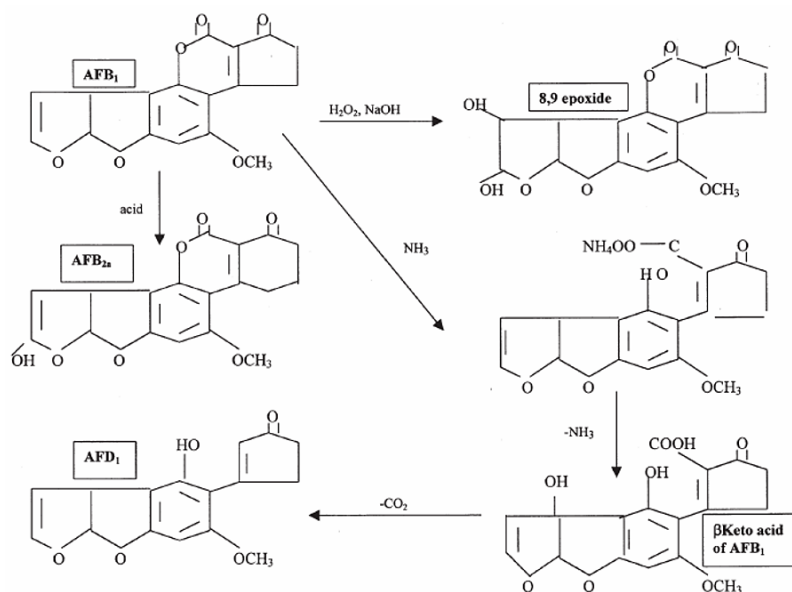


Fig.1: shows a possible pathway for aflatoxin B1 degradation.<sup>72</sup>

### 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.<sup>70,73-76</sup> The bad-looking kernels, shrivelled and immature, are reported to contain

high levels of AF, hence sorting to remove these kernel reduce AF.<sup>77</sup> Park reported 40-80% AF reduction levels by sorting out physically damaged and infected kernels from produce.<sup>75</sup>

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%.<sup>78,79</sup> According to Anyebuno *et al.*, visual sorting of blanched

kernels offers a practical opportunity to reduce AF considerably to below regulatory limits (5 and 10 $\mu$ g/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.<sup>80</sup>

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

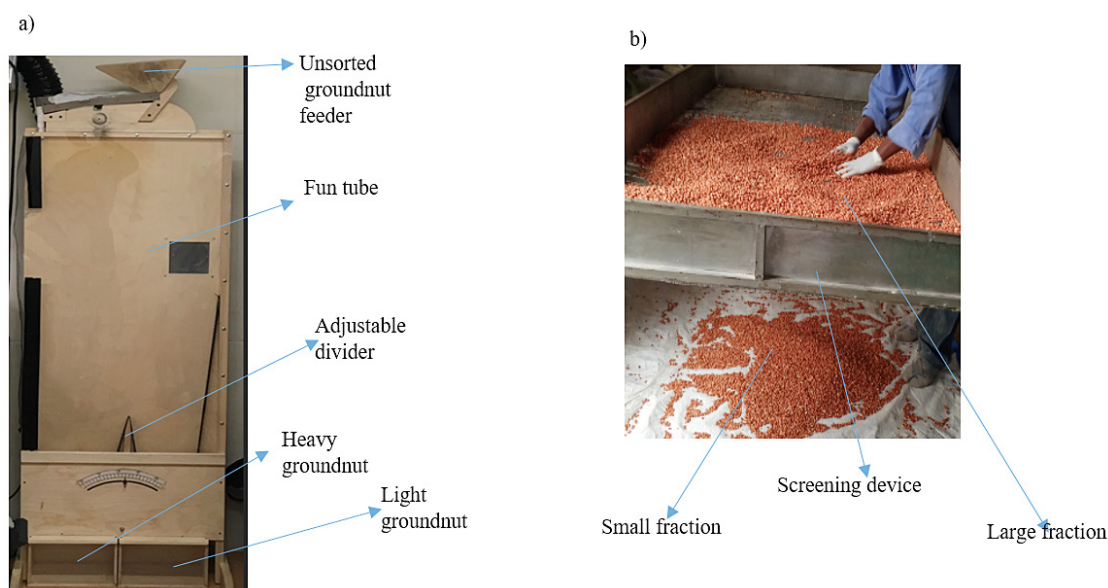
Size sorting refers to screening peanut kernels to obtain large and small ones (Figure 3b). Several findings reported a generally low concentration of AF as the size of the kernel increases. Whitaker *et al.* observed that smaller groundnut kernels tended to have higher concentrations of AF levels than 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.<sup>81</sup> At the same time, Davidson *et al.* confirmed that 80% of AF contamination is attributed to small and shrivelled kernels.<sup>82</sup> 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  $\mu\text{g}/\text{kg}$  globally accepted. In an AF partitioning study that divided groundnuts into various size categories, the initial average AF concentration was reduced from 73.7  $\mu\text{g}/\text{kg}$  to 42.5 and 66.2  $\mu\text{g}/\text{kg}$  in the small and medium-sized categories, respectively.<sup>81</sup> 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.<sup>82</sup> Morales reported a negative association between bulk density and fumonisin in maize.<sup>83</sup> Likewise, in 2020, Aoun said a negative correlation between bulk density and AF contamination in groundnut.<sup>31</sup> Air column, pod cleaner, gravity table,<sup>84</sup> and DropSort<sup>85</sup>

(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.<sup>84</sup> Dorner reported reducing AF for the heavier fraction, with 10.2, 44.5, and 69.6  $\mu\text{g}/\text{kg}$  in heavy, medium, and light by density sorting.<sup>86</sup> Kirksey *et al.* found the mean AF reduction from 301  $\mu\text{g}/\text{kg}$  to 20  $\mu\text{g}/\text{kg}$

(88% total AF removal) through a density sorting method involving peanut kernel flotation.<sup>88</sup> 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%<sup>89</sup> (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.<sup>31,90</sup> 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.<sup>91</sup> Whitaker *et al.* and Dörner 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.<sup>92</sup>

Winnowing effectively achieves significant AF and other mycotoxin removals.<sup>93</sup> It can also remove pests from stored grain.<sup>94</sup> Moreover, it is effective when there is wind<sup>95</sup>; this applies when used manually or by machine.

In addition, [unintelligible] 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.<sup>98</sup> Several studies published a significant decrease in mycotoxin in the dehulled feed materials.<sup>99</sup> 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.<sup>100</sup> Siwela *et al.* found that dehulling maize grains reduced AF levels in maize meal by approximately 92%.<sup>101</sup> The subsequent removal of bran and germ further reduced product contamination levels destined for human consumption.<sup>102</sup> 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).<sup>99</sup> Adebiji *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<sub>1</sub>, AFG<sub>1</sub>, T2-toxin, fumonisin B<sub>1</sub>, fumonisin B<sub>2</sub>, alpha-zearalenone, Ochratoxin A, and beta-zearalenone in Ga-Matlala village, Limpopo Province, South Africa.<sup>103</sup> The Bambara groundnut tested had mycotoxin below the regulatory limit in the country and elsewhere.<sup>104</sup>

**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 (150°C for 120min)	Total AF	45-83%		79
		AF B <sub>1</sub>	>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	AFG1	80%		
	At 40 min				
Winnow or Floatation	Groundnut	AF	60%	22%	92
Decortications /dehulling	Maize		80%		101
			92%		

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).<sup>105</sup>

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.<sup>106</sup> 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.<sup>110</sup> 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 feet<sup>3</sup>/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

## References

1. Alshannaq A, Yu JH. Occurrence, toxicity, and analysis of major mycotoxins in food. *International journal of environmental research and public health*. 2017;14(6):632.
2. Bullerman L. Significance of mycotoxins to food safety and human health. *Journal of Food Protection*. 1979;42(1):65-86.
3. Northolt MD, Bullerman LB. Prevention of mold growth and toxin production through control of environmental conditions. *Journal of Food Protection*. 1982;45(6):519-526.
4. Sweeney MJ, Dobson AD. Mycotoxin production by *Aspergillus*, *Fusarium* and *Penicillium* species. *International journal of food microbiology*. 1998;43(3):141-158.
5. Applebaum RS, Brackett RE, Wiseman DW, Marth EH. Aflatoxin: toxicity to dairy cattle and occurrence in milk and milk products—a review. *Journal of Food Protection*. 1982;45(8):752-777.
6. Lalah JO, Omwoma S, Orony D. Aflatoxin B1: Chemistry, environmental and diet sources and potential exposure in human in Kenya. Aflatoxin B1 Occurrence, Detection and Toxicological Effects. Published online 2019.
7. Min L, Fink-Gremmels J, Li D, Tong X, Tang J, Nan X, Yu Z, Chen W, Wang G. An overview of aflatoxin B1 biotransformation and aflatoxin M1 secretion in lactating dairy cows. *Animal Nutrition*. Published online 2021.
8. Santacroce MP, Conversano MC, Casalino E, Lai O, Zizzadoro C, Centoducati G, Crescenzo G. Aflatoxins in aquatic species: metabolism, toxicity and perspectives. *Reviews in Fish Biology and Fisheries*. 2008;18(1):99-130.
9. Abdel-Wahhab MA, Omara EA, Abdel-Galil MM, Hassan NS, Nada SA, Saeed A, ElSayed MM. *Zizyphus spina-christi* extract protects against aflatoxin B1-initiated hepatic carcinogenicity. *African Journal of Traditional, Complementary, and Alternative Medicines*. 2007;4(3):248.
10. Gong, Turner PC, Hall AJ, Wild CP. Aflatoxin exposure and impaired child growth in West Africa: An unexplored international public health burden. *Mycotoxins Detection Methods, Management, Public Health and Agricultural Trade*. Published online 2008:53-66.
11. Owaga E, Muga R, Mumbo H, Aila F. Chronic dietary aflatoxins exposure in Kenya and emerging public health concerns of impaired growth and immune suppression in children. *International Journal of Biological and Chemical Sciences*. 2011;5(3).
12. Castelino JM, Routledge MN, Wilson S, Dunne DW, Mwatha JK, Gachuhi K, Wild CP, Gong YY. Aflatoxin exposure is inversely associated with IGF1 and IGFBP3 levels in vitro and in Kenyan schoolchildren. *Molecular nutrition & food research*. 2015;59(3):574-581.
13. Nabwire Wangia-Dixon R, Xue KS, Alcalá J, Quach TH, Song X, Tang L, Ombaka J, Githanga DP, Anzala OA, Wang JS. Nutrition and growth outcomes are affected by aflatoxin exposures in Kenyan children. *Food Additives & Contaminants: Part A*. 2020;37(12):2123-2134.
14. Azziz-Baumgartner E, Lindblade K, Giesecker K, Rogers HS, Kieszak S, Njapau H, Schleicher R, McCoy LF, Misore A, DeCock K, Rubin C. Case-control study of an acute aflatoxicosis outbreak, Kenya, 2004. *Environmental Health Perspectives*. 2005;113(12):1779-1783. doi:10.1289/ehp.8384
15. Kamala A, Shirima C, Jani B, Bakari M, Sillo H, Rusibamayila N, De Saeger S, Kimanya M, Gong YY, Simba A, investigation team. Outbreak of an acute aflatoxicosis in Tanzania in 2016. *World Mycotoxin Journal*. 2018;(Special issue: Mycotoxins in Africa):311-320. doi:10.3920/WMJ2018.2344
16. Ngindu A, Kenya P, Ocheng D, Omondi T, Ngare W, Gatei D, Johnson B, Ngira J, Nandwa H, Jansen A, Kaviti J. Outbreak of Acute Hepatitis Caused By Aflatoxin Poisoning in Kenya. *The Lancet*. 1982;319(8285):1346-1348. doi:10.1016/S0140-6736(82)92411-4
17. Reddy BN, Raghavender CR. Outbreaks of aflatoxicoses in India. *African journal of food, agriculture, nutrition and development*. 2007;7(5).

18. Probst C, Njapau H, Cotty PJ. Outbreak of an acute aflatoxicosis in Kenya in 2004: identification of the causal agent. *Applied and environmental microbiology*. 2007;73(8):2762-2764.
19. Tola M, Kebede B. Occurrence, importance and control of mycotoxins: A review. *Cogent Food & Agriculture*. 2016;2(1):1191103.
20. Mitchell NJ, Bowers E, Hurburgh C, Wu F. Potential economic losses to the US corn industry from aflatoxin contamination. *Food Additives & Contaminants: Part A*. 2016;33(3):540-550.
21. Adegoke GO, Letuma P. Strategies for the prevention and reduction of mycotoxins in developing countries. *Mycotoxin and Food Safety in Developing Countries*; Makun, H, Ed. Published online 2013:123-136.
22. Bhat R, Rai RV, Karim AA. Mycotoxins in food and feed: present status and future concerns. *Comprehensive reviews in food science and food safety*. 2010;9(1):57-81.
23. Neme K, Mohammed A. Mycotoxin occurrence in grains and the role of postharvest management as a mitigation strategies. A review. *Food Control*. 2017;78:412-425. doi:10.1016/j.foodcont.2017.03.012
24. Suleiman RA, Kurt RA. Current maize production, postharvest losses and the risk of mycotoxins contamination in Tanzania. In: *American Society of Agricultural and Biological Engineers*; 2015:1.
25. Gbashi S, Madala NE, De Saeger S, De Boevre M, Adekoya I, Adebo OA, Njobeh PB. The socio-economic impact of mycotoxin contamination in Africa. *Fungi and mycotoxins-their occurrence, impact on health and the economy as well as pre-and postharvest management strategies* (ed Njobeh, PB). Published online 2018:1-20.
26. Mohamed M. Factors influencing aflatoxin contamination in maize at harvest and during storage in Kongwa district, Tanzania. Published online 2017.
27. Shephard GS. Aflatoxin and food safety: recent African perspectives. *Journal of Toxicology: Toxin Reviews*. 2003;22(2-3):267-286.
28. Strosnider H, Azziz-Baumgartner E, Banziger M, Bhat RV, Breiman R, Brune MN, DeCock K, Dilley A, Groopman J, Hell K, Henry SH. Workgroup report: public health strategies for reducing aflatoxin exposure in developing countries. *Environmental health perspectives*. 2006;114(12):1898-1903.
29. Wild CP, Gong YY. Mycotoxins and human disease: a largely ignored global health issue. *Carcinogenesis*. 2010;31(1):71-82.
30. Williams JH, Phillips TD, Jolly PE, Stiles JK, Jolly CM, Aggarwal D. Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions. *The American journal of clinical nutrition*. 2004;80(5):1106-1122.
31. Aoun M, Stafstrom W, Priest P, Fuchs J, Windham GL, Williams WP, Nelson RJ. Low-cost grain sorting technologies to reduce mycotoxin contamination in maize and groundnut. *Food control*. 2020;118:107363.
32. Falade TD, Neya A, Bonkougou S, Dagno K, Basso A, Senghor AL, Atehnkeng J, Ortega-Beltran A, Bandyopadhyay R. Aflatoxin contamination of maize, groundnut, and sorghum grown in Burkina Faso, Mali, and Niger and aflatoxin exposure assessment. *Toxins*. 2022;14(10):700.
33. Kachapulula P, Akello J, Bandyopadhyay R, Cotty P. Aflatoxin contamination of groundnut and maize in Zambia: observed and potential concentrations. *Journal of Applied Microbiology*. 2017;122(6):1471-1482.
34. Horn B, Greene R, Dorner J. Effect of corn and peanut cultivation on soil populations of *Aspergillus flavus* and *A. parasiticus* in southwestern Georgia. *Applied and Environmental Microbiology*. 1995;61(7):2472-2475.
35. Pitt J, Taniwaki MH, Cole M. Mycotoxin production in major crops as influenced by growing, harvesting, storage and processing, with emphasis on the achievement of Food Safety Objectives. *Food control*. 2013;32(1):205-215.
36. Anitha S, Tsusaka TW, Njoroge SM, Kumwenda N, Kachulu L, Maruwo J, Machinjiri N, Botha R, Msere HW, Masumba J, Tavares A. Knowledge, {Attitude} and {Practice} of {Malawian} {Farmers} on {Pre}- and {Post}-{Harvest} {Crop} {Management}

- to {Mitigate} {Aflatoxin} {Contamination} in {Groundnut}, {Maize} and {Sorghum}—{Implication} for {Behavioral} {Change}. *Toxins*. 2019;11(12):716. doi:10.3390/toxins11120716
37. Mollay C, Kassim N, Stoltzfus R, Kimanya M. Complementary feeding in Kongwa, Tanzania: Findings to inform a mycotoxin mitigation trial. *Maternal & Child Nutrition*. 2021;17(4):e13188.
  38. Masaka V, Ndlovu N, Tshalibe R, Mhande T, Jombo T. Prevalence of Aflatoxin Contamination in Peanuts and Peanut Butter from an Informal Market, Harare, Zimbabwe. *International Journal of Food Science*. 2022;2022.
  39. Kamika I, Takoy LL. Natural occurrence of Aflatoxin B1 in peanut collected from Kinshasa, Democratic Republic of Congo. *Food Control*. 2011;22(11):1760-1764.
  40. Elshafie SZ, ElMubarak A, El-Nagerabi SA, Elshafie AE. Aflatoxin B 1 contamination of traditionally processed peanuts butter for human consumption in Sudan. *Mycopathologia*. 2011;171(6):435-439.
  41. Mupunga I, Lebelo SL, Mngqawa P, Rheeder J, Katerere DR. Natural occurrence of aflatoxins in peanuts and peanut butter from Bulawayo, Zimbabwe. *Journal of Food Protection*. 2014;77(10):1814-1818.
  42. Katengesya TP. Aflatoxin and fumonisin contamination in homemade and commercial cereal based complementary foods with formula in Morogoro Municipality, Tanzania. Published online 2018.
  43. Magoke G, Krockenberger M, Bryden W, Alders R, Mramba F, Maulaga W. Aflatoxin contamination of village grains in Central Tanzania: Dietary and agricultural practices in relation to contamination and exposure risk. Multidisciplinary Digital Publishing Institute Proceedings. 2019;36(1):20.
  44. Kimanya ME, Meulenaer BD, Roberfroid D, Lachat C, Kolsteren P. Fumonisin exposure through maize in complementary foods is inversely associated with linear growth of infants in Tanzania. *Molecular Nutrition and Food Research*. 2010;54(11):1659-1667. doi:10.1002/mnfr.200900483
  45. Bui-Klimke TR, Guclu H, Kensler TW, Yuan JM, Wu F. Aflatoxin regulations and global pistachio trade: insights from social network analysis. *PLoS one*. 2014;9(3):e92149.
  46. Zain ME. Impact of mycotoxins on humans and animals. *Journal of Saudi chemical society*. 2011;15(2):129-144.
  47. Atanda S, Pessu P, Aina J, Agoda S, Adekalu O, Ihionu G. Mycotoxin management in agriculture. *Greener J Agric Sci*. 2013;3(2):176-184.
  48. Hell K, Mutegi C. Aflatoxin control and prevention strategies in key crops of Sub-Saharan Africa. *African Journal of Microbiology Research*. 2011;5(5):459-466.
  49. Lanubile A, Maschietto V, Borrelli VM, Stagnati L, Logrieco AF, Marocco A. Molecular basis of resistance to Fusarium ear rot in maize. *Frontiers in plant science*. 2017;8:1774.
  50. Warburton ML, Williams WP. Aflatoxin resistance in maize: what have we learned lately? *Advances in Botany*. 2014;2014.
  51. Setamou M, Cardwell K, Schulthess F, Hell K. *Aspergillus flavus* infection and aflatoxin contamination of preharvest maize in Benin. *Plant Disease*. 1997;81(11):1323-1327.
  52. Widstrom N, McMillian W, Beaver R, Wilson D. Weather-associated changes in aflatoxin contamination of preharvest maize. *Journal of Production Agriculture*. 1990;3(2):196-199.
  53. Bandyopadhyay R, Ortega-Beltran A, Akande A, Mutegi C, Atehnkeng J, Kaptoge L, Senghor AL, Adhikari BN, Cotty PJ. Biological control of aflatoxins in Africa: current status and potential challenges in the face of climate change. *World mycotoxin journal*. 2016;9(5):771-789.
  54. Adebo OA, Njobeh PB, Sidu S, Adebiyi JA, Mavumengwana V. Aflatoxin B1 degradation by culture and lysate of a *Pontibacter* specie. *Food Control*. 2017;80:99-103. doi:10.1016/j.foodcont.2017.04.042
  55. Gardner Jr H, Koltun S, Dollear F, Rayner E. Inactivation of aflatoxins in peanut and cottonseed meals by ammoniation. *Journal of the American Oil Chemists' Society*. 1971;48(2):70-73.
  56. Gomaa M, Ayesh A, Abdel Galil M, Naguib K. Effect of high pressure ammoniation procedure on the detoxification of aflatoxins. *Mycotoxin Research*. 1997;13(1):23-34.

57. Murashiki T, Chidewe C, Benhura M, Manema L, Mvumi B, Nyanga L. Effectiveness of hermetic technologies in limiting aflatoxin B1 and fumonisin B1 contamination of stored maize grain under smallholder conditions in Zimbabwe. *World Mycotoxin Journal*. 2018;11(3):459-469.
58. Waliyar F, Osiru M, Ntare BR, Kumar KV, Sudini H, Traore A, Diarra B. Post-harvest management of aflatoxin contamination in groundnut. *World Mycotoxin Journal*. 2015;8(2):245-252. doi:10.3920/WMJ2014.1766
59. Odongo N. Sorting is an affordable technology that can reduce mycotoxin contamination to safe levels. *African Journal of Food, Agriculture, Nutrition and Development*. 2016;6(2).
60. Raters M, Matissek R. Thermal stability of aflatoxin B 1 and ochratoxin A. *Mycotoxin research*. 2008;24(3):130-134.
61. Martins LM, Sant'Ana AS, Iamanaka BT, Berto MI, Pitt JI, Taniwaki MH. Kinetics of aflatoxin degradation during peanut roasting. *Food Research International*. 2017;97(24):178-183.
62. Yazdanpanah H, Mohammadi T, Abouhossain G, Cheraghali AM. Effect of roasting on degradation of aflatoxins in contaminated pistachio nuts. *Food and Chemical Toxicology*. 2005;43(7):1135-1139.
63. Yazdanpanah H, Mohammadi T, Abouhossain G, Cheraghali AM. Effect of roasting on degradation of aflatoxins in contaminated pistachio nuts. *Food and Chemical Toxicology*. 2005;43(7):1135-1139.
64. Emadi A, Jayedi A, Mirmohammadkhani M, Abdolshahi A. Aflatoxin reduction in nuts by roasting, irradiation and fumigation: a systematic review and meta-analysis. *Critical Reviews in Food Science and Nutrition*. Published online 2021:1-11.
65. Jalili M, Selamat J, Rashidi L. Effect of thermal processing and traditional flavouring mixture on mycotoxin reduction in pistachio. *World Mycotoxin Journal*. 2020;13(3):381-389.
66. Leong YH, Ismail N, Latif AA, Ahmad R. Aflatoxin occurrence in nuts and commercial nutty products in Malaysia. *Food Control*. 2010;21(3):334-338.
67. Opoku GF. Process and Product Optimization and Storage Characteristics of Canned Peanut Soup Base. Published online 2013.
68. Rushing BR, Selim MI. Aflatoxin B1: A review on metabolism, toxicity, occurrence in food, occupational exposure, and detoxification methods. *Food and chemical toxicology*. 2019;124:81-100.
69. Lee LS, Cucullu AF, Franz Jr A, Pons Jr WA. Destruction of aflatoxins in peanuts during dry and oil roasting. *Journal of agricultural and food chemistry*. 1969;17(3):451-453.
70. Fandohan P, Zoumenou D, Hounhouigan D, Marasas W, Wingfield M, Hell K. Fate of aflatoxins and fumonisins during the processing of maize into food products in Benin. *International Journal of Food Microbiology*. 2005;98(3):249-259.
71. Njapau H, Muzunguile EM, Changa RC. The effect of village processing techniques on the content of aflatoxins in corn and peanuts in Zambia. *Journal of the Science of Food and Agriculture*. 1998;76(3):450-456.
72. Petchkongkaew A. Reduction of mycotoxin contamination level during soybean fermentation. Published online 2008.
73. Fandohan P, Gnonlonfin B, Hell K, Marasas W, Wingfield M. Natural occurrence of *Fusarium* and subsequent fumonisin contamination in preharvest and stored maize in Benin, West Africa. *International Journal of Food Microbiology*. 2005;99(2):173-183.
74. Kimanya ME, De Meulenaer B, Tiisekwa B, Ndomondo-Sigonda M, Devlieghere F, Van Camp J, Kolsteren P. Co-occurrence of fumonisins with aflatoxins in home-stored maize for human consumption in rural villages of Tanzania. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*. 2008;25(11):1353-1364. doi:10.1080/02652030802112601
75. Park DL. Effect of processing on aflatoxin. *Mycotoxins and food safety*. Published online 2002:173-179.
76. Afolabi CG, Bandyopadhyay R, Leslie JF, Ekpo EJ. Effect of sorting on incidence and occurrence of fumonisins and *Fusarium verticillioides* on maize from Nigeria. *Journal of food protection*. 2006;69(8):2019-2023.

77. Bediako KA, Ofori K, Offei SK, Dzidzienyo D, Asibuo JY, Amoah RA. Aflatoxin contamination of groundnut (*Arachis hypogaea* L.): Predisposing factors and management interventions. *Food Control*. 2019;98:61-67.
78. Filbert ME, Brown DL. Aflatoxin contamination in Haitian and Kenyan peanut butter and two solutions for reducing such contamination. *Journal of Hunger & Environmental Nutrition*. 2012;7(2-3):321-332.
79. Xu YA, Doel A, Watson S, Routledge MN, Elliott CT, Moore SE, Gong YY. Study of an educational hand sorting intervention for reducing aflatoxin B1 in Groundnuts in Rural Gambia. *Journal of Food Protection*. 2017;80(1):44-49. doi:10.4315/0362-028X.JFP-16-152
80. Anyebuno G, Kyei-Baffour V, Narh D. Effect of manual sorting on Aflatoxins content in peanuts (*Arachis Hypogaea*, L.) from a Ghanaian market. *Ghana Journal of Agricultural Science*. 2018;52:5-15.
81. Whitaker TB, Dorner JW, Lamb M, Slate AB. The effect of sorting farmers' stock peanuts by size and color on partitioning aflatoxin into various shelled peanut grade sizes. *Peanut Science*. 2005;32(2):103-118.
82. Davidson Jr J, Holaday C, Bennett C. Separation and removal of aflatoxin contaminated kernels in peanut shelling plants. I. A case study. In: ; 1981.
83. Morales L, Marino TP, Wenndt AJ, Fouts JQ, Holland JB, Nelson RJ. Dissecting symptomatology and fumonisin contamination produced by *Fusarium verticillioides* in maize ears. *Phytopathology*. 2018;108(12):1475-1485.
84. Rucker KS, Kvien CK, Calhoun K, Henning RJ, Koehler PE, Ghate SR, Holbrook CC. Sorting Peanuts by Pod Density to Improve Quality and Kernel Maturity Distribution and to Reduce Aflatoxin 1. *Peanut Science*. 1994;21(2):147-152. doi:10.3146/i0095-3679-21-2-17
85. Nelson R. Sorting technologies to rehabilitate toxic maize. *Outlooks on Pest Management*. 2016;27(6):247-251.
86. Dorner J. Management and prevention of mycotoxins in peanuts. *Food Additives and Contaminants*. 2008;25(2):203-208.
87. Kirksey J, Cole R, Dorner J. Relationship between aflatoxin content and buoyancy of florunner peanut kernels. *Peanut Science*. 1989;16(1):48-51.
88. Kirksey J, Cole R, Dorner J. Relationship between aflatoxin content and buoyancy of florunner peanut kernels. *Peanut Science*. 1989;16(1):48-51.
89. Carolyne Ngure. Effectiveness of density sorting in reducing aflatoxin b1 and fumonisins in maize grain. Published online 2020.
90. Stafstrom W, Wushensky J, Fuchs J, Xu W, Ezera N, Nelson RJ. Validation and Application of a Low-Cost Sorting Device for Fumonisin Reduction in Maize. *Toxins*. 2021;13(9):652.
91. Simonyan J, Yiljep D. Investigating grain separation and cleaning efficiency distribution of a conventional stationary rasp-bar sorghum thresher. *Agricultural Engineering International: CIGR Journal*. Published online 2008.
92. Huff W. A physical method for the segregation of aflatoxin-contaminated corn. *Cereal Chemistry*. 1980;57(4):236-238.
93. Fandohan P, Zoumenou D, Hounhouigan D, Marasas W, Wingfield M, Hell K. Fate of aflatoxins and fumonisins during the processing of maize into food products in Benin. *International Journal of Food Microbiology*. 2005;98(3):249-259.
94. Mutungi C, Gaspar A, Abass A. Postharvest operations and quality specifications for rice: A trainer's manual for smallholder farmers in Tanzania. Published online 2020.
95. Boon KF, Kiefert L, Ctainsh GH. Organic matter content of rural dusts in Australia. *Atmospheric Environment*. 1998;32(16):2817-2823.
96. Kirksey J, Cole R, Dorner J. Relationship between aflatoxin content and buoyancy of florunner peanut kernels. *Peanut Science*. 1989;16(1):48-51.
97. Phillips TD, Clement BA, Park DL. Approaches to Reduction. The toxicology of aflatoxins: Human health, veterinary, and agricultural significance. Published online 1994:383-399.
98. Kirui C. Assessment of the traditional and improved processing methods in the reduction of aflatoxin levels in maize and

- maize products. Published online 2016.
99. Matumba L, Jacobs B, Saeger SD. Effectiveness of hand sorting, flotation/washing, dehulling and combinations thereof on the decontamination of mycotoxin-contaminated white maize. *Food Additives & Contaminants: Part A*. 2015;32(6):960-969.
100. Castells M, Marín S, Sanchis V, Ramos AJ. Distribution of fumonisins and aflatoxins in corn fractions during industrial cornflake processing. *International journal of food microbiology*. 2008;123(1-2):81-87.
101. Siwela AH, Siwela M, Matindi G, Dube S, Nziramasanga N. Decontamination of aflatoxin-contaminated maize by dehulling. *Journal of the Science of Food and Agriculture*. 2005;85(15):2535-2538.
102. Kamala A, Kimanya M, De Meulenaer B, Kolsteren P, Jacxsens L, Haesaert G, Kilango K, Magoha H, Tiisekwa B, Lachat C. Post-harvest interventions decrease aflatoxin and fumonisin contamination in maize and subsequent dietary exposure in Tanzanian infants: A cluster randomised-controlled trial. *World Mycotoxin Journal*. 2018;11(3):447-458. doi:10.3920/WMJ2017.2234
103. Adebisi JA, Kayitesi E, Njobeh PB. Mycotoxins reduction in dawadawa (an African fermented condiment) produced from Bambara groundnut (*Vigna subterranea*). *Food Control*. 2020;112:107141.
104. IARC CP, Miller JD, Groopman JD. Mycotoxin control in low-and middle-income countries. Published online 2015.
105. CAC. Code of practice for prevention and reduction of mycotoxin contamination in cereals, including annexes on ochratoxin A, zearalenone, fumonisins and trichothecenes. (CAC/RCP 51–2003) Joint FAO. WHO Food Standards Program, FAO, Rome. Published online 2003.
106. Anyebuno, Narh D, Scientific C, Box POM. Effect of manual sorting on Aflatoxins content in peanuts (*Arachis Hypogaea*, L .) from a Ghanaian market. Published online 2007:5-15.
107. Mutegi C, Wagacha M, Kimani J, Otieno G, Wanyama R, Hell K, Christie ME. Incidence of aflatoxin in peanuts (*Arachis hypogaea* {Linnaeus}) from markets in {Western}, {Nyanza} and {Nairobi} {Provinces} of {Kenya} and related market traits. *Journal of Stored Products Research*. 2013;52:118-127.
108. Dowell F, Dorner J, Cole R, Davidson Jr J. Aflatoxin reduction by screening farmers stock peanuts. *Peanut Science*. 1990;17(1):6-8.
109. Ogunsanwo B, Faboya O, Idowu O, Lawal O, Bankole S. Effect of roasting on the aflatoxin contents of Nigerian peanut seeds. *African Journal of Biotechnology*. 2004;3(9):451-455.
110. Kaaya AN, Kyamuhangire W. The effect of storage time and agroecological zone on mould incidence and aflatoxin contamination of maize from traders in Uganda. *International Journal of food microbiology*. 2006;110(3): 217-223.