PEER-REVIEWED ARTICLE

Food Protection Trends, Vol 36, No. 2, p. 96–107

6200 Aurora Ave., Suite 200W, Des Moines, IA 50322-2864

Wojciech J. Florkowski[1]* and Shashidhara Kolavalli[2]

[1]1109 Experiment St., 212 Stuckey Bldg., The University of Georgia, Griffin, GA 30223-1797, USA
[2]IFPRI Ghana, c/o International Water Management Institute (IWMI), PMB CT 112, Cantonments, Accra, Ghana

Aflatoxin Control in Groundnut Value Chain in Sub-Saharan Africa: The Case of Ghana

ABSTRACT

Groundnuts, which are widely consumed in West Africa, are prone to contamination by aflatoxins during production, storage and processing. Although aflatoxins play a role in many important health risks in developing countries, individuals and governments often ignore the risks because the health effects are not immediate. The objective of this paper is to examine production and marketing practices, particularly grading methods, in Ghana's groundnut value chain to obtain a clear understanding of the sources and levels of total aflatoxin contamination in the crop and how such contamination can be reduced in the environment of limited resources and lack of institutional capacity to control and enforce food quality regulations. The study finds that seemingly inferior kernels, which are likely to be contaminated, are indeed sorted out but that the 'rejects' are not eliminated from the food system. Instead, they are offered to consumers in a crushed form as an ingredient in cooking and flavoring. Testing for aflatoxins confirmed high levels of contamination, particularly in products that contained crushed groundnuts. The paper suggests a multipronged strategy suitable for a developing country, in which stringent enforcement of regulations may be infeasible.

INTRODUCTION

Aflatoxins are carcinogenic metabolites that are produced primarily by *Aspergillus flavus* and *Aspergillus parasiticus* and that contaminate groundnuts *(5)*. Groundnuts are an important cash crop in Ghana and an essential component of many Ghanaians' diets. Production is estimated to have tripled between 1995 and 2005 *(26)*. In 2009, Ghanaian farmers produced nearly 500,000 metric tons of groundnuts (Ghana Statistical Service, pers. comm., September 23, 2011).

In 2000, national per capita groundnut consumption was estimated at 0.61 kg per week *(3)*. Nearly 80 percent of Ghanaians consume groundnuts or groundnut products at least once a week and 32 percent at least three times a week *(17)*, because groundnuts are an important source of protein.

*Author for correspondence: Phone: +1 770.228.7233; Fax: +1 770.228.7208; E-mail: wojciech@uga.edu

Aflatoxins have been confirmed as, or suspected of, playing a role in 6 of the 10 most important health risks in developing countries, and are likely involved in acute toxicity, liver carcinogenicity, liver cirrhosis, immunosuppression, and impaired growth in children *(22, 23)*. However, aflatoxin-related illnesses often go unnoticed because symptoms are not immediately apparent, but rather manifest themselves only after long-term exposure to moderate to low aflatoxin concentrations. Some estimate that the toxic effects on immunity and nutrition are responsible for more than 40 percent of the disease burden in developing countries *(25)*. The economic costs of the direct and indirect effects of aflatoxin ingestion are huge although—because of the mode of inflicting damage—difficult to isolate and quantify. For example, African countries lose approximately $670 million annually due to inability to meet the aflatoxin standards of the European Union (EU) *(20)*.

Among developing countries, those in Africa suffer disproportionally from aflatoxin contamination. Soil is the primary source of inoculum *(1)*. The high temperatures and humidity typical of most African countries south of the Sahara favor the growth of the fungus and aflatoxin production *(24)* *(Photograph 1)*. *Aspergillus* species grow best at temperatures between 18°C and 33°C and at relative humidity greater than 50 percent.

The reason aflatoxin contamination does not attract great public attention in Africa is a lack of awareness of its presence in food and of its consequences. There have been changes recently, however. In March 2011, African leaders asked the African Union to emphasize sanitary and phytosanitary issues in the Comprehensive African Agriculture Development Plan framework, and to establish an Africa-led Partnership for Aflatoxin Control in Africa (PACA). Launched in October 2012, PACA aims to provide leadership and coordination for Africa's aflatoxin-control efforts.

Minimizing aflatoxin contamination of food and feed systems in developing countries is a challenge. The Ghana Standards Board, for example, allows only up to 20 µg/kg of total aflatoxin contamination in in-shell or shelled groundnut kernels, regardless of grade *(11)*. Specific grade requirements have not been established *(11)*, likely because of varietal differences. For example, kernel size varies in the three types of groundnuts grown in Ghana (Bugla, Abain and China), and the distinction is not clear because the certified (genetically uniform) groundnut seeds are unavailable to farmers. The processed groundnut products are required to meet the EU allowable limit of 4 µg/kg.

Although aflatoxin contamination is difficult to prevent, specific cultural and postharvest handling techniques can reduce it. Good agricultural practices, such as timely planting, optimal plant densities, and proper plant nutrition have been shown to reduce aflatoxin contamination, as have avoiding drought stress and controlling other plant pathogens, weeds, and insect pests *(7)*. Delayed and incomplete drying of harvested groundnuts encourages fungal growth on the pods, which usually act as barriers to protect kernels from becoming contaminated but cannot do so if groundnuts are stored for prolonged periods under conditions conducive to growth. A single contaminated pod can infect the entire batch, and as cross-contamination is rapid under Ghana's climatic conditions of high average temperatures and relative humidity, groundnuts have to be handled carefully during storage and processing. Sorting out physically damaged and infected kernels and grains can reduce postharvest contamination. Removing abnormal-looking kernels and grains can result in a 40 to 80 percent reduction in aflatoxin levels *(14)*.

Another technology that can reduce aflatoxin levels is mechanical shelling of groundnuts. Soaking the nuts in water to soften the shell for easier hand shelling is common, but this practice introduces moisture that promotes fungal growth on the kernels, exacerbating the problem of aflatoxin contamination.

Fumigation in storage, using compounds such as ethylene oxide and methyl bromide, has also been shown

Photograph 1. Molded, mature, immature and split goundnuts are likely to be contaminated by aflatoxin. Source: http://www.icrisat.org/aflatoxin/food_security.asp. Accessed October 26, 2015

to significantly reduce the incidence of fungi, and smoking has been shown to reduce infestation of harvested grain by fungi *(14)*. A technology that reduces the damage caused by consumption of contaminated foodstuffs is an additive such as NovaSil clay and chlorophyllin in food and feed that limit the absorption of aflatoxin by humans. Another strategy is the use of moisture-controlled drying and storage facilities that help reduce aflatoxin contamination in the postharvest period. Such a capital-intensive agricultural practice, however, often is too costly for African smallholder farmers and governments to adopt. Therefore, the challenge of controlling aflatoxins in African countries is to develop feasible control strategies that take into account the limited resources, lack of institutional capacity, and reality of insufficient food.

Technologies are available to reduce *Aspergillus* infestation in the field and during storage. The international agribusiness firm Syngenta, for example, offers a biocontrol product known as Afla-guard® to manage aflatoxins in groundnut fields. Afla-guard employs nontoxigenic, indigenous strains of *Aspergillus* that can competitively prevent toxigenic strains from colonizing crops, reducing aflatoxin contamination by 70 to 90 percent *(8)*. In Africa, the International Institute of Tropical Agriculture, the Agricultural Research Service of USDA, and their partners have successfully adapted this competitive displacement technology to produce Aflasafe™, and product development is now under way *(4)*.

Adoption of aflatoxin-resistant groundnut varieties appears to be the most practical control strategy for Africa. However, development of aflatoxin-resistant varieties is a long and complex process that includes direct selection for resistance to fungus and aflatoxin accumulation and indirect selection for resistance or tolerance to biotic and abiotic stresses. So far, development of aflatoxin-resistant strains for aflatoxin-susceptible crops is only in various early stages of testing *(4)*.

The objective of this paper is to examine production and marketing practices in Ghana's groundnut value chain to obtain a clear understanding of the sources and levels of aflatoxin contamination in the crop and how such contamination can be sharply reduced. The evidence generated through this study will then be used to contribute to the development of a strategy to minimize aflatoxin contamination in Ghana—one that might be appropriate for other developing countries in which vigorous regulation and control of aflatoxin is infeasible.

MATERIALS AND METHODS

Overall, information about groundnut consumption is fragmentary, and its paucity distorts the importance of groundnuts to regional and national economies and, more importantly, their critical role in diets and nutrition. To overcome the information gap and update past reports, a survey focusing on the groundnut value chain was implemented, with the aim of obtaining insights into postharvest practices relevant to preventing or increasing aflatoxin contamination. Between July 18 and July 24, 2010 and July 26 and August 2, 2010, the comprehensive survey involved 249 farmers, 22 wholesalers, 29 market vendors, and 30 cottage industry processors in the Northern Region of Ghana, the primary commercial groundnut production area in the country, and interviews with wholesale traders at the timber market, Nima and Madina markets in Accra, because shipments of groundnuts from wholesale traders in Tamale were destined primarily for Accra.

The villages for the farmer survey were randomly selected from lists for the districts surrounding Tamale. The numbers of farmers were then assigned to each location with the help of Microsoft Excel's random number generator. In the selected villages, the survey team approached assemblymen and other leaders and requested names of groundnut farmers. Names were randomly picked from the lists provided.

Wholesalers were randomly selected for interview. Of the 22 traders interviewed, 18 (82%) were at the Aboabo market, one (5%) at the Savana farmers' market in Tamale, and three (14%) at the timber market in Accra. About 47% of vendors were randomly selected for interview at the Aboabo market and consisted primarily of those selling raw shelled peanuts by the bowl; vendors' customers are other women who purchase groundnuts to make paste. Another 21% of vendors in the sample were interviewed at the old market and 11% at Ozu market in Tamale. The same proportion, 5%, of vendors were interviewed at each of the following locations: Tampiong, village common, home and Accra's Madina market.

The selection of small-scale processors posed a challenge because for only a few of them is groundnut processing a full-time job. They were identified with the help of neighborhood residents, who knew a person who sold processed products, buyers of groundnuts by the basin (containing 20–30 bowls) from women traders at the Aboabo market, or processors identified on the label of a groundnut product found in shops in Tamale.

RESULTS

Production practices in Ghana make the crop vulnerable to contamination with aflatoxins prior to harvest. Groundnuts are often intercropped with maize as well as cassava, millet, and sorghum, all of which are highly susceptible to aflatoxin contamination. Crops often go through drought stress, since irrigation is virtually nonexistent in the northern regions of Ghana, and drought, especially in the latter stages of growth, makes groundnuts susceptible to aflatoxin contamination *(19)*. Disease and insect infestations occur under favorable conditions and increase the chance of aflatoxin contamination *(13)*. One-third of 249 surveyed farmers reported using herbicides, but few of them take measures to control pests and plant diseases.

Some of the trading practices associated with groundnuts do reduce the spread of contamination. Traders do not

buy groundnuts with high moisture content from farmers, because they are aware of the risk of mold and discoloration, and they buy only shelled kernels so that they can inspect them for quality. Traders usually judge moisture content just by handling the kernels. Newly harvested groundnuts, high in moisture content, are difficult to sell; nearly 85 percent of the surveyed farmers did not sell immediately after harvest.

Producers store groundnuts at home, often under conditions that stimulate *Aspergillus* growth, selling them as and when cash is needed. An average farmer stores about 18 bags, or nearly half a ton, of groundnuts. Traditional storage structures known as pupuris, which allow air to circulate, potentially slowing the growth of *Aspergillus*, have been replaced by the use of jute or polyethylene bags. If groundnuts are not dried properly to bring the moisture content to less than 12 percent, the heat generated in the bags encourages contamination. Ghana's specification for groundnut moisture establishes at 9 percent for in-shell groundnuts and 7 percent kernels *(11)*. In addition, farmers often store groundnuts in bags that previously stored maize, rice, sorghum, beans, or cocoa, and it is highly probable that these reused bags will be sources of contamination by *Aspergillus* spores *(2, 13)*. Wholesalers, too, typically keep their inventory in jute or polyethylene sacks, which are kept in storage sheds that protect them from rain but do little to control temperature or relative humidity. Moreover, groundnut stocks are particularly susceptible to contamination through the general practice of wholesalers' combining small lots purchased from numerous suppliers.

Processing

Women process groundnuts on a small scale to sell as paste. Fewer than 10 percent of the interviewed women processed groundnuts daily. Typically, a woman processes 10 bowls of groundnuts at a time, to produce almost the same quantity of paste. Purchased groundnuts are lightly roasted, without removing the testa, and then ground at a neighborhood mill. Kernel discoloration, a reliable indicator of possible aflatoxin contamination, is not revealed when kernels are processed without the testa being removed, and even a few aflatoxin-containing kernels can contaminate an entire batch of paste.

In the northern region, women press groundnuts at home to obtain oil, retaining what they may need for home consumption, and sell the rest. The oil is often used to fry a snack, *kulikuli*, made from the pressed groundnut cake. Crushed *kulikuli*, called *kulikuli sim*, is a popular condiment used to flavor grilled meats, roasted plantains, and soups. To make paste or oil, the women often use damaged or split kernels, both more likely to be contaminated by aflatoxin than fully developed whole kernels.

Sorting for quality

The quality attributes important to traders have the potential to eliminate contaminated kernels along the chain. Traders reported they pay attention to three attributes: color, kernel size, and oil content *(Table 1)*. All three groups of buyers pay the most attention to kernel color, which indicates the variety and any damage from mold. The

Table 1. Quality preferences for groundnuts at time of purchase, Northern Region (%)

Surveyed Group/Attribute	Almost Never	Seldom	Neither Seldom Nor Often	Often	Very Often
Wholesalers (n = 22)					
Color	32	0	0	0	68
Kernel size	32	0	0	0	68
Oil content	87	0	0	0	13
Cottage processors (n = 30)					
Color	0	0	0	20	80
Kernel size	0	7	7	10	76
Oil content	10	3	3	3	80
Traders/vendors (n = 29)					
Color	11	0	5	21	63
Kernel size	21	0	0	32	47
Oil content	0	0	0	0	0

Source: Summary of authors' own survey results
Note: Sums may not add to 100 percent due to rounding.

traders are generally not aware of the problem of aflatoxins. Nevertheless, their use of color as a quality measure helps control the amount of aflatoxin in the groundnut value chain, as it eliminates at least a portion of potentially contaminated groundnuts from traded batches.

The cottage processors are the most discerning traders, but even these traders rarely remove sorted-out kernels from the food chain. Cottage processors identified kernel size as an important attribute they consider, but size appears to attract less attention than color, because immature and undersized kernels are not regularly removed although these are more likely to be contaminated by aflatoxins than mature, whole kernels are.

Wholesalers sort their groundnuts only when time permits. *Table 2* shows the frequency with which they undertake different sorting operations. The majority often or very often remove split (64 percent), broken (58 percent), discolored (59 percent), or damaged kernels (76 percent), all of which are possibly contaminated with aflatoxin. However, 20 to 33 percent of wholesalers seldom or almost never sort for such kernels. They appear to sort only when something is demanded by buyers. The absence of trading only in well-defined grades of groundnuts permits contaminated kernels to remain in the food chain.

Cottage industry processors often consider the presence of split or broken kernels when assessing quality, but one-fifth of them almost never pay attention to these two attributes *(Table 3)*. However, such processors frequently take account of kernel size. Skin color is the most frequently considered attribute, and removal of discolored kernels certainly reduces

Table 2. Sorting and premarketing functions performed by wholesalers (%)

Function	Almost Never	Seldom	Neither Seldom Nor Often	Often	Almost Always
Shell groundnuts	57	24	5	10	5
Clean groundnuts by removing foreign matter	—	14	5	23	59
Sort groundnuts by size	23	9	5	18	46
Remove split kernels	9	23	5	18	46
Remove broken kernels	19	14	10	10	48
Remove skin from kernels	29	10	—	24	38
Remove discolored kernels	14	18	9	23	36
Remove damaged kernels	10	10	5	24	52

Source: Summary of authors' own survey results
Note: Totals may not add up to 100 percent due to rounding. Dashes indicate that none of the respondents selected given option.

Table 3. Groundnut attributes considered by surveyed cottage industry processors (%)

Attribute	Almost Never	Seldom	Neither Seldom Nor Often	Often	Very Often
Color of skin	—	—	—	20	80
Taste	7	7	—	13	73
High oil content	10	3	3	3	80
Kernel size	—	7	7	10	76
Presence of split kernels	20	—	—	—	80
Presence of broken kernels	20	—	—	—	80
Presence of groundnut straw	20	—	3	—	77

Source: Summary of authors' own survey results
Note: Sum may exceed 100 percent due to rounding. Dashes indicate that none of the respondents selected given option.

the chances of aflatoxin contamination. However, removal of such discolored kernels was not done consistently.

From the standpoint of reducing aflatoxin contamination, sorting performed by processors removes potential sources *(Table 4)* (discolored or immature kernels and those damaged by insects or rodents). Heavy aflatoxin contamination can be detected visually in a batch of groundnuts, but the shell and the skin from each kernel must be removed. Current practice among cottage processors is to leave the skin on the kernels and grind skins and kernels together. Light roasting is a result of the desire to save fuel, which is expensive.

Even after contaminated groundnuts are removed from a batch, they can re-enter the food chain, because farmers use the removed groundnuts as food or feed. More than half of wholesalers sell the rejects *(Table 5)*, while many traders or vendors sell them or grind them into paste.

Despite sorting, the marketed groundnuts still contain aflatoxin in amounts exceeding allowable limits. Aflatoxin contamination of food has been a persistent problem in Ghana. A survey in the early 1960s showed high contamination in 69 percent (11 out of 16 samples) of samples tested by use of thin layer chromatography *(6)*. For the current study, we obtained groundnut and groundnut product samples from farmers, wholesalers, vendors, cottage processors, hawkers, and supermarkets. All samples (70 total) were tested for total aflatoxin content by a commercial laboratory in the United States. The sample size was a standard volume consisting of about two handfuls of groundnuts. As expected, the groundnuts that were stored longer or had been processed had higher levels of contamination *(Figs. 1 through 3)*.

The new crop of groundnuts (groundnuts harvested at the beginning of August 2010), contained low, allowable levels of aflatoxin, i.e., less than the 15 µg/kg limit for EU-destined groundnuts *(Fig. 1)*. However, between harvests, the contamination level of stored groundnuts rose with time, significantly exceeding the allowable level. The highest levels of contamination were found in rejected kernels (288.78 µg/kg) purchased at one of the Accra markets. The rejects included discolored, molded, or split kernels sorted out of a batch of raw groundnuts marketed by one of the vendors.

Table 4. Sorting procedures used by the surveyed cottage industry processors (%)

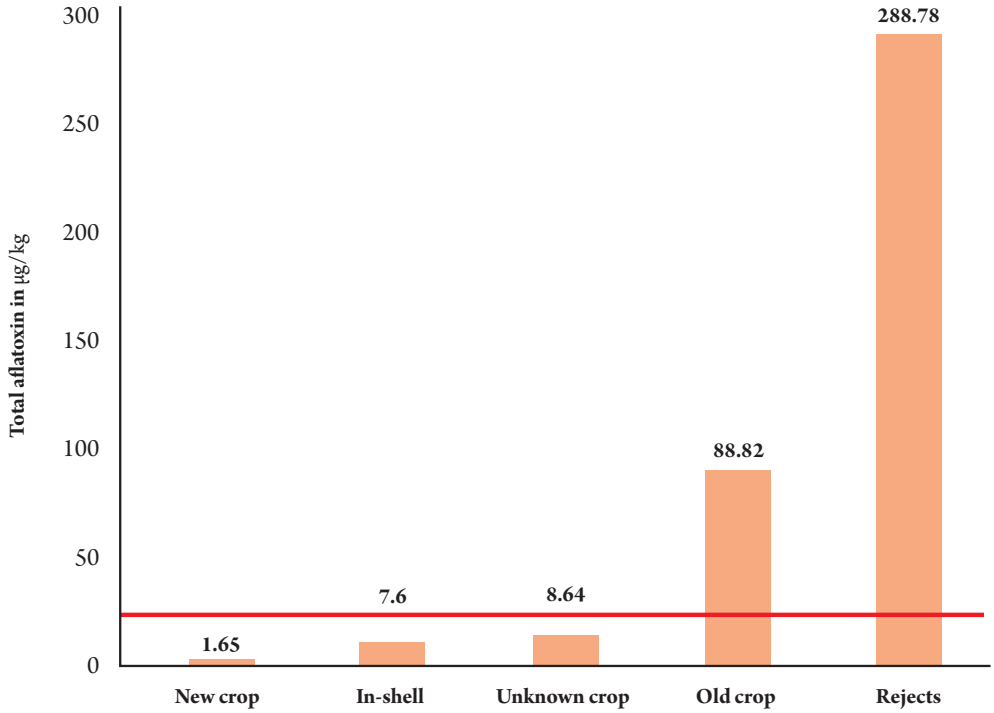
Sorting function	Almost Never	Seldom	Neither Seldom Nor Often	Often	Very Often
Shell groundnuts myself	13	67	3	13	3
Sort kernels by size	21	14	4	7	55
Remove skin from kernels	—	—	—	—	100
Remove discolored kernels	—	—	3	17	80
Remove kernels damaged by insects	—	—	—	17	83
Remove kernels damaged by rodents	3	3	—	17	77
Remove kernels I think are bad	—	—	—	17	83
Roast groundnuts	10	—	—	7	84

Source: Summary of authors' own survey results
Note: Sums may exceed 100 percent due to rounding. Dashes indicate that none of the respondents selected given option.

Table 5. Disposal of rejected kernels by wholesalers and cottage industry processors (%)

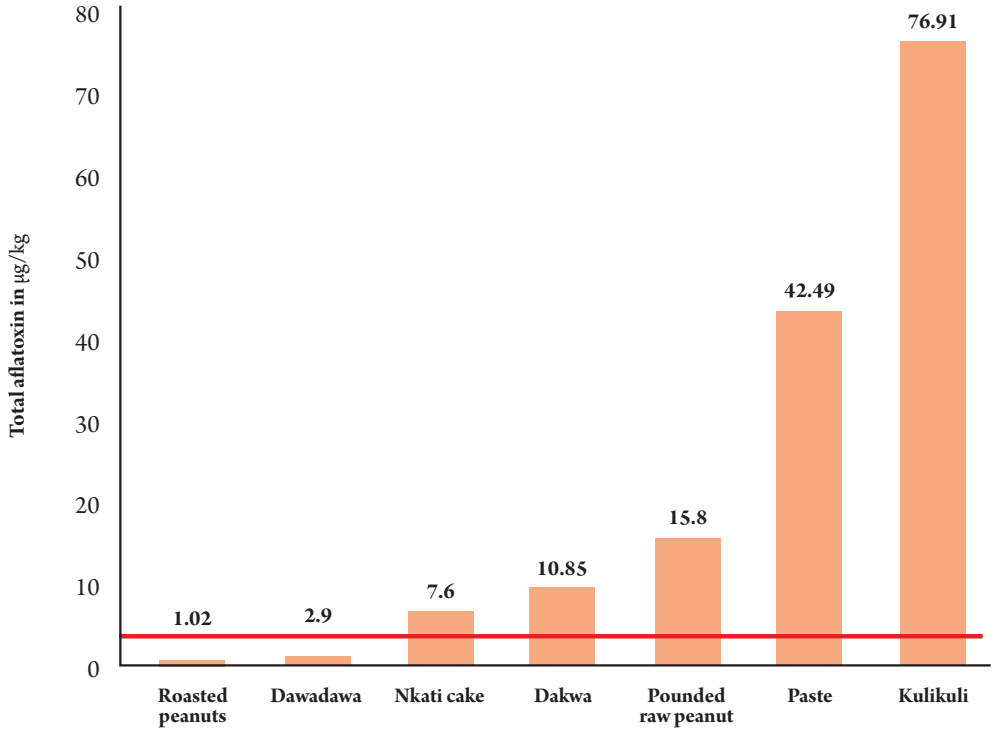
Action	Wholesalers	Traders/Vendors
Ground into paste	—	30
Sell them as they are	55	25
Other	45	55

Source: Summary of authors' own survey results
Note: Dash indicates that none of the respondents selected given option.



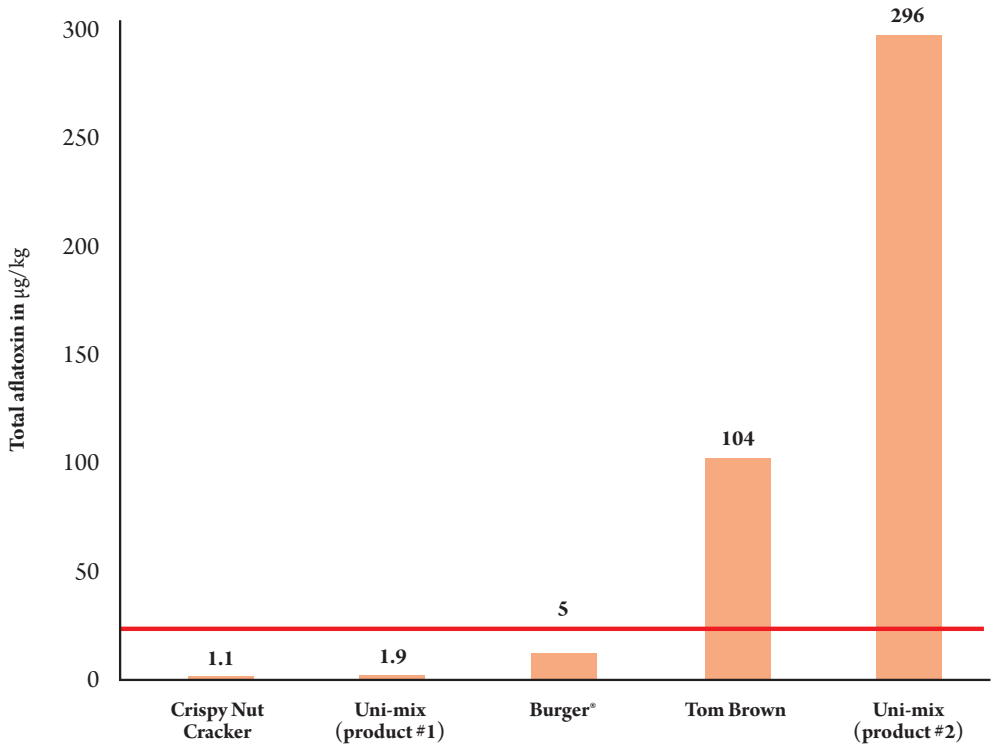
Note: The EU limit in processed food products, shown in red, is 4 micrograms per kilogram. The line shows the 15 micrograms per kilogram limit, the maximum allowable content of aflatoxin in groundnuts exported to the EU.

Figure 1. The Average Total Aflatoxin Content in Raw Groundnuts (n = 37)



Note: The European Union limit in process food products that include groundnuts is 4 ppb. The results do not include one sample of boiled new crop groundnuts, which did not exceed the allowable limit.

Figure 2. The Average Total Aflatoxin Content in Cottage Industry Processed Groundnut Products (n = 33)



Note: The European Union limit in process food products that include groundnuts is 4ppb.

Figure 3. The Average Total Aflatoxin Content in Manufactured Peanut Products (n = 6)

Levels of contamination varied among the processed products sold by cottage industries *(Fig. 2)*. It was not surprising to observe unacceptably high contamination of groundnut paste (on average, 42.49 µg/kg, about 10 times higher than the threshold for entry to the EU). Moreover, very high average contamination was found in kulikuli (76.91 µg/kg). The test results for commercially produced products revealed no particular pattern of contamination *(Fig. 3)*. For example, two weaning mixes that contained groundnut flour showed markedly different contaminant levels.

Grades and testing facilities

Although Ghana has standards that are as stringent as those of the EU, informal processing of groundnuts makes their enforcement infeasible. The cottage processing industry, which does not package its products, escapes these regulations. Although these regulations apply to commercially packaged groundnut products, our testing showed that aflatoxin contamination in such products significantly exceeded the allowable threshold of 4 µg/kg permitted in the EU, even in manufactured products packaged in moisture-barrier materials.

Testing for aflatoxin is expensive, and Ghana does not have commercial laboratories capable of conducting the tests. While government research institutions or the leading universities have the expertise and equipment, small groundnut processors cannot afford the $100 cost of a single test *(10)*. Even commercial manufacturers might find this cost prohibitively expensive if testing each batch were to be required.

None of the interviewed traders or processors mentioned using official standards for grading groundnuts in their trade or marketing practices. In fact, none of them were aware of the existence of such standards. Ghana's published standards *(11)* did not provide specifics for grades, indicating that they were under development. Absence of foreign matter is specified, and aflatoxin level is indicated at 20 µg/kg. The latter is the most important, because most groundnuts are processed into paste or meal; safety is more important than a specific grade, given this utilization.

Awareness of aflatoxin

Although awareness of the health effects of aflatoxin-contaminated food is low among the public in Ghana, occasional panics about aflatoxins have occurred. In 1998, a front-page newspaper article led to public panic by reporting that *kenke*, a common maize-based food, contained aflatoxins and caused cancer *(21)*. However, after emotions had subsided, the issue of aflatoxins in food was sidelined and received little public attention.

Moreover, few agriculturists or health professionals in Ghana are aware of the health risks associated with aflatoxins *(16)*. Some of those professionals are charged with allocating

resources to reduce contamination, but they are unaware of the extent of the associated economic and health risks *(15)*. Even if the knowledge exists, these professionals may assign aflatoxins a low priority, as might policymakers, given the range of other, more pressing issues they need to address.

DISCUSSION

In developed countries, stringent enforcement of regulations backed by advanced sorting and testing processes and repeated testing drive innovations to control aflatoxin contamination during crop production and storage. The cost of such regulation would be prohibitive for a developing country such as Ghana, particularly because groundnuts are produced by numerous smallholders, traded at hundreds of places, processed informally in all communities, and served in all eating establishments. Technologies that have been developed in wealthier countries would also not be widely adopted. If such controls were to add to costs, producers and traders would have incentives to adopt them only if regulatory enforcement or a premium on quality existed.

Producers, traders, and processors periodically sort for defective groundnuts, but the practice does not bring aflatoxin contamination down to acceptable levels. Moreover, the rejects re-enter the food chain by being sold at a discount for use in various food products.

While Ghana has regulations on aflatoxin contamination that are consistent with international standards, enforcement is limited to commercial processors, if they are enforced at all. This leaves the vast informal sector unregulated. To regulate the sales at numerous open-air markets, street stalls, or mobile hawkers is virtually impossible.

A strategy appropriate for minimizing aflatoxin contamnation in Ghana must take several factors into consideration: the costs of enforcing existing regulations, the burden those regulations may place on various agents in the value chain, and consumer willingness to pay for products free from contamination *(Table 6)*. There are options available in two broad categories:

- Consumer driven: A market-based approach minimizes contamination because of consumer demand. This would necessarily entail consumers' willingness to pay for products with acceptable levels of contamination. However, this strategy entails consumer education and appropriate testing and labeling of products, as consumers cannot visually assess the quality. To the extent that some consumers are willing to buy and eat contaminated kernels and even rejects, this approach would not reach all consumers.
- Regulation driven: This approach uses regulations to drive innovations among various actors in the groundnut value chain to minimize contamination or bring it down to publicly acceptable levels. Consumer awareness is not necessary, but regulations would be accepted if they did not place undue burden on any actors in the value chain, including consumers.

Approaches based on willingness to pay would benefit, at least initially, only a small portion of the consumers but would offer a price premium for producers and processors of aflatoxin-free material. The assumption is that it would be difficult to create awareness among the entire population and that most people would not change their groundnut consumption behavior, because the detrimental health effects of aflatoxin contamination are not immediately apparent. The willingness to pay on the part of a small portion of consumers, however, needs to be channeled into the development of products and the emergence of processors to supply those aflatoxin-free products. Ideally these processors can offer incentives upstream to reduce contamination and sustain grading practices, causing traders and producers to change behavior. At the other end of the consumer spectrum, the challenge is to persuade retailers and informal processors to remove contaminated products from the food chain *(Table 6)*.

One point of entry would be to begin where regulation enforcement is feasible, which is among formal processors. However, they may need to be subsidized by the government initially, as the costs of fully complying with the regulations might be more than the premium consumers may be able to bear, putting at risk the businesses of those producers of groundnut products that meet the regulations. In Ghana, for example, processors may have to discard 25 percent of the kernels from groundnuts purchased in wholesale markets, thus increasing costs significantly. If a safe domestic groundnut supply cannot be established, the domestic commercial processing sector either will wither because of unprofitability or will turn to imports to meet the domestic (and possibly subregional) demand for aflatoxin-safe products. Formal processing and marketing units might be able to create a niche for their products, taking advantage of the willingness of discerning consumers to pay for aflatoxin-safe products. These products might also meet the import requirements within West Africa as well as the lucrative markets of the EU and the United States.

These commercial units may be assisted by an aflatoxin-control initiative in a number of ways to encourage the development of products. One of them could be to help develop an aflatoxin-free value chain; another way could be to help product and market development, which would serve the public purpose of generating awareness. The units could be trained by the initiative to remove contaminated groundnuts from the food chain through the application of simple and inexpensive techniques that involve presorting and in-process sorting on premises *(18)*.

What the processing plants would do with kernels that have been sorted out remains a question. They could extract oil from them but would still have the incentive to release the cake into the food chain. For example, the United States still limits the use of groundnut cake to feed and fertilizer markets, as the material contains high aflatoxin concentrations *(12)*. Additional

Table 6. Groundnut value chain participants and factors that might offer them incentives to supply aflatoxin-safe groundnut products

Actors	Desired behavior	Some of the disincentives	Intervention
Consumers	Reject products that are contaminated with aflatoxin	A small section that could be persuaded to pay for aflatoxin-free products does not have the opportunity The remaining will continue to consume because they are not convinced of the health effects, economic considerations, or both	Introduce aflatoxin-safe products and market development-oriented awareness
Formal processors	Not to process aflatoxin-contaminated raw material Take advantage of willingness to pay for aflatoxin-safe products	They will continue to process as before unless regulated They will likely cease production if it is not viable for them to meet the regulatory requirements	Provide formal processors with assistance (market development and establishment of aflatoxin-free supply chains) to develop aflatoxin-safe products
Informal processors	Take groundnut rejects out of the food system	They will not do so unless regulated or consumers begin to question the quality of groundnuts that go into products such as paste	Develop schemes to purchase rejects and turn them into products safe for the livestock sector, for example, establishing enterprises that buy sorted-out groundnuts to produce safe products for the animal and poultry industries
Traders	Grade, offer premium for higher quality kernels, and dispose of sorted-out groundnuts	They will do so only if a premium is offered down-stream for aflatoxin-free groundnuts.	Introduce a market for graded groundnuts through formal processors Train traders in sorting and the use of moisture meters
Producers	Adopt production and storage practices that reduce contamination	They will do so only if offered higher prices or if their outputs are rejected; in the case of the latter, if there are no feasible technical options they will withdraw from groundnut production	Create a market for graded groundnuts Provide access to and information about technologies to meet the demands downstream for contamination-free raw material Introduce technologies that make producers no worse off economically, while minimizing contamination

Source: Authors.

incentives are needed to persuade Ghanaian processors to push oil cakes out of the food system.

The feasibility of establishing enterprises that buy sorted-out groundnuts to produce safe products for the animal and poultry feed industries needs to be considered. This is especially true given the need to take sorted-out groundnuts not only from formal processors but also from informal processors, who lack incentive to take them out of the food chain. The viability of such an enterprise would depend on the extent to which grading would take place,

the price of groundnuts and the cost of technologies to turn cake into safe product.

The introduction of low-cost testing facilities is an obvious and necessary complementary step. There is an opportunity for the private sector to answer the need for rapid testing methods that can robustly assess whether the aflatoxin level in a batch of groundnuts or a groundnut product is too high. The rapid testing procedure could more than halve the current costs of about $100 per test *(10)*. The technology for this procedure should also include moisture meters. The fact that commercial processors will accept only groundnuts that meet a specific moisture content could encourage good drying practices by smallholders *(9)*.

Having met the quality requirements, the commercial units involved would signal stakeholders upstream to supply aflatoxin-safe material and offer a premium for locally produced nuts. Training programs in grading and sorting for traders who supply commercial processors would serve as a subsidy for the processing firms and traders.

For informally processed groundnut and groundnut products, the essential issue is consumer education. Massive consumer education is unrealistic. However, through traders and vendors, some information will flow to the rest of the population about the factors that are detrimental to their health and livelihoods. Then, over time, consumers can be expected to become more selective about purchasing groundnut products.

Interventions therefore would include support to formal processors to develop aflatoxin-safe products for niche markets. This support would entail market development, stringent regulation, and certification of products from formal processing. It would also entail development of testing facilities, training of traders engaged in formal processing supply chains, and piloting of processing centers in smaller towns. These processing centers would purchase rejects for producing feed for animals. This means that multiple approaches are required to begin to introduce products that are free from high levels of contamination. These various approaches complement each other; some interventions may trigger changes that make other interventions more effective. Therefore, one needs to consider pathways of change that can be expected from different interventions, along with their costs and feasibility. Moreover, the interventions may need to be sequenced. This would reduce implementation costs and enhance the benefits of the interventions by building on the secondary changes that some interventions are capable of generating.

ACKNOWLEDGMENTS

The authors express their appreciation to Dr. Larry R. Beuchat, Center for Food Safety, and Manjeet S. Chinnan, The University of Georgia, for comments on the earlier draft of this paper, and for comments of several anonymous internal reviewers. The authors extend their appreciation to Marilyn Slocum, Amanda Hollar, Jerri Snodgrass, John Cruickshank, and IFPRI Office staff in Accra, Ghana, for assistance in technical preparation of the manuscript and literature search. The authors acknowledge financial support for this study provided by IFPRI to collect the field data. The authors thank Dr. Mohammed Ibrahim, Fort Valley State University, for his guidance in data collection in Ghana.

REFERENCES

1. Accinelli, C., H. K. Abbas, R. M. Zablotowicz, and J. R. Wilkinson. 2008. *Aspergillus flavus* aflatoxin occurrence and expression of aflatoxin biosynthesis genes in soil. *Canadian J. Microbiol.* 54:3379.
2. Awuah, R. T., and K. A. Kpodo. 1996. High incidence of *Aspergillus flavus* and aflatoxins in stored groundnut in Ghana and the use of microbial assay to assess the inhibitory effects of plant extracts on aflatoxin synthesis. *Mycopathologia* 134:109–114.
3. Awuah, R. T., O. Kwaku, S. Agyemang, C. Fialor, and C. M. Jolly. 2000. Aflatoxigenic fungi and aflatoxin contamination of groundnut and groundnut-based products in Ghana: Implications and concerns. Proceedings of a National Workshop on Groundnut and Groundnut Aflatoxins, 19–21 September 1999, edited by R. T. Awuah and W. O. Ellis, 17–26. Kumasi, Ghana: Kwame Nkrumah University of Science and Technology.
4. Bandyopadhyay, R., and P. J. Cotty. 2013. Biological controls for aflatoxin reduction. 2020 Focus Brief 20(16). Washington, D.C. International Food Policy Research Institute.
5. Bandyopadhyay, R., P. J. Cotty, M. Kumar, and J. F. Leslie. 2007. Relative severity of aflatoxin contamination of cereal crops in West Africa. *Food Addit. and Contamin.* 24(10):1109–1114.
6. Bearwood, C. J. 1964. Detection of aflatoxin in groundnut in Accra. *Ghana Med. J.* 3:87–88.
7. Dietzgen, R. G. Queensland Department of Primary Industries, and Institut Pertanian Bogor. 1999. Elimination of Aflatoxin Contamination in Peanut: A Collaborative Workshop Project between the Queensland Department of Primary Industries and Australia and Bogor Agriculture University, Indonesia. ACIAR Proceedings, 89. Canberra: Australian Centre for International Agricultural Research.
8. Dorner, J. W. 2009. Development of biocontrol technology to manage aflatoxin contamination in peanuts. *Peanut Sci.* 36(1):60–67.
9. Emmott, A. 2013. Market-led aflatoxin interventions: smallholder groundnut value chains in Malawi. 2020 Focus Brief 20(8). Washington, D.C. International Food Policy Research Institute.
10. Food Research Institute 2012. Council of Scientific and Industrial Research, Accra, Ghana, personal information obtained in January 2012.
11. Ghana Standards Board. 2001. Nuts—Specification for Groundnut. GS 313, 2001. Accra, Ghana.
12. Gray, N. 2012. Enzyme technology may provide value-added extracts from peanut waste. Food Navigator. Available from www.foodnavigator.com/Science-Nutrition/Enzyme-technology-may-provide-value-added-extracts-from-peanut-waste. Accessed 30 July, 2014.
13. Hell, K., K. F. Cardwell, M. Setamou, and H. M. Poehling. 2000. The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *J. Stored Prod. Res.* 36:365–382.
14. Hell, K., K. F. Cardwell, M. Setamou, H. M. Poehling, and C. Mutegi. 2011. Review: Aflatoxin control and prevention strategies in Kenya crops of sub-Sahara Africa. *Afr. J. Microbiol. Res.* 5:459–466.

15. Hendrickse, R. G. 1999. Of sick turkeys, Kwashiorkor, Malaria, perinatal mortality, heroin addicts and food poisoning: Research on the influence of aflatoxins on child health in the tropics. *Annals Trop. Paediat.* 19:229–235.

16. Jolly, C. M., B. Bayard, R. T. Awuah, S. C. Fialor, and J. T. Williams. 2009. Examining the structure of awareness and perceptions of groundnut aflatoxin among Ghanaian health and agricultural professionals and its influence on their actions. *J. Socio-econ.* 38:280–287.

17. Jolly, C. M., B. Bayard, R. T. Awuah, S. C. Fialor, J. T. Williams, R. T. Awuah, S. C. Fialor, K. O. Agyemang, J. M. Kagochi, and A.D. Binns. 2008. Groundnut consumption frequency in Ghana. *Int. J. of Consum. Stud.* 32:675–686.

18. Lustre, A. O., L. S. Palomar, M. L. Francisco, and A. V. A. Resurreccion. 2007. Impact assessment of the peanut CRSP project in the Philippines, Part 2. USA–Philippines Monograph Series No. 9. Griffin, GA, U.S.: University of Georgia, U.S. Agency for International Development—Peanut Collaborative Research Support Program.

19. Mehan, V. K., R. C. Nageswara Rao, D. McDonald, and J. H. Williams. 1988. Management of drought stress to improve field screening of peanuts for resistance to *Aspergillus flavus*. *Am. Phytopatho. Soc.* 78:(6):659–663.

20. Otsuki, T., J. S. Wilson, and M. Sewadeh. 2001. Saving two in a billion: quantifying the trade effect of European food safety standards on African exports. *Food Pol.* 26 (2001):495–514.

21. Plange, P. K. 1999. Fufu, Gari Can Also Cause Cancer—Food Research Inst. Ghana Chronicles. www.modernghana.com/news2/7772/4/mr-ibu-is-champion-sportsman.html. Accessed 30 July, 2014.

22. Taniwaki, M. H., and J. I. Pitt. 2013. Mycotoxins. *In* Food Microbiology: Fundamentals and Frontiers, edited by M. P. Doyle and R. L. Buchanan, (4th ed.). Washington, D.C. U.S. *ASM Press,* 597–618.

23. Turner, P. C., A. Sylla, M. S. Diallo, J. J. Castegnaro, A. J. Hall, and C.P. Wild. 2002. The role of aflatoxins and hepatitis viruses in the etiopathogenesis of hepatocellular carcinoma: A basis for primary prevention in Guinea–Conakry, West Africa. *J. of Gastro. Hep.* 17 (suppl.):S441–448.

24. Wagacha, J. M., and J. W. Muthomi. 2008. Mycotoxin problem in Africa: current status, implications to food safety and health and possible management strategies. *Int. J. Food Microbiol.* 124:1–12.

25. Williams, J. T., T. D. Phillips, P. E. Jolly, J. K. Stiles, C. M. Jolly, and D. Aggarwal. 2004. Human aflatoxicosis in developing countries: A review of toxicology, exposure, potential health consequences and interventions 1'2'3. *Am. J. Clin. Nutr.* 80:(5):1106–1122.

26. Yaw, A. J., R. Akromah, O. Safo-Kantanka, H. K. Adu-Dapaah, S. Ohemeng-Dapahh, and A. Agyeman. 2008. Chemical composition of groundnut, Arachis hypogaea (L) landraces. *Afr. J. Biotech.* 7:(13):2203–2208.