Aflatoxins: A Negative Nexus between Agriculture, Nutrition and Health

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Over the past decade, development literature has placed significant emphasis on learning how agriculture can be leveraged for improved nutrition and health. It is generally expected that agricultural development should lead to improved health and nutritional outcomes, but evidence has been scant to support this hypothesis (see Fan and Pandya-Lorch, 2002 for a detailed literature review). In this paper we argue that Aflatoxins, which are poisons that occur naturally in the environment, create a negative nexus between agriculture production and public health because any level of aflatoxin in foods makes it unsafe to consume. It is possible that they could explain away lack of the positive link in certain geographies. Aflatoxins are produced mainly by Aspergillus flavus and Aspergillus parasiticus fungi that are present in soils and can contaminate many important staple crops: maize, sorghum, millet, rice, oilseeds, spices, groundnuts, tree nuts, and cassava. Hot, humid, and drought-prone climates located within 40ºN and 40ºS latitude are favorable environments for the fungus, implying that aflatoxins are most prominent in developing countries.

Aflatoxin contamination during crop development and maturity depends on environmental conditions that are optimal for the growth of fungi. During crop development, damage by pests (birds, mammals, and insects) or the stress of hot, dry conditions can result in significant infections. Drought stress (elevated temperature and low relative humidity) increases the number of *Aspergillus* spores in the air, increasing the chance of contamination. In addition, other stresses (e.g., nitrogen stress) that affect plant growth during pollination can increase the level of aflatoxin produced by the *Aspergillus* fungi. The impact of drought on aflatoxin contamination is further exacerbated by the fact that drought stress can reduce the ability of crops to resist the growth of aflatoxin-causing fungus. At the time of harvest, high moisture and warm temperatures can increase the risk of aflatoxin contamination. Inadequate drying and improper storage also increases the risk of aflatoxin contamination. Therefore, although environmental factors play a role, lack of good agricultural practices and poor access to irrigation and fertilizer that are important for plant health implies that developing countries are more likely to have higher aflatoxin prevalence in crops. Exacerbating the problem, once crops are contaminated, their presence can only be confirmed through specialized testing, they can be present in healthy looking grains and it is also not possible to ‘neutralize’ aflatoxins by, for example, washing or heating.

Chronic exposure to the B1 form of aflatoxins causes liver cancer (IARC, 2002), and is linked to cirrhosis of the liver (Kuniholm et al., 2008) as well as to immune suppression in humans (Williams et al., 2004). Evidence also suggests that aflatoxins may cause stunting in children (Khlangwiset et al., 2011). Because of its natural presence in soils and the difficulty in verifying its presence, production, trade and consumption of aflatoxin-contaminated crops is a significant concern in developing countries. Though this issue is recognized by the global markets, in many developing countries aflatoxin-contaminated food produced by the agriculture sector is consumed domestically, resulting in significant social costs of diet-related illness. This represents a failure of private markets to generate a socially efficient quantity of the ‘food safety’–a public good. Even when domestic food markets can discern the aflatoxin-free food, ‘food safety’ good may be under-provided. This is because the contaminated food could still be consumed by poorer households that are unable to participate in the aflatoxin-free food markets.

A Conceptual Framework to Estimate Economic Impact of Aflatoxin Contamination

To assist potential government interventions in the context of sub-Saharan Africa, this paper developed a conceptual framework for assessing the interrelated public health, trade, and agriculture impacts of aflatoxin contamination in maize (a key African staple) and groundnuts using an integrated approach to assess the relative impacts on these sectors. The relative importance of these impact categories depends on the final uses of the susceptible crops. It also depends on the level of public awareness and the effectiveness government food safety standards, both of which are low in sub-Saharan Africa. Potentially contaminated crops are traded locally, used for own consumption or as animal feed. However, they do not experience revenue losses from periodic aflatoxin outbreaks nor do their production costs reflect the use aflatoxin controls. Short-run international trade losses are also low, because the food security concerns limit export. Consequently, the impact of aflatoxin outbreaks is predominantly on the public health.

Our framework has three distinct steps to assess aflatoxin contamination impacts in a country:

Step 1: Identify Key Crops of Concern. The impacts are estimated for key crops of concern, which have high production high percentage share of consumption in household diets and also have high aflatoxin contamination. If information on aflatoxin contamination is not available, then the focus can be on the crops that are known for their susceptibility to high aflatoxin contamination globally (e.g. groundnuts and maize) and are produced and consumed in large quantities in the country of interest.

Step 2: Characterize Risks of Aflatoxin Contamination and Exposure. In this step, the core risk of aflatoxin contamination for the key crops of concern is established (i.e., whether the largest impact is expected to be on the country's agriculture and food security, trade, or health). First we determine the prevalence of aflatoxins in the crops using secondary data, and using primary data if secondary data is not available. Next we determine the final uses of aflatoxin-susceptible crops to determine how the economic impacts are distributed, which is helpful in narrowing down the focus of the analysis to the most significant areas of concern. Therefore, in this step we assess the main uses of the crop in the country—whether for direct consumption, domestic sale, or international trade. In addition, since aflatoxins can affect the entire supply chain, we examine the core aflatoxin risks all along value chains of the selected crops, beginning with pre-harvest and post-harvest contamination that directly impact agriculture, then considering risks of contamination and exposure in domestic commerce and international trade, and finally considering factors that directly affect human health.

Step 3: Estimate Economic Impact from Aflatoxin Contamination. The hazard of aflatoxin contamination in maize and groundnuts originates in farmer fields, but can then be controlled or get exacerbated at the post-harvest and storage stages. As the grain enters the domestic and international markets, the existence, content, and enforcement of regulations then affects the extent to which aflatoxin contaminated products are traded in the market. Finally, consumer perceptions and the market's response to those perceptions affect the risk that aflatoxin contaminated food is consumed, resulting in adverse health impacts. In this step we estimate the economic impacts on agriculture and food security, economic impacts resulting from market losses in both domestic and international markets, and economic impact resulting from the consumption of aflatoxin-contaminated food by humans. Depending on the finding from step 3, the analysis can focus on the most significant impacts (e.g., health impacts).

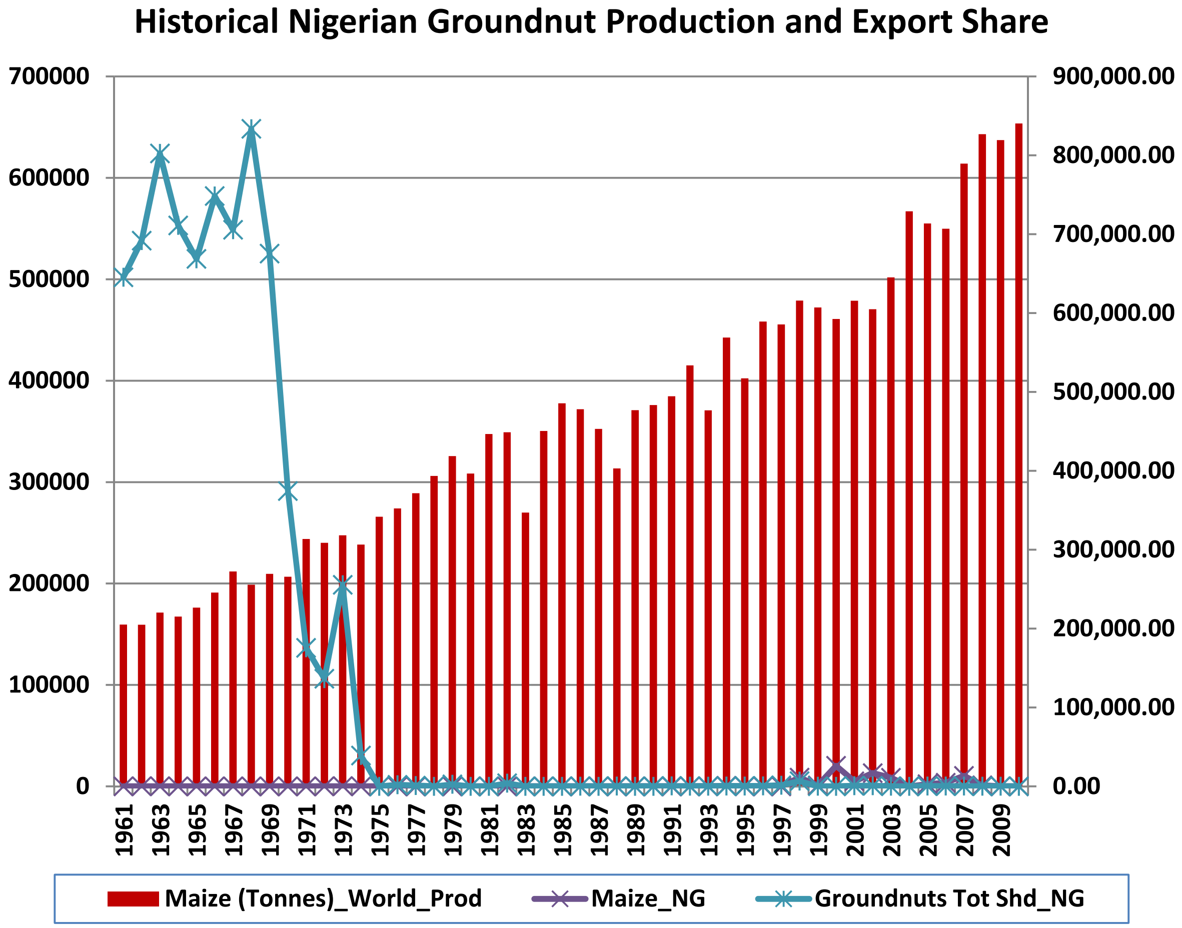
Which sector bears the largest economic impact of aflatoxin - Agriculture Health or Trade?

For Nigeria and Tanzania our analysis focused on maize and groundnuts because our assessment of available crop production and consumption data suggested maize is an important crop both in terms of production and consumption. In Tanzania, maize is the most important agricultural crop in terms of production and comprises as much as 40% of calorie intake of households. In Nigeria, sorghum and cassava have higher production than maize but the aflatoxin prevalence data suggests high contamination in maize and groundnuts making them important candidates to base the analysis on. In Tanzania, groundnuts are important because of their use in weaning foods for children.

Next, we characterize the risk of concern and assessed the expected impacts in agriculture, trade and health. Whether the risks of aflatoxin-contamination are greater on a country's agriculture and food security, trade, and/or health is determined by: (1) the end-market for aflatoxin-contaminated crops (whether destined primarily for domestic consumption or international trade, or human or animal use); (2) levels of awareness about aflatoxins among farmers and consumer; and (3) the application of tolerances within the food marketing systems and types of actions taken by regulators and buyers to mitigate the risk. If there is general awareness and use of aflatoxin controls in a country, and there are supporting regulations and institutions, then the human health impact of aflatoxin contamination will be low while the impact on agriculture, food security and trade will be high. On the other hand, if awareness is low –both among farmers and consumers – and there are inadequate regulations to control it, aflatoxin-contaminated grain will be traded freely, in which case the health impacts will be high.

In Tanzania and Nigeria based on our assessment of the end market, the level of awareness and regulations, we concluded that the large majority of economic impacts are expected in the health sector. There are no expected trade impacts because most of Tanzania and Nigeria's maize and groundnut crop is used for direct human consumption and only a negligible fraction of groundnuts are exported. In 2010/2011, for example, of the available 9,706 MT of maize, 78% was used for human consumption, 17% was used for feed and residual uses, and a small percentage was set aside for re-planting (USDA FAS, 2012). In Tanzania, according to the 2009 Food Balance Sheet, for example, of the 3,324 MT of maize produced with additional 416 MT from stocks and net imports, 68 percent was used for human consumption, 19 percent used for feed, 12 percent was used for other residual uses, and a small percentage (2 percent) was set aside for re-planting (FAOSTAT, 2012). In addition, maize exports are often banned because of the crops importance in food security. In Nigeria, historically groundnuts were an important export commodity – in 1963 Nigeria accounted for 42 percent of shelled groundnut exports – but since the oil price shock of 1973 the agriculture sector lost favor to oil exports (see Figure 1). Undoubtedly there are gains to be had by entering the international market for groundnuts, some of which cannot be accessed because of aflatoxin contamination. But we argue that aflatoxin contamination is not the key constraint in increasing these exports.

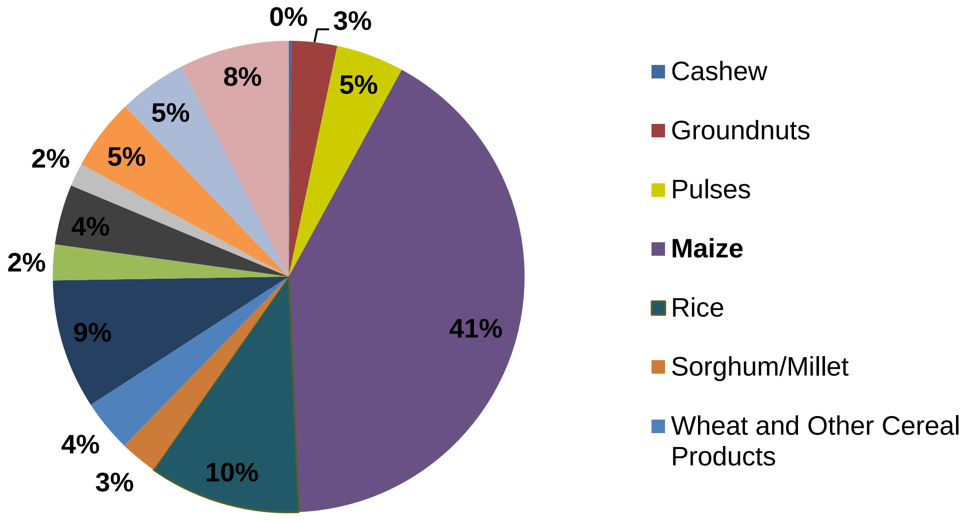
Figure 1 Nigerian Groundnut Production and Export



In both countries the direct impact of aflatoxin contamination on agriculture and perceived food security is negligible because aflatoxin contamination often does not cause visible damage to the crop. In the current market environment, farmers in the two countries do not have to discard harvest because of aflatoxin contamination, nor do they face lower prices for aflatoxin-contaminated food. Because the market does not differentiate between aflatoxin-free and aflatoxin-contaminated food, farmers also do not incur any costs for mitigating aflatoxin. The use of good agricultural practices that promote plant health and consequently reduce the likelihood of aflatoxin contamination is low. Adoption of improved post-harvest storage practices are also low imply that aflatoxin contamination is not contained on the field with consequent non-existent economic impact of aflatoxin in the agriculture sector. This increases the risk of aflatoxin contamination in grains and with the lack of awareness and regulation in the domestic market, implies that the entire impact of aflatoxin contamination is on health through consumption of contaminated crops. If consumers are aware of aflatoxin risks, they can control exposure by demanding aflatoxin-free supply of the affected crop or by shifting consumption to crops that are less susceptible to aflatoxins. Greater awareness amongst farmers would also imply reduced aflatoxin exposure insofar as their own consumption comprises a large fraction of the consumption. Yet field research suggests that consumers' level of aflatoxin knowledge is still very low in Tanzania and Nigeria.

Furthermore, the consumption of maize and groundnuts is high in the two countries; nationally, maize and groundnuts contribute 10 percent of the calorie intake of Nigerian diets, with much higher contribution in Tanzania: Nationally, maize contributes as much as 41 percent of the calorie intake of Tanzanian diets, while groundnuts comprise 3 percent of the calorie intake (see Figure 2**Error! Reference source not found.**). Together, they account for 44 percent of the calorie intake.

Figure 2: Share of Maize and Groundnuts in Calorie Intake of Tanzanian Households

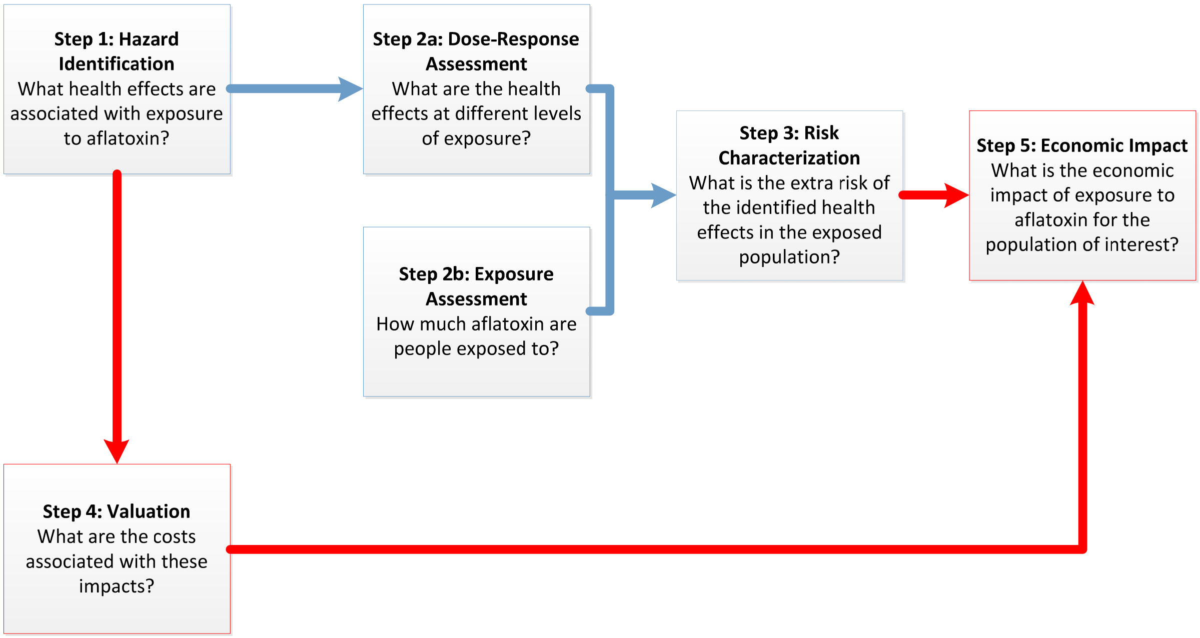


Data Source: LSMS-ISA, 2008/2009.

Estimating Health Impacts of Aflatoxin

For reasons explained earlier, the largest impact of aflatoxin contamination in Tanzania and Nigeria is expected to be on human health. Economic impacts/damages due to consumption of aflatoxin-contaminated food by humans come from health impacts of aflatoxin toxicity. To determine these impacts, it is necessary to conduct a quantitative risk assessment for aflatoxin and then value the estimated damages to human health. A risk assessment is a four-step process consisting of (1) determination of the health effects associated with exposure to aflatoxin (hazard identification, step 1 in figure 3); (2) determination of the health effects at different levels of exposure (dose-response analysis, step 2a in **Error! Reference source not found.**); (3) determination of the levels of aflatoxin that people are exposed to (exposure assessment, step 2b in **Error! Reference source not found.** 3); and (4) determination of the extra risk for the identified health effects to occur in the exposed population (risk characterization, step 3 in Figure 3). The risk assessment steps in **Error! Reference source not found.** 3 are shown in blue. Steps 2a and 2b are concurrent. Once the risk characterization is complete, it is possible to estimate the economic impacts from aflatoxin exposure. Step 1 of risk assessment (i.e., hazard identification) and Step 3 (risk characterization) contribute directly to economic impact estimation. The steps for economic impact estimation (steps 4 and 5 in Figure 3) are shown by the red arrows and boxes in Figure 3.

Figure 3: Approach to Estimating the Health Impact of Aflatoxin Contamination



Hazard identification is based on several studies that have found evidence that *chronic exposure* to aflatoxin is associated with several human health effects, including liver cancer (IARC, 2002), liver cirrhosis (Kuniholm et al., 2008), immunologic suppression (Williams et al., 2004), and growth impairment (Khlangwiset et al., 2011). High levels of exposure (i.e., *acute exposure*) may result in acute aflatoxicosis. We do not include this endpoint in our assessment because the dose-response relationship has not yet been developed and the frequency of such high exposures is unknown (Wu et al., 2011). We develop numerical estimates of health impacts due to aflatoxin exposure only for liver cancer (hepatocellular carcinoma, HCC), because this is the only endpoint for which a dose-response relationship was established and accepted by the Joint FAO/WHO Expert Committee on Food Additives (WHO, 1998). There is evidence that supports the association between aflatoxin exposure and stunting in animals and humans (Khlangwiset et al., 2011; Gong et al. 2002). However, stunting is also correlated with poor nutrition and poor gastrointestinal function, and the interactions between contributing factors are not well understood. Because the latter problems are common in sub-Saharan Africa, it is difficult to ascertain whether aflatoxin exposure by itself causes stunting in the absence of malnutrition and/or poor GI function, or if there is a synergistic effect where aflatoxin exposure amplifies the effects of malnutrition and poor GI function on growth impairment. Nevertheless, because the evidence for the association is strong, preliminary estimates of the economic impact are estimated using Gong et al. (2002).

The **dose-response** relationship between aflatoxin exposure, measured in nanograms (ng) of aflatoxin per kilogram (kg) of body weight (bw) per day, and HCC incidence per 100,000 population is linear. Further, consistent with other carcinogens, *it is assumed that the dose-response relationship does not have a threshold, meaning that any aflatoxin exposure level can cause a risk.* Cancer potency (i.e., an increase in annual HCC incidence rate per unit change in aflatoxin exposure) varies across populations by HBV status: There is a 30-fold higher liver cancer risk for HBV-positive individuals. Specifically, in HBV-positive populations, aflatoxin HCC potency is 0.3 cancers/year per 100,000 population per one ng/kg-bw/day, while in HBV-negative populations, aflatoxin HCC potency is 0.01 cancers/year per 100,000 population per one ng/kg-bw/day (WHO, 1998).

Exposure assessment, or determining the exposure of Tanzanians to aflatoxins, requires information on the amount of aflatoxin-contaminated food consumed by individuals, the concentration of aflatoxin in the food, and the body weight of the individual. It is important to note that in the case of HCC, the dose response is defined for aflatoxin B1. Hence, we consider the prevalence only of aflatoxin B1 in our analysis. Body weight is important because the same amount of consumption can have different health impacts for people with different weights.

$$\text{Exposure (ng/kg-bw/day)} = \frac{\text{Amount Consumed } (\frac{\text{g}}{\text{day}}) \times \text{Aflatoxin Concentration } \left(\frac{\text{ng}}{\text{g}}\right)}{\text{Body Weight (kg)}}$$

Information on consumption was derived from the LSMS surveys for Tanzania and Nigeria that provide household-level weekly consumption of various food items and several individual characteristics (e.g., age, sex, height, and/or weight). To allocate household consumption to individuals and obtain estimates of individuals' daily intake of maize and groundnuts, we used the Adult Male Equivalent approach that has been applied to develop inputs for food fortification and other nutrition program evaluations (Neufeld et al., 2012). This approach uses individuals' age and sex, reference body weights from the World Health Organization (WHO), basal metabolic rate (BMR) based on body weight, and physical activity levels (PAL) to calculate total daily energy requirements (TEE).[1]

Figures 4 and 5 present the estimated average consumption of maize and groundnuts in grams per person in Nigeria and Tanzania. For our health estimates we estimated the average consumption per person per kilogram of body weight using LSMS-ISA (2009). In general, maize consumption is very high in the West and Southern Highlands, ranging from 400-500 grams per person per day. Overall in mainland Tanzania, maize consumption is quite high and above 200 grams per person per day. As discussed more in detail below, this implies that the risk of aflatoxin exposure at a given prevalence level is likely to be the highest in this region. In fact, as is argued later, even at low levels of prevalence such high levels of consumption can imply a measurable health impact.

In Nigeria, maize consumption is greater in the North. The consumption of groundnuts and maize is the greatest in the North East, suggesting that the risk of aflatoxin contamination at a given prevalence level is likely to be the largest in this region.

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[1] **WHO reference weights:** We use the weights provided by Weisell and Dop (2012) for adult men and women and WHO weight-for-age tables for children aged 0-9 years. For children aged 10-17 years, weight-for-age tables are not available. Therefore, we estimate body weight based on body mass index (BMI) and height at each age, using WHO reference tables. Note that the estimated weights (based on BMI) for age 17 would be higher than the adult weights given by Weisell and Dop (2012). Therefore, we truncate weights at 64 kg for males and 55 kg for females. **BMR equations:** BMR equations are provided in Schofield (1985) for adults and Table 5.2 of FAO (2004) for children. **PAL:** We assume a PAL value of 1.75 based on Weisell and Dop (2012).**TEE equations:** The equations for TEE are from Section 4.2 of FAO (2004) for children and from Section 5.3 of FAO (2004) for adults.

Figure 4: Regional Average Consumption of Maize and Groundnuts in Nigeria (2010–2011)

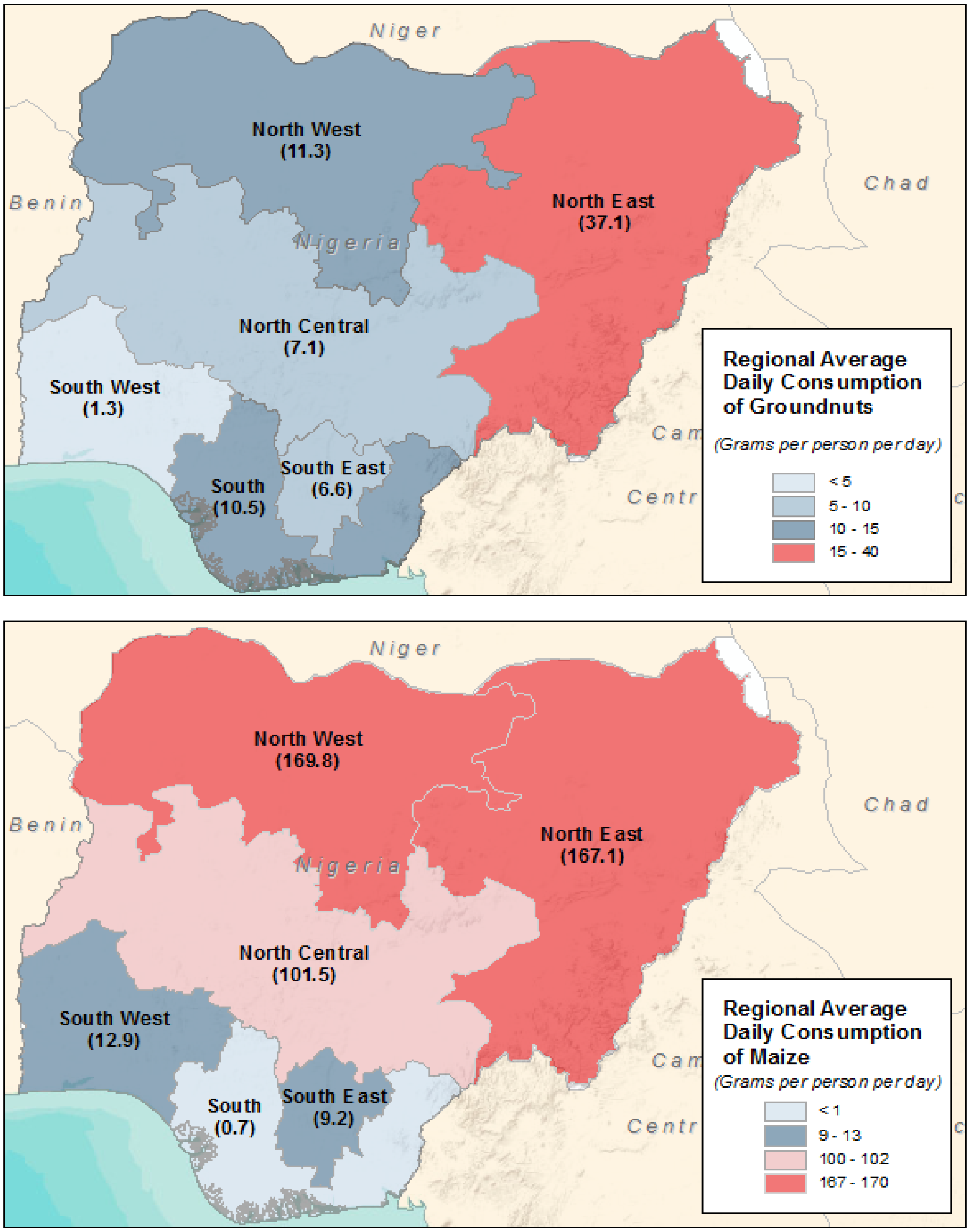
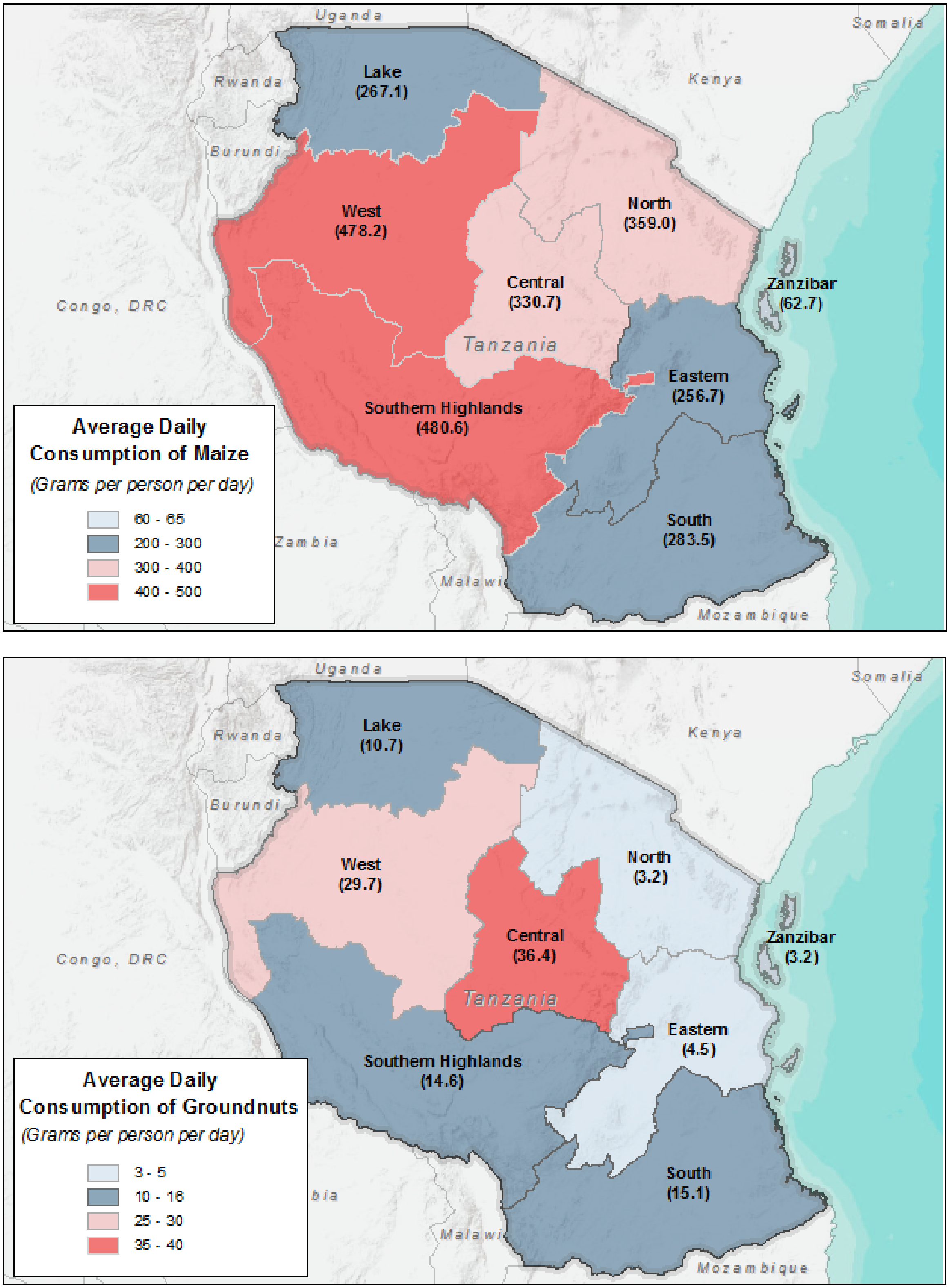


Figure 5: Regional Average Consumption of Maize and Groundnuts in Tanzania (2008–2009)



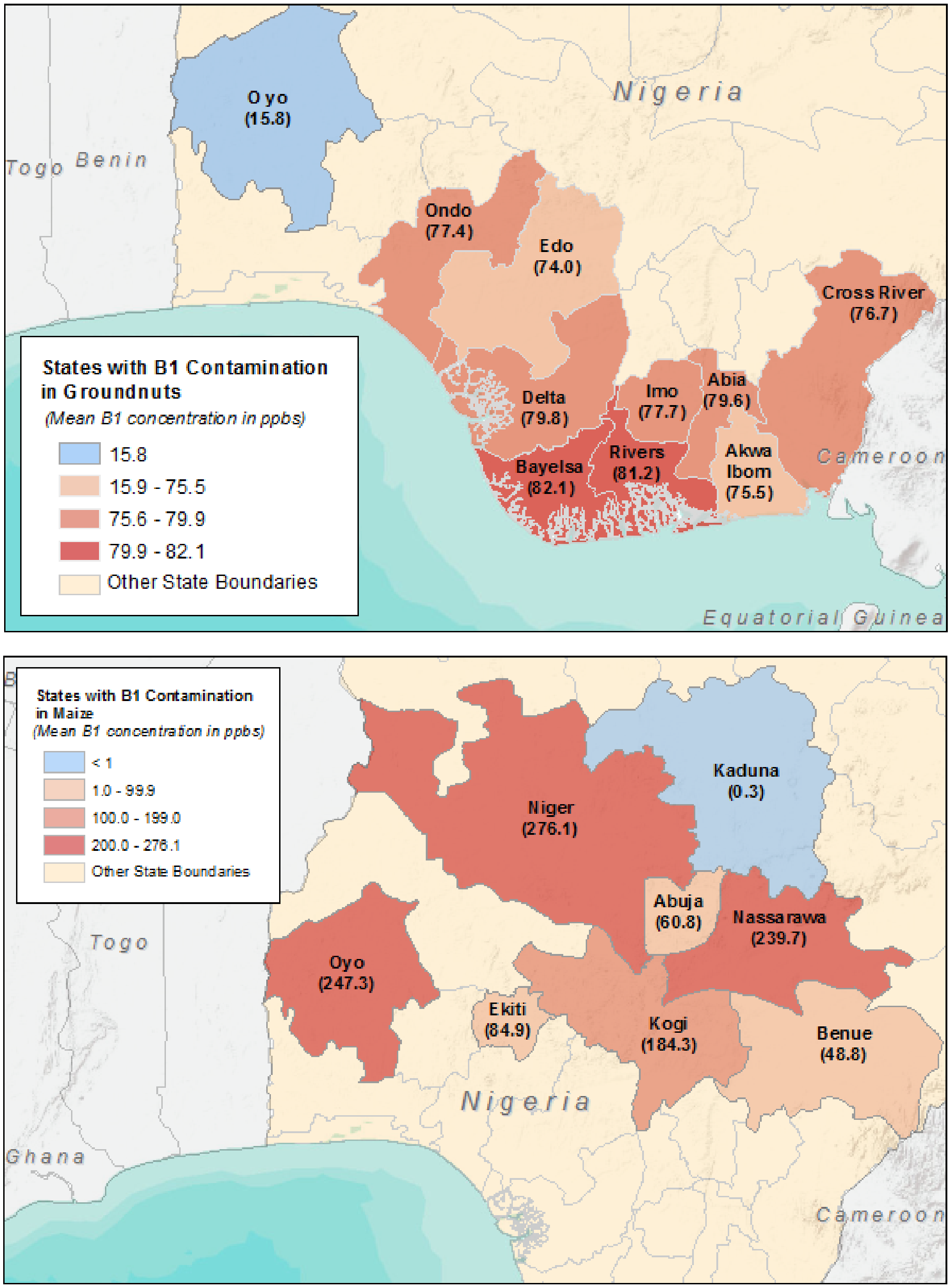
Aflatoxin contamination in maize and groundnuts is well above safe levels in Nigeria. Although data are not available for all regions in Nigeria, published prevalence data from Nigeria suggests that aflatoxin contamination in maize and groundnuts is considerably higher than the European Union (EU) aflatoxin standard (4 ppb) or the U.S. standard (20 ppb). A recent review of published articles reveals that the mean level of aflatoxin contamination in these two crops in Africa ranges as high as 300 ppb in maize and 48,000 ppb in groundnuts (see **Error! Reference source not found.** 6).

We collected primary data to establish aflatoxin concentration in maize and groundnuts in Tananzia. The results indicate that there is significant variability in the prevalence across the regions and overall prevalence was low (see Table 1). Overall, only 14 percent of the 274 maize samples (includes 254 PACA samples and 20 samples in Tukuyu district in Mbeya from VLIR-UOS) had aflatoxin B1 levels above the regulated levels (5 ppb) in Tanzania. In the Eastern zone (Morogoro), 43 percent of the maize samples were above 5 ppb; and in the Western zone (Shinyanga), 40 percent of the samples were above 5 ppb, with average contamination of 50 ppb and 28 ppb, respectively. The contamination was much lower in other zones. In the Northern zone (Manyara), 9 percent of the samples were above 5 ppb; in the Southern Highlands (Iringa, Mbeya, and Rukwa), only 4 percent were above 5 ppb; and in the Southern zone (Ruvuma), none of the samples were above 5 ppb.

The groundnut samples had more limited geographical coverage. As noted above, however, there should be more information available on groundnut contamination in Tanzania once other ongoing prevalence testing is complete. Furthermore, Ministry of Agriculture also has some ongoing sampling for which we did not have data. Samples from the Northern, Southern (Mtwara), and Western zones indicate that 20 percent, 20 percent and 8 percent of the samples, respectively, had aflatoxin B1 above 5 ppb with mean contamination at 20 ppb, 18 ppb and 20 ppb.

In summary, prevalence data from 2012 suggest that there are aflatoxins in Tanzanian maize and groundnuts. However, the prevalence varies significantly in maize, with certain regions having very little contamination (Southern zone and Southern Highlands), and others having more prevalence (Western and Eastern zones).

Figure 6: Prevalence of Aflatoxin B1 in Maize and Groundnuts in Nigeria



Based on data from 1. Bankole and Mabekoje, 2004; 2. Udoh et al., 2000; 3. Atehnkeng et al, 2008; 4.Oluwafemi and Ibeh, 2011; 5. Bandyopadhyay et al, 2007; 6. Oyelami etl al, 1996; 7. Adebajo et al, 1994; 8.Thomas et al 2003; 9. Jimoh and Kolapo, 2008; 10. Akano and Atanda, 1990; 11.Odoemelam and Osu, 2009; 12. Ezekiel et al, 2012.

Table 1: Aflatoxin Prevalence Summary for Tanzania

		Aflatoxin B1			Aflatoxin Total		
Zone	**N**	**Share >5 ppb**	**Mean of Detects >5 ppb**	**Range (ppb)**	**Share >10 ppb**	**Mean of Detects >10 ppb**	**Range (ppb)**
Maize							
East	40	43%	49.92	5.30-159.5	43%	61.69	12.5-162.4
North	65	9%	17.79	12.1-23.5	9%	21.30	16.4-27.6
South	40	0%	--	--	0%	--	--
Southern Highlands	99[1]	4%	11.85	5.7-19.2	2%	17.53	15.3-19.7
West	30	40%	27.72	6.3-58.4	40%	52.27	11.8-99.5
National	**274**	**14%**	34.24	5.3-159.5	**14%**	49.70	11.8-162.4
Groundnuts							
North	20	20%	20.31	5.2-38.3	20%	28.67	17.8-40.3
South	40	20%	18.26	5.5-31	20%	23.60	10.3-37.5
West	40	18%	19.51	11.6-30.7	18%	25.54	13.7-33.6
National	**100**	**19%**	19.15	5.2-38.3	**19%**	25.1	10.3-40.3

Data Source: Aflatoxin testing by TFDA, 2012.

1. Includes 20 samples from Tukuyu district, Mbeya from VLIR-UOS effort.

Risk Characterization involves estimating the population cancer risk, which is equal to the aflatoxin exposure as calculated above times the HCC potency, which is an average of HBV status-specific HCC potencies weighted by HBV prevalence in Tanzania and Nigeria respectively:

Population Risk (cancers/year/100,000) = Exposure ×
(Share of HBV-positive × HBV-positive HCC Potency +
Share of HBV-negative × HBV-negative HCC Potency)

To derive the annual number of HCC cases that occur due to aflatoxin exposure, we multiplied the estimated population risk by the region-specific population (expressed in 100,000s).[2]

Disability Adjusted Life Years (DALYs) Lost. Under the assumption that all estimated HCC cases result in death within the same year, we estimated annual Disability Adjusted Life Years (DALYs) lost due to aflatoxin contamination-related HCC cases. DALY is an epidemiological measure of disease

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[2] Note that in each region, population risk was characterized separately for males and females by estimating sex-specific maize and groundnut consumption, HBV prevalence, and population.

burden expressed in the number of healthy life years lost due to death or disability caused by disease. We used regional estimates of total liver cancer deaths and total liver cancer DALYs from the Global Burden of Disease project (WHO, 2008) to derive a DALY value for an HCC case in Tanzania.[3]

Monetized Health Impact. The health impact estimates assume that that all estimated HCC cases result in death within the same year. The estimates do not include any morbidity or illness related costs particularly because access to treatment is limited in developing countries; in that sense they are a lower bound estimate. We monetized the total aflatoxin-related liver cancer burden by extrapolating values from the United States, with adjustments for differences in income between the two regions using a transfer approach proposed by Hammitt and Robinson (2011). Specifically, we started with an estimate of willingness to pay for small changes in mortality risk—i.e., the value of a statistical life (VSL)—developed for the U.S at 6.3 million U.S. dollars (FDA, 2006). This value was adjusted for differences in income per capita between U.S. and the two countries.[4] Following recommendations in Hammitt and Robinson (2011), we assumed that risk reductions were a luxury good and used several income elasticity values (1, 1.5, and 2) for the transfer and bound the derived VSL estimate (from below) using the present value of future consumption (at 3% discount rate). We estimate a high VSL estimate of $118,000 per HCC death (using income elasticity of 1) and a low VSL estimate of $32,000 per HCC death (based on the present value of future consumption) for Tanzania and we estimate a high VSL estimate of $285,000 per HCC death (using income elasticity of 1) and a low VSL estimate of $49,000 per HCC death (based on the present value of future consumption) for Nigeria[5]. These estimates assume that the willingness to pay for to avoiding risk of death in Tanzania and Nigeria differ from U.S. only in scale because of differences in the level of incomes. In reality, there are many other population and risk characteristics that may affect VSL.

Health Impact Estimates. In Tanzania, the prevalence data that has been gathered thus far imply that there is a great degree of variability in aflatoxin contamination across the country, and within zones. A large percentage of the samples tested had aflatoxin contamination below the minimum level of detection. Yet there were samples with aflatoxin contamination well above regulated levels. This suggests that there is significant uncertainty in determining mean aflatoxin contamination. Therefore, we have conducted a sensitivity analysis of impacts for different levels of aflatoxin prevalence, using the current maize and groundnut consumption patterns, HBV prevalence rates, and 2010 regional population estimates in Tanzania.

Following Shephard (2008), **Error! Reference source not found.** 2 shows the number of HCC cases at different levels of aflatoxin B1 prevalence given the regional consumption of maize and groundnuts, the 2010 regional population estimate, the age and sex distribution, and the sex-specific HBV prevalence. Note that the analysis assumes that the prevalence is the mean contamination levels for food consumed through an individual's lifetime. In reality, there will be seasonal and regional variation in the

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[3] We derived sex-specific HCC DALY estimates using WHO's AFR D region data. The estimated value for males was 12.3 DALYs per HCC case, and the estimated value for females was 13.8 DALYs per HCC case.

[4] The Purchasing Power Parity (PPP) based GNI per capita for 2010 (from the World Development Indicators Database, http://data.worldbank.org/indicator) was used in all calculations. The U.S. PPP-based GNI per capita was $47,360 (in 2010 U.S. dollars) and the Tanzania PPP-based GNI per capita was $1,430 (in 2010 U.S. dollars). . The U.S. PPP-based GNI per capita was $47,360 (in 2010 U.S. dollars), and the Nigeria PPP-based GNI per capita was $2,170 (in 2010 U.S. dollars).

[5] All values are in 2010 U.S. dollars.

contamination. Secondly, the contamination levels are related to the food that is ready for consumption and not maize on the field. There is potential for reduction in prevalence levels between maize that leaves the field and the form that it is consumed (e.g., *ugali)*.

We find that even at the regulated level of aflatoxin B1—5 ppb— of contaminated maize and groundnuts, the total annual cancer cases attributable to aflatoxin contamination are estimated to be 546, which is more than a third of the total estimated liver cancer cases in Tanzania in 2010. Of these cases, the West, which has one of the highest maize consumption levels, accounts for the largest number of these cases. *At even at low levels of aflatoxin contamination of key staples, there is measurable health impact because of high contribution of the staples in the Tanzanian diet.*

Table 2 also presents the regional estimates of HCC cases at different prevalence levels accounting for regional differences in consumption and population levels. In the Eastern zone and West zones the recent data suggests found aflatoxin B1 above 5 ppb in 43 percent and 40 percent of the samples with average contamination of 50ppb and 28ppb. These regions are likely to have higher average aflatoxin contamination. At average aflatoxin contamination of 10 ppb, 115 liver cancer cases can be attributed to aflatoxins in the Eastern zone and 277 in the Western zone. At 10 ppb, the national annual cancer cases attributable to aflatoxin contamination would be 1,092, accounting for more than 90 percent of the total liver cancer cases in Tanzania.

Table 2: Estimated HCC Cases Attributable to Aflatoxin B1 Contamination in Tanzania for Ranges of Aflatoxin Prevalence Levels

Zone	Maize and Groundnut Consumption (g/person(60kg)/day)	Aflatoxin B1 Contamination (ppb)					
		2	5	10	20	50	100
Central	367	18	45	90	181	452	903
East	261	23	58	115	230	575	1150
Lake	278	30	75	149	298	746	1491
North	362	34	85	171	342	854	1708
South	299	16	41	81	162	406	812
Southern Highlands	495	41	102	203	406	1015	2030
West	508	55	139	277	554	1385	2770
Zanzibar	66	1	3	6	11	28	55
National	**521**	**218**	**546**	**1,092**	**2,184**	**5,460**	**10,920**

Estimated number of liver cancer cases in Tanzania is 1,209 (derived using the 2010 Tanzania population estimate and 2004 liver cancer incidence rate – 2.8 deaths per 100,000 population-- estimated for Tanzania by the Global Burden of Disease Project, WHO, 2008).

Table 3 presents the equivalent DALY and the monetized value of aflatoxin-related liver cancer burden, at different contamination levels for Tanzania. At prevalence rates of 5 ppb, the monetized burden is between $18 million and $102 million (in 2010 U.S. dollars), while at 10 ppb the monetized burden is between $35 million and $204 million (in 2010 U.S. dollars).

Table 3: DALY and Monetized Burden of Liver Cancer Cases by Contamination Levels for Tanzania

	Aflatoxin Contamination level (ppb)					
	2	5	10	20	50	100
DALY	2,851	7,127	14,253	28,507	71,267	142,534
VSL-Low ($1,000)	6,989	17,472	34,945	69,890	174,724	349,448
VSL-High ($1,000)	40,970	102,424	204,849	409,697	1,024,243	2,048,486

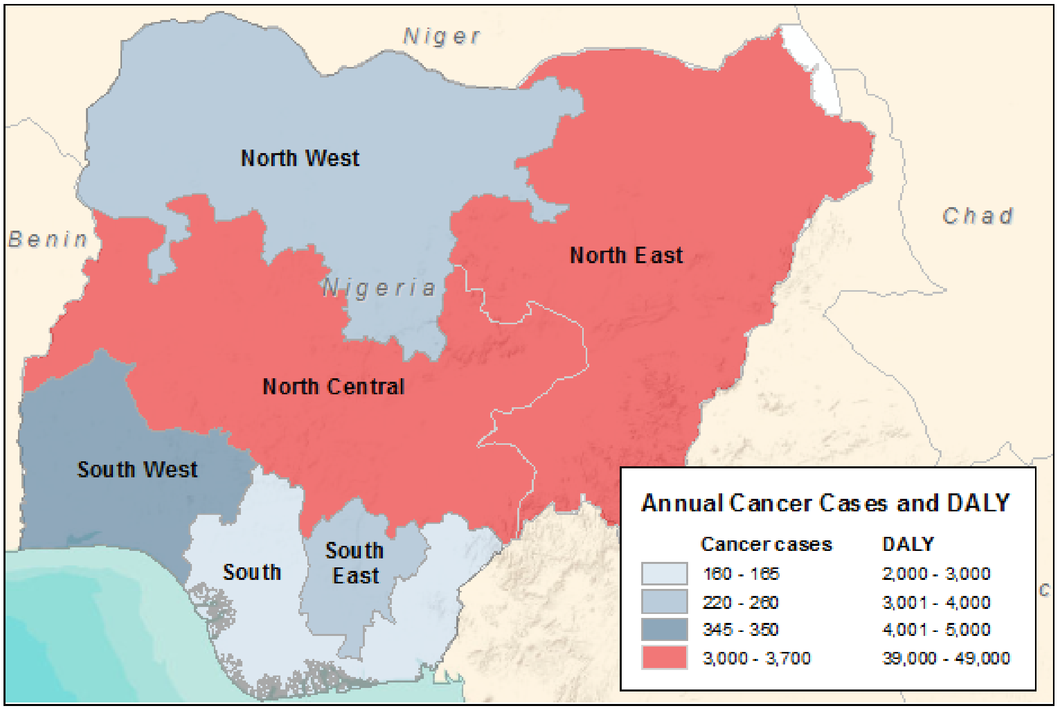
Analysis of Sensitivity to Assumptions about HBV Prevalence in Tanzania. We also assessed the impact of reducing HBV prevalence on the number of aflatoxin-related liver cancer cases. We find that if the HBV prevalence is reduced to zero, at the same levels of aflatoxin contamination as well as maize and groundnut consumption, the number of aflatoxin-related liver cancer cases from aflatoxin contamination could be three times smaller (at 5 ppb, 188 HCC cases per year as compared to 546 HCC cases per year).

Health Impact Estimates in Tanzania. The region-specific number of HCC cases, DALYs and VSL attributable to aflatoxin contamination in maize and groundnuts are presented in Table 4 and a corresponding map is presented in Figure 7. At the national level, we estimate that aflatoxin contamination in maize and groundnuts results in 7,761 liver cancer cases resulting in a total burden of 100,965 DALYs. The impact of contamination is greater in the North East and North Central regions. The North East consumes the largest quantity of maize and groundnuts; the North Central region has the highest prevalence of aflatoxin in maize, and also consumes a reasonable quantity of maize. Using the transferred VSL estimates from U.S., the monetized total aflatoxin-related liver cancer burden, at the baseline aflatoxin contamination levels as well as baseline maize and groundnut consumption patterns, was estimated to be between $265 million and $2,213 million (in 2010 U.S. dollars).

Table 4: Health Impact of Aflatoxin Contamination in Nigeria: HCC Cases, DALY and Monetized Health Impact

Region	Maize	Groundnuts	Population in 2010	HCC Cases[a]	DALY	VSL (low)	VSL (high)
	(consumption in g/day)		(in thousands)	(cancers/ year)		(in millions)[b]	
North Central	102	7	22,571	3,698	48,161	$181	$1,055
North East	167	37	21,066	3,075	39,987	$151	$877
North West	170	11	39,854	221	2,864	$11	$63
South East	9	7	18,235	258	3,375	$13	$73
South South	1	11	23,352	163	2,115	$8	$47
South West	13	1	30,763	346	4,462	$17	$99
National	**84**	**12**	**155,842**	**7,761**	**100,965**	**$380**	**$2,213**
Notes: a. Estimated annual HCC cases due to aflatoxin (central estimate). b. In 2010 U.S. dollars							

Figure 7: Annual Cancer Cases and Disability Adjusted Life Years Lost Because of Aflatoxin Contamination in Maize and Groundnuts in Nigeria



Analysis of Sensitivity to Assumptions about Aflatoxin Prevalence Levels in Nigeria. There is a substantial amount of uncertainty in the aflatoxin prevalence data, to which the outcome of our analysis is quite sensitive. Therefore, we calculated the range of impacts for different levels of aflatoxin prevalence, using the current maize and groundnut consumption patterns, HBV prevalence rates, and 2010 regional population estimates in Nigeria. Table 5 shows that even at low prevalence rates at around 10 ppb, the total annual cancer cases attributable to aflatoxin contamination are estimated to be 1,152 nationally. At 20 ppb, which is the regulatory limit for maize and groundnuts for human consumption in the United States, the total annual cancer cases attributable to aflatoxin contamination are 2,305. Table 5 also shows a range of the monetized total aflatoxin-related liver cancer burden, at different assumptions about contamination levels. At prevalence rates of 10 ppb, the monetized burden is between $39 million and $328 million (in 2010 U.S. dollars), while at 20 ppb the monetized burden is between $78 million and $656 million (in 2010 U.S. dollars). *It is noteworthy that in 2010, Nigeria GDP was $197 billion (in 2010 U.S. dollars), so the high estimate at 20 ppb constitutes roughly 0.35% of Nigeria GDP.*

Analysis of Sensitivity to Assumptions about Aflatoxin Prevalence and Food Intake Levels in Nigeria. Since we consider aflatoxin burden only from maize and peanuts, it is useful to assess the sensitivity of these results to different levels of food intake (this could be generalized to any food item) and at different levels of aflatoxin prevalence. Following Shephard (2008), in Table 5 we report the annual number of HCC cases estimated to occur due to aflatoxin contamination in Nigeria at several aflatoxin prevalence (AFB1) and food intake levels. Table 5shows that, given the 2010 regional population estimates, the age and sex distribution, and the sex-specific HBV prevalence, aflatoxin contamination of even 10 ppb would imply that 1,152 liver cancer cases could be attributed to aflatoxin.

This amounts to more than one-tenth of 10,130 liver cancer deaths that were estimated to occur in 2010 in Nigeria.[6]

Table 5: Estimated HCC Cases Attributable to Aflatoxin Contamination in Nigeria for Ranges of Aflatoxin Prevalence Levels and Ranges of Food Intake Levels

AFB1 Level (ppb)	**Levels of Food Intake by Person Weighing 60kg (g/person(60kg)/day)**						
	124[1]	10	50	100	150	200	400
1	**115**	**9**	**46**	**93**	**139**	**185**	**371**
2	**230**	**19**	**93**	**185**	**278**	**371**	**742**
5	**576**	**46**	**232**	**464**	**695**	**927**	**1,854**
10	**1,152**	**93**	**464**	**927**	**1,391**	**1,854**	**3,709**
20	**2,305**	**185**	**927**	**1,854**	**2,781**	**3,709**	**7,417**
100	11,524	**927**	**4,636**	**9,271**	13,907	18,543	37,085

Notes:

1. *Estimated Intake of Maize and Groundnuts in Nigeria (g/person(60kg)/day)*

Estimated number of liver cancer cases in Nigeria is 10,130 (derived using the 2010 Nigeria population estimate and 2004 liver cancer incidence rate -- 6.5 deaths per 100,000 population-- estimated for Nigeria by the Global Burden of Disease Project, WHO, 2008). Therefore, the plausible values of HCC cases attributable to aflatoxins is bolded.

Analysis of Sensitivity to Assumptions about HBV Prevalence in Nigeria. We also assessed the impact reducing HBV prevalence on the number of aflatoxin-related liver cancer cases. We find that, if the HBV prevalence is reduced to zero, at the same levels of aflatoxin contamination as well as maize and groundnut consumption that were used to derive our baseline Nigeria, the number aflatoxin-related liver cancer cases from aflatoxin contamination could be three times smaller (2,175 HCC cases per year as compared to 7,761 HCC cases per year).

Discussion

Based on the published aflatoxin sampling results for Nigeria, we estimated that a consumption-weighted aflatoxin B1 contamination level could be 67ppb. While Nigeria does not have an aflatoxin B1 standard, its safety standard for total aflatoxin in food for human consumption is 4ppb. Our contamination level estimate is highly uncertain. However, chronic exposure to aflatoxin B1 at 67ppb could be causing as many as 7,761 liver cancer cases per year out of the estimated 10,130 total liver cancer cases in Nigeria in 2010. Exposure to this level of contamination was estimated to result in monetized damages between $265 million and $2,213 million (in 2010 U.S. dollars). *It is noteworthy that the high monetary estimate at 67ppb constitutes roughly 1.1% of Nigerian GDP in 2010, which was $197 billion 2010 U.S. dollars.* In Tanzania, the prevalence of aflatoxins is lower than in Nigeria. However, exposure to aflatoxins could still be significant because of high maize consumption (400-500 grams per day on average). At 5ppb, which is the national safety standard for aflatoxin B1 in maize and groundnuts, the total estimated annual excess liver cancer cases were 546, accounting for more than a third of the total estimated liver cancer cases in Tanzania in 2010. The monetized health impact at the 5ppb aflatoxin B1 contamination level is between $12 million and $102 million (in 2010 U.S. dollars). Because liver cancer risk from aflatoxin B1

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[6] The estimate was derived using the 2010 Nigeria population estimate and 2004 liver cancer incidence rate (6.5 deaths per 100,000 population) estimated for Nigeria by the Global Burden of Disease Project (WHO 2008).

exposure also depends on the hepatitis B prevalence, focusing efforts on immunization programs could generate a three-fold reduction in the number of aflatoxin-caused liver cancers cases.

Our paper shows that a problem that originates in farmer fields can result in significant negative health impact, particularly in developing country environments where there is low awareness to control for the problem in the field, and low awareness and poor implementation of regulations to control the movement of contaminated crops in the domestic markets. Other factors limit the trade of these commodities so that the impact of aflatoxin contamination on trade is not significant, but it is a barrier for these countries as the look to increase trade, particularly in groundnuts. Aflatoxin problem can be mitigated somewhat by good agricultural practices but the problem can still persist if the environmental conditions are ripe. With better awareness and access to control technologies (e.g. biocontrol), the impact of aflatoxin will shift from health to agriculture in the form of higher cost of production. However, this increase in costs can be retrieved by creating awareness that results in premium markets for aflatoxin-free maize. In the long-run, however, the differential markets should disappear with agriculture sector bearing the costs for aflatoxin control, as is the case in developed countries such as the United States.

Since creating awareness takes time, we argue that the governments should also consider subsidizing the aflatoxin control measures. These measures, such as bio controls or specialized pre-harvest and post-harvest practices, are costly and poorer members of society could fail to participate in the aflatoxin-free food markets. Further, the wide-spread poverty in sub-Saharan Africa may prevent establishment of aflatoxin-free maize markets altogether. Our estimates of the monetized health damage at different contamination levels could serve as guidelines for the size of a government program designated to reduce the risks from aflatoxin contamination. Such a program could include an information campaign, consistent testing, and provision of subsidized aflatoxin control measures. This work will be extended by carrying out cost-benefit analyses of specific aflatoxin control strategies, focusing on their adoption potential, effectiveness, and costs. We presented our results at high level stakeholder meetings in Tanzania and Nigeria and in Tanzania our work and workshop resulted in the formation of a National Forum for Mycotoxins Control and a supporting steering committee. This effort was funded by Tanzania Food and Drug Administration and continues to convene and move towards change in policy. Our work therefore is a true example of policy analysis leading policy action.

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