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AFLATOXINS IN FOOD AND FEED
Impacts, Risks, and Management Strategies

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Aflatoxins are fungal metabolites—mainly produced by Aspergillus flavus and Aspergillus parasiticus living in soil—that contaminate crops throughout growth, harvest, storage, transportation, and processing. Aflatoxin B1 is not only the most potent natural carcinogen known, but also the most commonly produced toxic strain. As of 2010, roughly 5 billion people worldwide were estimated to be exposed to high levels of aflatoxins. High consumption levels can result in aflatoxicosis, which is often fatal. Habitual consumption at lower levels causes liver cancer and immune suppression, and is strongly associated with stunting. Of 315 cases of aflatoxicosis in Kenya in 2004, 125 people died. Consumption of aflatoxins is cumulative: they are not eradicated through standard cooking processes, and the body is unable to destroy or excrete them. This policy note examines what aflatoxins are; how they are linked to gender, climate change, and nutrition; and how they can be controlled and managed effectively.

Existing Occurrence and Impacts

Aflatoxins plague crops in tropical regions between 40 degrees north and south of the equator, which includes all African countries. Contamination in the field is more likely in hot, dry conditions and is exacerbated by humidity and poor drying for storage and transportation. Although aflatoxins affect many grains (such as maize, wheat, rice, sorghum, millet, and quinoa), legumes (groundnuts), tree nuts (brazil nuts, almonds, pistachios, walnuts, and pecans), seeds (such as niger and sunflower seed), and spices, maize and groundnuts generally have the highest levels of contamination. And although mold on harvested grain is a sign of potential contamination, aflatoxins are invisible—hence, an absence of mold is *not* evidence that grain is safe to consume.

Levels of aflatoxin contamination are regulated in most countries. In Europe the limit for cereals designated for human consumption is below 4 parts aflatoxin per billion parts cereal (ppb), and for infant foods below 0.025 ppb. In the United States the critical level is 20 ppb. The magnitude of the problem in African countries was illustrated by the Aflastop project, funded by the United States Agency for International Development and Bill & Melinda Gates Foundation, which collected 53 tons of bagged maize for testing from a number of farmers in two high-aflatoxin districts of Kenya between March and June 2014, with the goal of testing storage technologies for contaminated grain (ACDI/VOCA 2014a). In one district, 61 percent of bags tested had levels above 150ppb, and in the other, 35 percent of bags had levels above 150ppb.

The use of contaminated crops as animal feed results in animal-source foods also being affected. Contamination can be particularly high in the "waste" products of oil seed extraction, where the residues are made into feed cake for animals. The International Livestock Research Institute showed that high contamination in milk in Addis Ababa was due to high levels of aflatoxins in noug feed cake, derived from the residues of niger seed after oil extraction (Gizachew et al. 2016). Less than 10 percent of milk samples collected had contamination levels below European Union (EU) limits for milk, and more than a quarter were ten times above the limit. Similarly, the production of groundnut oil in Malawi generates "press cake" used as animal feed, leading to the same problem in milk.

Aflatoxins are virtually indestructible in normal food processing (boiling, frying, roasting), and the strain that contaminates milk is unaffected by normal dairy processing (pasteurization and ultraheat treatment). Ultimately, aflatoxins are considered unavoidable in both food and feed production, so the issue is to minimize the occurrence and spread of contamination along the food chain through effective management and control mechanisms.

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Compared with people in developed countries who consume, on average, an estimated 10 grams of maize per day, the average African is estimated to consume 400 grams of maize per day—significantly increasing their aflatoxin exposure. Globally, factoring in peanut and maize consumption, and the exposure to aflatoxins, some populations could consume more than 200 nanograms of aflatoxins per kilogram of body weight per day. As a result, as much as 28 percent of liver cancer cases can be linked to aflatoxin consumption, with rates of liver cancer 16–32 times higher in developing countries (Liu and Wu 2010; Wu 2013).

Aflatoxins and Climate Change

The ability of fungi to evolve and to produce mycotoxins, including aflatoxins, is governed by environmental conditions—notably temperature and relative humidity—and insect populations. Climate change has a significant impact on all of these factors. Notably, the five hottest years in recent records were all in the 2010s. Extreme dry, hot weather results in plant stress, leading to increased pest and insect damage—the ideal conditions for increased fungal contamination and aflatoxin production. A recent study of groundnuts in Malawi showed that four weeks of prolonged drought stress increased aflatoxin contamination in the resulting crop almost 15-fold (compared with no drought stress), and significantly increased the levels of aspergillus flavus in the soil (Sibakwe et al. 2017).

To date, aflatoxins have largely been confined to the warmer tropical and subtropical zones, with Africa being one of the most affected continents. Africa as a whole is also one of the most vulnerable continents to climate change due to its high exposure and low adaptive capacity. All these conditions are likely to exacerbate the current aflatoxin problem, change its known geographic incidence, and make addressing it even more challenging.

Given its temperate climate, the EU has focused its aflatoxin concern on food imported from tropical and subtropical climates. In the 1960s, Africa south of the Sahara dominated the groundnut market, but the region's share has dropped to just 5 percent, despite the market being more than five times larger. One reason for the decline is the introduction of strict EU safety limits on aflatoxins: Malawi lost 42 percent of its groundnut exports in 2005 due to aflatoxin contamination (USAID–CRS–ICRISAT 2016). Between January 1, 2010, and March 1, 2014, 57 percent of exports from South Africa rejected by the EU were due to mycotoxins, of which aflatoxins are one type (Henson undated).

Under climate change, more temperate regions have started to develop aflatoxin problems. During 2000–2010, hot, dry seasons in northern Italy led to aflatoxin contamination of maize. Used as animal feed, this also resulted in milk contamination, with several thousands of tons of milk exceeding the EU's regulatory levels. Little is known about the global expansion of aflatoxin hotspots in response to climate variability and change, but a companion study under the Gender, Climate Change, and Nutrition Integration Initiative is currently modeling changes in areas and key crops potentially affected by aflatoxins as a result of climate change, the results of which are due to be made available in the second half of 2018.

Extreme weather in 2012 resulted in serious problems in maize and milk in Serbia, Croatia, and Romania. A severe drought in Serbia resulted in aflatoxin-contaminated maize being exported to German producers of animal feed, ultimately leading to milk contamination in both Germany and the Netherlands. The EU's Rapid Alert System for Food and Feed identified the problem, and maize exports were returned to Serbia, but the problem prompted Germany to reinstate its own aflatoxin expertise to avoid future issues.

The Gender Dimension

Production-Related Gender Issues

Aflatoxins are a key gender issue for several reasons. Some of the most susceptible crops, maize and groundnuts, form the backbone of household diets in many countries, particularly for young children. Women's roles in cultivating crops, their lower access to extension and financial services, and their reduced access to inputs (such as fungicides and insecticides) and to hired labor make it more difficult for them to use crop management and control techniques. Women's labor is often prioritized to plots managed by men and geared toward immediate sale. This, combined with their other household responsibilities, including childcare, can make timely crop management difficult for women, causing issues, such as delayed weeding and failure to implement techniques that retain soil moisture, all of which can increase the risk of contamination.

Women are often responsible for postharvest sorting, drying, and storage. The lack of attention to postharvest drying and storage technologies, and their inaccessibility to women, cause crops to be stored in conditions conducive to exponential aflatoxin growth. Levels of aflatoxin contamination can increase tenfold in three days under high-moisture storage conditions (Hell et al. 2008).

Women are usually responsible for groundnut shelling, a time-consuming task estimated to take 4 billion hours per year in Africa (Emmott 2013). To make their lives easier, and the task less painful, women often soak the shells in water to soften them, introducing additional moisture, which—combined with inappropriate storage—results in higher aflatoxin loads. Mechanical shellers would address the problem but are not normally accessible to poor female smallholders. Exploring creative lease and rental contracts, including collective action contracts, with local suppliers would be one way forward.

Crops produced by men are more likely to be marketed than those produced by women. In poor, cash-constrained communities, such crops are sold immediately after harvest, at which time the aflatoxin load may be lower—although in many supply chains aflatoxin testing is absent or rudimentary at best. Crops destined for market are often sorted prior to sale, with damaged (more susceptible) grains that would lower price retained for the household granary or used for animal feed. A study in Ghana and Nigeria showed that farm household samples of groundnuts had higher levels of aflatoxin contamination compared with market samples (Perrone et al. 2014).

Nutrition-Related Gender Issues

High levels of aflatoxins in grains stored in household granaries, as well as use of contaminated feed leading to contaminated animal-source foods, mean that human consumption of aflatoxins through grains, legumes, and animal-source foods can be high.

Once consumed aflatoxins are virtually indestructible. Consumption by pregnant women is damaging to them and to their unborn children. Initial research on mice has also shown that aflatoxin consumption during pregnancy increases DNA damage to the mother, and potentially increases susceptibility to liver cancer (Sriwattanapong et al. 2017). Aflatoxins have been found in neonatal cord blood and in breast milk, so a mother's consumption is passed to her infant both in utero and through breast milk. One study in Tanzania showed that all breast milk samples contained aflatoxins, that 90 percent of samples exceeded EU limits for aflatoxins in infant food, and that 76 percent of samples exceeded levels for dairy milk and milk products (Magoha et al. 2014).

Additionally, a small, but significant association exists between infant exposure levels to breast milk and underweight and stunting levels. Whether aflatoxin levels are higher in either breast milk or cows' milk has yet to be determined, but this is an important policy issue in pastoralist areas where women often stop exclusive breastfeeding earlier. Exclusive breastfeeding is still recommended based on its wide-ranging benefits.

The likelihood of a low birth-weight baby increases with increasing aflatoxin levels in maternal serum, with likelihood doubling for mothers in the highest aflatoxin in maternal blood serum quartile compared with those in the lowest quartile in Kumasi, Ghana (Shuaib et al. 2010a). Similarly, the likelihood of a pregnant woman being anemic increased by 21 percent with each quartile of aflatoxin levels in maternal serum. In the highest quartile of aflatoxins in pregnant women, the likelihood of anemia increased by 85 percent over the lowest quartile (Shuaib et al. 2010b). Increased anemia levels are associated with increased maternal mortality.

Contaminated feed leads to reduced animal growth, reduced yields of products like milk and eggs, and increased feed conversion ratios (the amount of feed required to produce a given unit of animal product). Milk, meat, and eggs are important nutrient sources for young children when available, so contamination damages infant and child nutrition. Moreover, in many poor households, women separate out grains that are noticeably moldy and feed them to their chickens and small livestock, while keeping the "clean" grains—where the potential toxin is invisible—for human consumption.

A CGIAR study showed that, as the aflatoxin load in children in Benin increased, both stunting and underweight also increased (Gong et al. 2002). Aflatoxin levels in the blood albumin of severely stunted and underweight children were more than double those of well-nourished children. It is particularly challenging for mothers to source high-quality, nutritious foods for infants and young children, with animal-source foods being a key source. A study in Malawi showed that, while imported baby cereals had no aflatoxin contamination, locally produced maize-based baby cereals had levels of aflatoxins above EU regulatory limits.

Of even more concern are groundnut-based therapeutic foods, used to address severe child wasting. One study found aflatoxin levels 16–30 times the EU regulatory limit in such foods (Limbikani et al. 2013). A study in southern India by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) found aflatoxins in groundnuts at levels 40 times higher than the Indian regulatory limits (ICRISAT 2018). A study in the Indian states of Karnataka and Tamil Nadu showed that all samples of ultra-high temperature milk analyzed contained aflatoxins, and that 38 percent of the samples were contaminated at levels over the permitted Codex and Indian food safety limits (Siddappa, Nanjegowda, and Viswanath 2012).

Strategies to Reduce Aflatoxin Levels

Strategies to address aflatoxins fall under two key domains. The first involves minimizing contamination in the growing cycle through the use of good agricultural practices and by mitigating accelerated toxin development in the postharvest supply chain, both of which reduce aflatoxin levels in food. ICRISAT demonstrated that good agricultural practices were effective not only in lowering aflatoxin contamination levels in groundnuts, but also in managing costs (Parimi, Kotamraju, and Sudini 2018).

The second core focus is to reduce the consumption of contaminated food by diversifying the diet to include more fruits, vegetables, legumes, and animal-source foods, reducing the dominance in the diet of staples—particularly maize with its likely high contamination with aflatoxins. This is a win–win–win scenario in that (1) it reduces ingestion of the toxins, (2) it increases consumption of the micronutrients essential for child growth and good nutrition, and (3) it reduces the dominance of calorie-dense staple foods and, hence, the likelihood of overweight and obesity in adults. At a minimum, any agricultural project targeting maize or groundnuts should include training on aflatoxin management and control, and that training should take into account the different roles of men and women throughout the value chain, from farm to fork.

Good Agricultural Practices

Crop selection. Farmers should use crop varieties that are resilient to local growing conditions, particularly drought, insects, and pests, and those that have resistance to fungal contamination. For maize and groundnuts—two of the crops most affected by aflatoxins—breeding for drought-resistance has been more successful than breeding for fungal contamination resistance. However, Sharma et al. (2018) introduced a double-defense breeding system for groundnuts that made aflatoxin levels undetectable after fungal infection compared with control levels that were more than 3,000 times higher. Choosing the best crop variety for the prevailing conditions can reduce fungal contamination due to reductions in crop stress. Agricultural extension services do not, yet, routinely provide information on or training for aflatoxins, and often fail to meet the specific needs of women. As a matter of policy, it is recommended that no projects be implemented on aflatoxin-sensitive crops without mitigation and control measures. A number of materials focusing on aflatoxins are available. Access Agriculture, for example, offers a video on aflatoxins in groundnuts in ten African languages (Access Agriculture undated).

Biocontrol. Not all strains of aspergillus flavus produce aflatoxins. Aflasafe—a biological control product, developed by the International Institute of Tropical Agriculture, using a sterile sorghum seed as a carrier for a native, atoxic strain of aspergillus flavus—is applied to fields in order to "out-compete" the toxic strain. Aflasafe can result in an 80–90 percent reduction in field contamination. Biocontrol is also cost effective, as demonstrated in one study for maize in Nigeria (Wu and Khlangwiset 2010), with a cost-effectiveness ratio of 5–25, far in excess of the World Health Organization's benchmarks of 0.33 for "cost effective," and 1 for "very cost effective." Aflasafe does, however, require an additional investment by farmers, who—given the invisibility of aflatoxins and limited testing in the value chain—are unlikely to adopt this technology without government regulation and enforcement and/or the ability to secure premium prices for their clean grain.

Crop management to reduce plant stress. Irrigation, fungicides, herbicides, and insecticides can improve plant health resulting in resistance to the aflatoxin-producing fungus. However, as previously mentioned, this can be particularly challenging for women given their time constraints and lower access to knowledge and inputs. Targeting women with training, microfinance, and agricultural input packages is an important control strategy for crops managed by women and often destined for household use. Good agricultural practices for groundnuts have been shown to reduce aflatoxin contamination by 62–94 percent and to increase yields by up to 30 percent, increasing net income per hectare by US$25 (ICRISAT 2016). Such practices include not growing groundnuts repeatedly in the same fields; avoiding late planting, which can lead to drought and insect exposure late in growth; using farming techniques that retain soil moisture, such as using ridges; and ensuring timely weeding and harvest (USAID–CRS–ICRISAT 2016).

Postharvest drying and storage. Managing moisture levels postharvest is key to controlling aflatoxin contamination: toxin development on groundnuts, for example, stops when moisture levels fall below 7 percent. In many countries, women are responsible for the postharvest drying and storage of crops, particularly for household use, but they lack technologies needed to reduce moisture content. Maize is often left to dry on the ground and stored with too high a moisture content. Simple drying racks can be an effective solution. The Rwandan government assists farmer cooperatives both with access to drying racks and sorting equipment in warehouses for maize destined for sale. Rwandan farmers have replicated the technology on their farms by tying ropes between trees and hanging their maize cobs over the ropes to keep them off the ground. While testing for aflatoxins can be time consuming and expensive, simple moisture meters and innovative contracting can viably address the problem.[1] Premium prices for low moisture sales encourage farmers to use moisture meters; such premiums can be valuable for buyers, too, because they secure a higher weight of actual product.

Solar dryers are another solution to control moisture levels in crops prior to storage. The Aflastop project piloted and tested a number of drying and storage technologies.[2] Postharvest interventions are extremely cost-effective if widely applied. The monetized savings in terms of lives saved, and the improvements in quality of life gained by reducing aflatoxin-induced liver cancer, far exceed the costs of implementing either intervention. When applied to peanuts in Guinea, the cost-effectiveness ratio was 0.2–2.1, which is less cost effective than biocontrol on maize, but nonetheless effective. It should be noted that these cost-effectiveness ratios are considerably understated, given that the study only accounted for disability-adjusted life years saved in terms of liver cancer and did not include immune-system improvement or reduced stunting among children.

Binders for animal feed. A key problem in food-insecure areas is feeding moldy and damaged grain to animals. Households are unlikely to throw grain away, but adding binders to feed can address the issue and is more achievable for low-income farmers. In essence, these binders attach to the aflatoxins to reduce their absorption.

Food-aid food swaps. Switching contaminated grain for clean grain, using food-aid food swaps, could provide the necessary incentive for farmers and traders to produce and purchase clean grain. Farmers and traders would receive training on how to reduce aflatoxin levels—a key step in the move toward enforcing regulatory limits. To support learning on aflatoxin control, upon completion of the training, phased swaps would be made where testing showed that aflatoxin levels were still above the limit. The initial swap maybe at the 90 percent level, but this percentage would decline over a transition period to encourage farmers and traders to implement their learning before being subject to regulatory enforcement. This innovative strategy, which would have the added benefit of removing contaminated grain from the food supply, would work particularly well in countries where regulations are being introduced or enforcement is being strengthened.

Dietary Diversification

Women's ability to diversify household diets, especially for children, is a key factor in reducing aflatoxin consumption. Dietary diversification has the benefit of reducing both exposure and consumption, while also directly improving nutrition. Dietary diversity generally improves (and indicates) dietary quality and the adequate intake of micronutrients. In China, pre-1980 agricultural policies forbade inter-county trade of food to promote national food self-sufficiency. Quidong, a county in the province of Hunan, was unsuitable for growing rice and, hence, grew maize. Once the policy changed and inter-county food trade grew, rice consumption in Quidong rose, and maize consumption fell sharply. The median biomarker levels of aflatoxins fell from 19.3pg/mg albumin in 1989 to undetectable levels by 2009. In addition, the age-standardized rate of liver cancer deaths fell by 45 percent following the policy change (Chen et al. 2013).

Consumption of green, leafy vegetables seems to have some protective effect by impeding aflatoxin absorption. Cruciferous vegetables, onions, and garlic contain protective phytochemicals that impede the processes through which aflatoxins lead to liver cancer (Wu et al. 2014). Production of these types of vegetables should be integrated into home gardens.

Addressing aflatoxins in the groundnut value chain is particularly important given groundnuts are usually the basis of ready-to-use supplemental foods for children because of their nutrient density and long shelf life. Manufacturing them safely within Africa or Asia, as opposed to importing them, offers both increased availability and, potentially, reduced costs.

Binders in food for human consumption work in the same way as those outlined above for animal feed. One trial study in Ghana indicated a reduction of 21 percent and 24 percent in serum aflatoxin levels, respectively, with low- and high-dose capsules of Novasil clay before meals (Wang et al. 2008). However, given that the link between aflatoxins and stunting is not well understood, it is not clear whether this would improve linear growth, nor whether it would limit the uptake of other micronutrients that are crucial for growth.

Notes

1. For more information on moisture meters, see Fell (2017).
2. Three hermetic devices—Purdue improved crop storage (PICS) bags, metal silos, and Grainsafe (an automated aeration controller)—limited the increase of aflatoxin levels to 5 percent per month. Of these, the PICS bags were the most cost-effective, but they still involve an additional cost that may be too high, especially for women (ACDI/VOCA 2014b, 2016).

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