TECHNICAL BRIEF

Aflatoxin Management for Smallholder Farmers of Maize and Groundnuts:

PRACTICES AND TECHNOLOGIES FOR DETECTION AND PREVENTION

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Maize farming in Kenya.
(Karen Kasmauski for CRS)

Approximately 25% of the world's agricultural commodities are contaminated by aflatoxin and other mycotoxins, resulting in nearly one billion tons of food loss every year[1]. Although there are multiple types of mycotoxins, aflatoxins are of particular concern because of how their high toxicity affects human health and the significant economic losses associated with contaminated staple crops.

WHAT ARE AFLATOXINS?

Aflatoxins are an odorless, colorless, flavorless toxin produced by the fungi strain *Aspergillus* and are highly toxic to humans and animals. For this reason, many countries have placed strict limits on the amount of aflatoxin that can be present in food commodities and animal feed. For human consumption, limits range from 4 ppb (parts per billion) in the European Union to 20 ppb in the United States. For farm animals, such as cows, pigs, and chickens, feed can safely contain up to 100 ppb. However, there are many countries that either do not have regulatory limits on aflatoxins or do not have the capacity to enforce such regulations.

PREVALENCE

Aflatoxins are most prevalent in tropic and sub-tropic regions. Although *Aspergillus* is found in the soil pre-harvest, contamination can also occur during or after harvest as heat and humidity help spread the fungus, and resulting toxin, quickly. Aflatoxin affects many staple crops including cereals and legumes, as well as tree nuts and spices. However, aflatoxins are most prevalent in maize and groundnuts because these crops are the most susceptible and have high consumption rates.

WHY IS IT IMPORTANT?

HUMAN HEALTH:

Chronic exposure to aflatoxins can lead to liver cancer[2], weakened immunity, worsening of certain diseases such as hepatitis B and HIV/AIDS[3] and has been associated with child stunting[4]. Additionally, acute exposure with extremely high levels of aflatoxins can lead to death. In Kenya, a crop of contaminated maize, ranging from more than 20 ppb to over 1,000 ppb, killed 125 people and sickened hundreds more[5].

1 Agrilinks: Food for Thought *https://agrilinks.org/print/node/2258*
2 Wild (2007).
3 Jolly et al. (2013).
4 Leroy. (2013).
5 Lewis et al. (2005).

IN THE AFRICAN CONTINENT, IT IS ESTIMATED THAT ECONOMIC LOSSES OF GRAIN DUE TO AFLATOXIN CONTAMINATION ARE MORE THAN US$750 MILLION ANNUALLY[7].

ECONOMIC LOSS:

Aflatoxin contamination can also affect agricultural livelihoods in various ways. First, it can cause crop loss due to low yields. Second, the market value of and uses for a contaminated crop decrease dramatically. Third, farm animals can have stunted growth and lower yields of by-products such as milk and eggs when given contaminated feed. Lastly, there are healthcare costs associated with aflatoxin exposure, and smallholder farmer families are most likely to consume contaminated crops[6].

PREVENTION

Aflatoxins will only contaminate plants that have already been weakened by other factors, such as drought or pests. Therefore, following good agriculture practices for crop production will help to maintain soil fertility and ensure a healthy crop that will be more able to resist diseases and stress.

PRE-HARVEST BEST PRACTICES

- Use improved varieties that are resistant to diseases, drought-tolerant, and early maturing.
- Use good quality seed with a high germination rate, thereby reducing competition with weeds.
- Rotate legumes crops (groundnuts) with grain crops (maize, sorghum) to break pest and disease cycles and improve soil fertility.
- Apply appropriate soil amendments, such as lime (calcium), animal manure, and compost.
- Use appropriate Integrated Pest Management that controls insect pests and foliar diseases.
- Plant in a timely manner to avoid mid- and late-season drought.

PRE-HARVEST PROMISING PRACTICES

Bio-char, similar to charcoal, is made from woody agricultural residues. It is thought that the incorporation of bio-char into the soil reduces plant stress as it moderates soil moisture and ultimately soil temperature. In a pilot test in Haiti, bio-char was found to prevent aflatoxin contamination in groundnuts in comparison to adjacent plots that were not treated with bio-char[8].

Biological control is also being tested as a feasible approach to preventing aflatoxin contamination. The theory is that by introducing nontoxic *Aspergillus* strains into soil, it will out-compete the *Aspergillus* strains that produce toxin. One commercial product, Aflasafe, is being piloted in 11 African countries. However, due to policy constraints, each country must develop their own strain of Aflasafe (nontoxic *Aspergillus*).

Aflasafe has been shown to reduce aflatoxin contamination by 80–100%. However, practical barriers remain including affordability and consumer awareness and value of an aflatoxin-free product[9]. For the most current list visit: *https://aflasafe.com/aflasafe-where-i-am*.

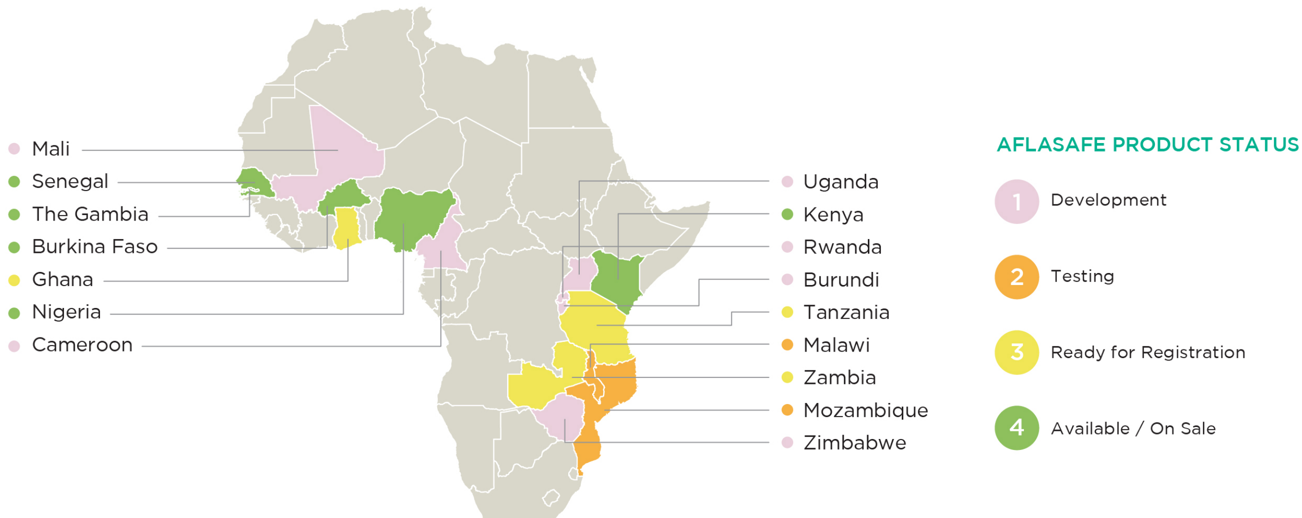
AFLATOXIN MITIGATION DURING PRE-HARVEST IS NOT SUFFICIENT TO PREVENT ***AFLATOXIN CONTAMINATION***. AFLATOXIN MANAGEMENT MUST CONTINUE AT THE HARVEST AND POST-HARVEST PERIODS.

HARVEST

Aflatoxin contamination can be prevented during harvest time by following some simple best practices:

- Timely harvesting at maturity, as immature or overly mature crops are more susceptible to contamination.

6 Schmale & Munkvold (2009); Suleiman & Rosentrater (2015).
7 Negedu et al. (2011).
8 Unpublished research in Haiti with *Carbon Roots* and *Meds & Foods for Kids* (2014).
9 *http://agresults.org/en/283*



Source: Adapted with permission from IITA presentation at World Food Prize 2017

- Avoiding damage to the crop by using appropriate harvesting methods is also critical, as damaged crops are more susceptible to aflatoxin contamination.
- When harvesting groundnut, avoid soil contact and remove soil from the groundnut.

GENDER & AFLATOXINS

A study done in Zambia found that women who had more control over groundnut production were more successful in managing aflatoxins. It was found that women with decision-making power could implement Good Agricultural Practices by hiring extra labor when timeliness was critical, such as during harvest, drying, or processing. Additionally, a woman's control of assets allowed her to pay for the labor as well as prioritize her time to attend farmer field school.

Source: INGENAES webinar 26 April 2017 Aflatoxins and Extension in Zambia *https://www.slideshare.net/INGENAES/aflatoxins-and-extension-in-zambia*

POST-HARVEST

Post-harvest strategies are critical in preventing aflatoxin contamination given *Aspergillus'*[10] ability to grow and spread during this period. Using appropriate sorting, drying, and storage techniques can significantly reduce aflatoxin contamination (63-88%)[11].

Sorting

Sorting damaged, moldy, shrunken, or otherwise nonconforming crops can be extremely effective in reducing aflatoxin levels. In fact, physical sorting alone has been found to reduce aflatoxin levels by 40–80%[12]. In Haiti, a crop of groundnuts initially tested at 214 ppb was reduced to less than 5 ppb with several rounds of sorting. Meanwhile, the rejected groundnuts were tested to have toxicity levels up to 14,500 ppb[13].

Drying

For many smallholder farmers, the most feasible option for drying their crops is using natural direct sunlight. By following Good Agricultural Practices (GAP) for natural drying, farmers can help to mitigate aflatoxin contamination during this process. GAP include:

10 Turner et al. (2005).
11 Unnevehr & Grace (2013).
12 Kumar et al. (2017).
13 Unpublished research in Haiti with Carbon Roots and Meds & Foods for Kids (2014).

- Using a clean ground cover and not drying crops directly on the soil, as it can be source of contamination.
- Storing or covering crops every evening or before rain.
- When possible, using a dark-colored surface or elevated mesh to expedite drying, as the shorter the drying period, the less likely it is the crop will become contaminated.

Another drying method, Mandela Corks, is a type of ventilated stacking used for groundnuts as a slow curing process. Mandela Corks provide a feasible alternative to the common practice of drying groundnuts on the soil or roofs, which leads to moisture absorption and fungal growth that encourages aflatoxin development[14]. This method is being promoted by CRS UBALE as an alternative to natural drying.

Another technology, the shallow bed dryer, was identified by the AflaSTOP[15] project as the only cost-effective and appropriate technology for smallholder farmers[16]. The project developed and tested the feasibility of the Easy Dry M500 (M for maize and 500 for kilograms per batch) with local manufacturers, entrepreneurs, and smallholder farmers in East Africa for drying maize and groundnuts. The business model allows farmers to dry their maize in approximately 3 hours for $9.70 per batch. Adapting the technology for drying groundnuts is also feasible and could increase the profitability for the operator/owner of the dryer and potentially decrease the user cost as well[17].

Source: ACDI/VOCA, AflaSTOP project

Moisture

After drying and before storage, it is imperative to ensure that crops have reached optimal moisture levels in order to discourage mold and toxins from growing while in storage. For maize, the moisture content should be below 13.5% and for groundnuts below 7% before storing.

A new technology, developed by the UC Davis Horticulture Innovation Lab and targeting smallholder farmers, is the DryCard, which costs under $0.25 USD to manufacture and is being sold for $1/card by local manufacturers. The card is placed in the middle of a product sample in an airtight container for 30–60 minutes. If the color becomes pink, farmers know that their crop is not dry enough to store. Cards can be re-used indefinitely as long as the cobalt chloride strip does not come in contact with water and is not damaged.

DryCard, developed by UC Davis Horticulture Innovation Lab, measures moisture and is targeted to smallholder farmers.

Source: UC Davis Horticulture Innovation Lab

Storage

The AflaSTOP project also assessed three storage technologies for aflatoxin prevention in maize: metal silos, PICS bags, and GrainPro storage bags. After testing, it was determined that PICS bags were the most successful solution for smallholder farmers of maize as it prevents the increase of aflatoxins[18] and the infestation of pests. The metal silos were deemed too expensive and difficult to use for smallholder farmers. (Note: Hermetic storage [PICS, GrainPro] was not found to prevent the growth of fumonisins, another form of mycotoxins.)

DETECTION

It is important to use diagnostic tools to ascertain if there is aflatoxin contamination and at what level. High Performance Liquid Chromatography and Thin Layer Chromatography **(HPLC/TLC)** are considered the gold standard for aflatoxin detection (also called reference methodology). In practice, other detection technologies are measured against HPLC/TLC to determine their accuracy. This detection technology is very expensive and requires a well-equipped lab and skilled technician.

The ***ELISA*** (Enzyme Linked Immunosorbent Assays) method also requires a skilled technician and a national lab/university. This technology is not as expensive as HPLC, but the results are considered

14 ICRISAT (2016).
15 AflaSTOP, a project funded by USAID and the Bill & Melinda Gates Foundation, studied promising storage and drying practices accessible to smallholder farmers.
16 AflaSTOP (2016).
17 ACDI/VOCA (2017).
18 ACDI/VOCA (2017).

comparable. UBALE , the CRS-led Food for Peace project in Malawi, is using the IC-ELISA (Indirect Competitive) for testing aflatoxin levels in groundnuts and found it cost-effective and useful for testing multiple samples at a time.

Dipstick tests are available in a field setting for aflatoxin diagnosis. It does not require a laboratory, making detection more accessible and affordable for farmer cooperatives, traders, and food processors in developing countries. The results are qualitative—test kits are calibrated to determine if aflatoxin levels are above or below a specific level, such as 10, 20, or 100 ppb. A dipstick test kit would also require other necessary items to conduct the testing, such as a mill to grind the sample and a solvent (methanol or ethanol) to perform the extraction.

The ***mReader*** is software in which test strips, such as those from dipstick tests, can be read on a mobile device and give a quantitative measure (exact number) of aflatoxin levels. This technology has been validated for accuracy by the HPLC method and is an opportunity to bring more accurate results to the field level.

Sampling
Proper sampling for detection is as important as the actual testing for aflatoxins. If done improperly, it can lead to inaccurate results that could produce false positives, which penalize the farmer/seller, or false negatives, which could harm the consumer/buyer. Best practices for sampling include:

- Pulling a representative sample from the lot.
- Grinding the entire sample.
- Analyzing the sample.

The variability of results mostly depends on the number of samples pulled from the lot and, to a much lesser extent, on the portion tested from each sample and the test itself. In addition to using these best practices, it is important to identify an accept/reject limit (e.g., 20 ppb) determined by national regulations or buyers.

The mReader allows for quantitative field testing of aflatoxins.

Source: Mobile Assay

ALTERNATIVE USES

To successfully eliminate aflatoxins from the food supply, it is not sufficient to only train smallholder farmers on prevention methods. Even with proper education and awareness raising, farmers need productive alternatives so they can still benefit from contaminated crops. Below are some promising practices, some at the farm-enterprise level, where farmers could divert all their contaminated crop, and some at the household level, where food may already be contaminated with aflatoxins. **(Note: All of these practices require further validation.)**

Edible oil industry
There is some evidence that the processing of contaminated groundnuts into refined oil can significantly reduce the aflatoxin level in the finished product. However, if the groundnuts are not properly pressed and refined, the aflatoxins may not be adequately filtered out of the oil[19].

Animal feed
Because most farm animals can tolerate up to 100 ppb before negatively impacting their growth and production, crops that are contaminated above the legal limit (using 20 ppb for countries with no limit in place) but below 100 ppb could be fed to animals. At the farm level, this would require a dipstick test that measures at 100 ppb.

Food as fuel
There is a possibility that contaminated maize and groundnuts can be used as fuel, but research is needed to understand if aflatoxins are released when burnt and if this is detrimental to health.

19 Bordin et al. (2014).

For example, contaminated groundnuts can be used to make cooking briquettes in low efficiency stoves. A study conducted in Haiti found that the briquettes were comparable to the local charcoal traditionally used[20]. This alternative use is beneficial not only because it keeps aflatoxins out of the food supply, but it also has the potential to contribute to climate change mitigation by providing an alternative source of cooking fuel and thereby preventing deforestation for charcoal. An additional example of food as fuel is maize being used to generate power for the EasyDry M500. The AflaSTOP project found that it took 30–36 kilograms of maize to dry 500 kilograms of maize for 3 hours[21].

Fermentation

There is some evidence that fermentation can help to detoxify aflatoxins but only to a limited extent. A study in Kenya found that traditionally fermented maize gruel using lactic acid also reduced aflatoxin levels by 68%[22]. This may be a feasible alternative in countries where fermenting is already part of the traditional cuisine.

Animal feeding in Ethiopia.

(Ric Francis for CRS)

Nixtamalization

Nixtamalization is a traditional Mexican method of cooking maize with boiling water and food-grade lime (calcium hydroxide). One study found that the alkalizing process of the lime can be effective in reducing aflatoxin from approximately 80% (for B1,B2) up to 100% (for G1,G2)[23]. In 2016, the government of Kenya officially adopted nixtamalization as a method of processing maize and reducing aflatoxin exposure in the food chain.

Dietary Diversity

Recent research has suggested that dietary diversity may help to reduce the danger presented by dietary exposure to aflatoxins. Chlorophyllin, a derivative of chlorophyll and a common component of many fruits, may bind to aflatoxin, helping to prevent absorption by the gut. Additionally, cruciferous vegetables, such as broccoli, bok choy, cabbage, and kale, as well as alliums, such as onion and garlic, stimulate the production of certain liver enzymes that have the effect of preventing damage by aflatoxin metabolites[24].

* * * * *

Aflatoxins are the source of both poor health and poor livelihood outcomes. In order to support smallholder farmers in developing countries, it is important to equip them with the knowledge, practices, and access to technology that will allow for proper and effective aflatoxin management.

For more information, contact *harley.stokes@crs.org*, *bryan.sobel@crs.org* or *valerie.davis@crs.org*.

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21 Email from AflaSTOP Chief of Party (September 5, 2017).
22 Mugula (2016).
23 del Carmen de Arriola et al. (1988).
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Catholic Relief Services 228 W. Lexington Street, Baltimore, MD 21201, USA
For more information, contact harley.stokes@crs.org, bryan.sobel@crs.org, or valerie.davis@crs.org.