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FOCUS 20

AFLATOXINS

FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

EDITED BY
LAURIAN UNNEVEHR AND DELIA GRACE

Aflatoxins: Finding Solutions for Improved Food Safety

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A key tenet of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH) is that agricultural practices, interventions, and policies can be better configured both to maximize health and nutrition benefits and to reduce health risks. This is particularly true regarding aflatoxins and other mycotoxins, an important food safety health risk with significant implications for developing countries.

Aflatoxin exposure is particularly problematic in low-income populations in the tropics that consume relatively large quantities of staples, particularly maize and groundnuts. The best documented health impact of chronic exposure to aflatoxins is liver cancer. It is estimated that 26,000 Africans living south of the Sahara die annually of liver cancer associated with aflatoxin exposure. Broader health effects such as immune suppression with higher rates of illness and child stunting have also been associated with aflatoxin exposure. The presence of aflatoxins can also limit the growth of commercial markets and trade. As but one example, aflatoxin contamination has sharply limited the quantities of maize that the World Food Programme has been able to purchase locally in Africa since 2007.

Given the complexity of the problem of controlling aflatoxins, IFPRI's 2020 Vision Initiative and A4NH invited Laurian Unnevehr and Delia Grace to convene a diverse panel of global aflatoxin experts to write briefs surveying the emerging policy-relevant research. We would like to express our appreciation to the editors, Laurian Unnevehr and Delia Grace, the authors of the briefs, and the anonymous peer reviewers for their contributions to this effort. This set of 2020 Vision briefs provides key insights into aflatoxin control and how we can bring about a shift from a market characterized by poor information, low food quality, and high public health risk to one in which improvements in both information and technology facilitate better market opportunities and income, higher quality food, and reduced health risk.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Tackling Aflatoxins: An Overview of Challenges and Solutions

LAURIAN UNNEVEHR AND DELIA GRACE

Aflatoxins, naturally occurring carcinogenic byproducts of common fungi on grains and other crops, occur more frequently in the tropics, particularly in maize and groundnuts. Persistent high levels of aflatoxins pose significant health risks in many tropical developing countries. In addition, they are also a barrier to the growth of commercial markets for food and feed, including exports. In the European Union (EU) countries and the United States strict standards have been set to minimize aflatoxins on crops consumed in foods or as animal feed. Where aflatoxins are more widespread and costs of mitigation and testing are higher, meeting such standards remains challenging.

Attention to aflatoxin issues from the policy community has increased in recent years, with growing recognition of their health risks as well as the barrier they pose to market development. The 2002 imposition of new, stricter aflatoxin regulations in the EU has raised concerns about the future for African exports of groundnuts and other crops. Local food procurements by the World Food Programme in Africa in 2007 encountered significant levels of aflatoxins, thus raising awareness of potential contamination in food supplies for the poor. The recent formation of the Partnership for Aflatoxin Control in Africa (PACA) demonstrates the commitment of governments and donors to addressing this public health and market development issue.

Because aflatoxins are a pervasive environmental risk, control will require a multifaceted approach. Many different efforts will be required to move toward higher quality food and reduced food safety risk. The briefs in this series thus provide several perspectives on solutions for reducing aflatoxins. The series begins with what is known about the health risks from aflatoxins, as this is the foundation for public health policy. Next, efforts to build new market channels and incentives that can improve aflatoxin control are considered. The international trade and policy context for action in developing countries follows, including how risk analysis might inform policy. Finally, briefs from several CGIAR centers outline how new technologies and new detection methods can overcome constraints to aflatoxin control.

Health risks from aflatoxins

Aflatoxins pose both acute and chronic risks to health. Exposure to aflatoxins is particularly high for low-income populations in the tropics that consume relatively large quantities of staples such as maize or groundnuts. Consumption of very high levels of aflatoxins can result in acute illness and death, as observed in Kenya in recent years (brief 2). It is well established that chronic exposure to aflatoxins leads to liver cancer (especially where hepatitis is prevalent), and this is estimated to cause as many as 26,000 deaths annually in Africa south of the Sahara (brief 3). Other effects of chronic exposure are less understood due to the difficulties in establishing causality when putative effects are correlated with a number of adverse health determinants. Chronic exposure is associated with immune suppression and higher rates of illness. For infants, exposure is associated with stunting, but the specific role of aflatoxins in stunting has not been identified (brief 4), just as a dose-response relationship has also not been identified. Animal studies provide ample evidence that high levels of aflatoxins in animal feeds have adverse effects for animal health, growth, and productivity. These are suggestive of such effects in humans, but animal studies typically involve much higher levels of aflatoxin exposure than is usually observed in human populations (brief 5).

Using markets to encourage aflatoxin reduction

Markets in developing countries generally do not reward reduced aflatoxins in crops because it is difficult to discern aflatoxin contamination or its risks. The presence of mold is a potential, but highly imperfect, indicator of aflatoxin contamination. Surveys in a few African countries show that farmer knowledge and awareness are far from perfect, as are storage and drying practices (brief 7). While some moldy grain is diverted to uses that somewhat reduce direct human exposure (such as for brewing and animal feeds), quality differentiation based on either market rewards or public standards is still unusual in most developing countries.

Commercial markets can provide incentives for reduced aflatoxins, but this may mean new institutional arrangements to communicate requirements to producers. A comprehensive approach to supply chain management such as that used by Mars, Inc. (brief 6) is a well-integrated, holistic process to better manage aflatoxin risks throughout a supply chain. This kind of comprehensive "from farm to consumer" approach is required even when value chain actors lack the ability to employ sophisticated statistical sampling methods. For example, identification of high-risk elements of the supply chain should help prioritize those areas where market actors can intervene to reduce the incidence of aflatoxins. The World Food Programme's Purchases for Peace program (brief 9) has a simpler approach: the introduction of basic grain quality evaluation tools. These tools can be seen as an essential building block, providing the foundation for quality assessment and evolution toward improved supply chain management.

Another approach is to change handling and processing. TwinTrade, an NGO operating in Malawi, is introducing groundnut shellers, which reduce mold growth and contamination, and is also diverting contaminated product to a new market outlet through peanut oil processing (brief 8). IITA is working closely with Doreo, an NGO operating in West Africa, to introduce aflatoxin biocontrol agents to Nigerian farmers to improve the quality of supply in the feed grain market, thus providing incentives for adoption of this new technology (IITA 2013). Taken together, these market intervention examples suggest that reducing aflatoxins will require changes in both institutions and technologies.

Policy and economic challenges

In addition to the challenge of creating market incentives for reducing aflatoxins, there is also an economic challenge in reducing the costs of control. A wide range of control methods exist, including cultivation practices and postharvest handling. There are also limited means for mitigating effects of exposure. None is in wide use in developing countries due to cost, logistics, and lack of incentives (brief 11). However, preliminary estimates in Kenya show that a simple package of low-cost interventions, such as improved drying and storage, could be effective (brief 10), indicating potential for change if markets reward aflatoxin reduction.

As both a food safety risk and potential barrier to trade, aflatoxins pose challenges that cut across policy sectors. From a public health perspective, the risk assessment framework is widely embraced as the best method for addressing food safety risks (brief 14). Very few risk analyses have been carried out for aflatoxins in developing countries, and this approach could be more widely applied to help focus efforts based on dietary exposure, "hot spots" where aflatoxin levels are particularly high, use of preventative approaches, and communication strategies to reach producers and consumers with risk-mitigation messages.

From a market perspective, it is clear that differences among countries in aflatoxin standards (and ability to meet standards) tend to reduce international trade or to divert low-quality exports to lower-value markets (brief 12). At the international level, Codex Alimentarius standards provide guidance on appropriate levels of aflatoxins, and these serve as an international reference (brief 13). Codex standards are set through an international process of data gathering and consensus building, but more data are needed from developing countries so that standards can be developed that properly reflect risk conditions in diverse circumstances.

Policy initiatives to address aflatoxin control are underway in PACA, in other regional organizations, and in individual countries (brief 15). For example, there are regional approaches to setting standards or to biocontrol registration, which can reduce the costs of individual country action and may promote regional trade.

Promising technologies for aflatoxin control

Because growth of the molds that produce aflatoxins is affected by multiple factors, control is thus complex. Good management practices in crop production, drying, handling, and storage are necessary but not always sufficient for control (brief 18). Resistant strains can be identified, but resistance is a complex characteristic, and thus considerable research is required for incorporating resistance along with desirable agronomic characteristics for different production environments (briefs 17 and 18). Thus, while some progress is being made, both host resistance and improved management will require long-term efforts in research and extension.

Biocontrol offers a preventative measure to reduce the levels of aflatoxins arising during cultivation and thus during storage as well; it consists of the application of non-toxic fungus strains that outcompete the toxic strains (brief 16). This technology is already in widespread use in the United States and is now being adapted to tropical maize and groundnuts. Field trials indicate that this new technology has potential to reduce aflatoxins substantially at their initial source: in farmers' fields.

Development of new detection and diagnostic tools that are cheaper, more reliable, and more easily used in the field is also underway (brief 19). Such tools would facilitate both public monitoring for aflatoxins as well as the development of commercial markets for improved-quality grain.

Concluding remarks

While there are growing concerns about aflatoxin issues in tropical environments, little is definitively known about their public health risks or about effective market and technology solutions. There is thus a continued need for multidisciplinary and comprehensive research to inform policy and to test potential solutions. Such research can use the tools of risk analysis to better inform policymakers about the scope of public health risks. Given the nature of this food safety risk, solutions need to be evaluated within the context of the entire supply chain. This includes assessing incidence and exposure, evaluating the costs and benefits of control at different intervention points, and testing how interventions could be adopted by different market actors. Such research could identify where market incentives can support improved food safety and better health outcomes for poor consumers.

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HEALTH

AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Aflatoxicosis: Evidence from Kenya

ABIGAEL OBURA

RESEARCH PROGRAM ON
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This brief examines the impact of acute aflatoxicosis on human health in Kenya. Ingestion of large amounts of aflatoxins causes acute toxicity, and, as described below, Kenya is the country with the highest incidence of acute toxicity possibly ever documented. Outbreaks have occurred since the 1980s, with certain areas and age groups being most at risk. Apart from outbreaks, a population survey in Kenya also revealed a high exposure to aflatoxins. This essay demonstrates the cost-effectiveness of better control of aflatoxins and presents promising approaches to surveillance.

Aflatoxicosis outbreaks in Kenya

People in Kenya, especially those in the country's eastern region, have the highest known exposure to aflatoxins as evidenced by the country's history of outbreaks.

Exposure to aflatoxins occurs primarily through ingestion of contaminated food. Ingestion of aflatoxins at very high levels (>6000mg) results in hepatic (liver) failure and death within 1–2 weeks of exposure—a condition known as acute aflatoxicosis (Groopman 1988). Chronic or prolonged low-level aflatoxin consumption increases the risk for liver cancer and is associated with stunting and immunosuppression (brief 4). Aflatoxins have also been implicated in the etiology and pathogenesis of malnutrition diseases as well as in increased neonatal susceptibility to infections and jaundice (Hendrickse 1997).

In 1981, Kenya experienced its first recorded outbreak of aflatoxicosis. At that time, investigators found that after about seven days of consumption of maize grain containing 3.2–12mg/kg of aflatoxin B1, symptoms of abdominal discomfort, anorexia, general malaise, and low-grade fever were exhibited in 20 cases, with patients ranging between 2.5 and 45 years of age. Hepatic failure developed in 12 of the 20 patients, all of whom eventually died between 1 and 12 days following hospital admission.

The most severe aflatoxicosis outbreak ever reported in Kenya occurred in Eastern Province in 2004. This outbreak resulted in 317 cases and claimed 125 lives, a case fatality rate (CFR) of 39 percent. Of the 308 patients for whom age data were available, 68 (22 percent) were <5 years, 90 (29 percent) were 5–14 years, and 150 (49 percent) were >15 years. Children younger than 14 years, representing 51 percent of the child population, were thus presumed to have had a greater predisposition to aflatoxicosis risk. CFR was significantly higher in Makueni district than in Kitui district (CDC 2004). Since 2004, outbreaks among subsistence farmers have recurred annually in Eastern Province.

During the outbreak that occurred in 2010, the levels of aflatoxin-B1 serum found in Kenya were among the highest ever recorded in the world.

Assessment of aflatoxin exposure in populations

Population studies have also assessed aflatoxin prevalence in Kenya outside of outbreaks. In 2011, the US Centers for Disease Control and Prevention (CDC) conducted data analysis on aflatoxin-B1-lysine results from a subset of stored serum samples from the population survey Kenya Aids Indicator Survey (KAIS). The objectives were (1) to characterize aflatoxin exposure across Kenya; (2) to identify populations in Kenya with the highest aflatoxin exposure in order to target future public health interventions; and (3) to compare aflatoxin exposure in Kenya to other countries.

Extensive aflatoxin exposure was found throughout Kenya, with approximately 80 percent of KAIS participants having detectable levels. With the limit of detection (LOD) at 0.02 ng/mL, exposure ranged from <LOD–211 pg/mg albumin, with a median of 1.78 pg/mg albumin. The extent of exposure persisted across the spectrum of age, gender, and socioeconomic status. The exposure varied regionally and was highest among KAIS participants from Eastern Province and lowest in Rift Valley and Nyanza Provinces. These findings are consistent with the geographical distribution of acute outbreaks. Aflatoxin exposure was associated with self-reported adverse health events, and participants who reported recent illness or who recently sought healthcare had higher serum aflatoxin levels than did participants who had not recently reported illness or sought healthcare (CDC 2012).

Current interventions in Kenya

RAPID SCREENING OF GRAINS

Since these outbreaks occurred, the CDC and the Kenya Ministry of Public Health and Sanitation have focused on prevention efforts to reduce aflatoxin contamination in homegrown maize. During the 2006 outbreak investigation, a portable screening tool was adapted for rapid assessment of aflatoxin contamination in maize in the rural village setting. This tool was used to identify households with contaminated maize, a key step in the maize-replacement effort.

A Cost Effectiveness Analysis (CEA) study was carried out in 2006 to compare the benefits of replacing the current system, an aflatoxicosis intervention strategy designed to urgently identify contaminated maize and guide replacement efforts for the aflatoxicosis affected focal area of the Eastern Province. The study determined that society would save US$913.71 per aflatoxicosis case prevented by adopting the proposed new strategy—that of field testing homegrown maize for aflatoxin contamination using the portable rapid screening technology followed by laboratory confirmation (Saha 2009).

SURVEILLANCE

In May–June 2010, a surveillance system that involved the use of moisture meters coupled with rapid test kits and a laboratory confirmation system detected extensive contamination in both Eastern Province and Coastal Province. Visual inspection was most frequently used (95.0 percent), followed by laboratory testing (84.2 percent) and then moisture meter testing (84.2 percent). At the time of the assessment, only 5.3 percent of millers employed

rapid test kits. MoPHS tested aflatoxin levels at large, commercial maize millers throughout Kenya, with the majority indicating that they employ various methods to prevent aflatoxin contamination. The sensitivity of the test strip (Agri-Strip) technology in comparison with the laboratory confirmatory tests was 92 percent (Saha 2009). This meant that 8 percent of the maize tested falsely negative, posing a risk of aflatoxicosis for the population in the affected area. (Saha 2009).

Conclusions, policy choices, and recommendations

The findings from the population survey suggest that there is a large population at risk of aflatoxicosis in Kenya, particularly in Eastern, Coastal, Central, and Nairobi Provinces, with children below 15 years of age being most at risk. An innovative evidence-based strategy is urgently needed in Kenya to decrease aflatoxin exposure. Resources are also needed to quantify the burden of disease and associated health effects as well as to decrease aflatoxin exposure. We propose the following policy recommendations:

As suggested by the CEA data, a substantial potential reduction in aflatoxicosis cases and savings to society can be brought about by adopting the proposed aflatoxicosis intervention program (Saha 2009).

One practical and innovative approach to preventing morbidity from aflatoxin exposure during outbreak times is dietary interventions, such as the use of refined calcium dioctahedral smectite clay, branded under the name NovaSil. NovaSil binds aflatoxins with high affinity and high capacity in the gastrointestinal tract, preventing its bio-availability.

Due to widespread food movement across the region, a regional approach to containing aflatoxin exposure, such as the Partnership for Aflatoxin Control in Africa (PACA), should be the focus.

FOR FURTHER READING

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Aflatoxin Exposure and Chronic Human Diseases: Estimates of Burden of Disease

FELICIA WU

Aflatoxins are a group of about 20 chemically related toxic chemicals produced primarily by the foodborne mold *Aspergillus flavus* and *A. parasiticus*. Aflatoxins contaminate a variety of staple foods including maize, peanuts, and tree nuts; they cause an array of acute and chronic human health disorders. Aflatoxin-contaminated maize was the most likely cause of the 1981 and 2004 acute aflatoxicosis outbreaks in Kenya, which resulted in 317 illnesses and 125 deaths, respectively (Strosnider et al. 2006). Aflatoxin B1, the most toxic of the aflatoxins, is a potent liver carcinogen, causing hepatocellular carcinoma (HCC) in humans and a variety of animal species. There is also an increasing body of evidence that aflatoxins modulate the immune system (Williams et al. 2004; Jiang et al. 2005) and may lead to stunted growth in children (Gong et al. 2002, 2004; Khlangwiset et al. 2011).

This brief summarizes information on the two chronic conditions for which the greatest body of evidence exists for a linkage with aflatoxin exposure: aflatoxin-induced liver cancer and aflatoxin-associated childhood stunting. A brief description is given of studies linking aflatoxins to immune system modulation.

Aflatoxin-induced liver cancer

For decades, it has been known that aflatoxin exposure causes liver cancer in humans and a variety of animal species. The International Agency for Research on Cancer has classified "naturally occurring mixes of aflatoxins" as a Group 1 human carcinogen. Concomitant exposure to aflatoxins and the hepatitis B virus (HBV) is common in developing countries and greatly increases HCC risk (Wu et al. 2013). Individuals with both exposures have multiplicatively greater risk of developing HCC than those exposed to aflatoxins or HBV alone (Groopman et al. 2008). A recent systematic review and meta-analysis determined that the risk of developing liver cancer was over 6 times higher in individuals with detectable aflatoxin biomarkers than in those without, over 11 times higher in individuals with chronic HBV infection than in those without, and over 73 times higher in individuals with both detectable aflatoxin biomarkers and HBV positivity compared with those with neither risk factor—a nearly perfectly multiplicative relationship (Liu et al. 2012).

Two separate analyses have been conducted to estimate the global burden of liver cancer attributable to aflatoxins. Liu and Wu (2010) used a quantitative cancer risk assessment approach, using dose-response data for the relationship between aflatoxins and liver cancer risk in populations of HBV-negative and HBV-positive individuals (JECFA 1998; Henry et al. 1999) and multiplying the corresponding cancer potency factors by aflatoxin exposure data for multiple nations worldwide. In their analysis that included about 5 billion individuals around the world (summing populations across nations for which aflatoxin data were available), they estimated that 25,200–155,000 liver cancer cases annually could be attributed to aflatoxin exposure.

In a follow-up study, Liu et al. (2012) used a different approach to estimate global burden of cancer caused by aflatoxins: estimating population-attributable risk from a systematic review and meta-analysis of 17 epidemiological studies on aflatoxins, HBV, and liver cancer in Africa and Asia. It was estimated that about 23 percent (21–24 percent) of all HCC cases annually maybe attributable to aflatoxins, for a total of up to 172,000 cases per year. Since liver cancer is the third-leading cause of cancer deaths worldwide, and mortality rapidly follows diagnosis, the contribution of aflatoxins to this deadly cancer is significant.

Aflatoxin-associated childhood stunting

Aflatoxin exposure has also been associated with childhood stunting: a condition in which the child's height for his or her age is two standard deviations or more below a World Health Organization (WHO) growth reference. Stunting is important from a public health perspective because it is associated with effects such as increased vulnerability to infectious diseases and cognitive impairments that last well beyond childhood (Ricci et al. 2006).

Khlangwiset et al. (2011) summarize the epidemiological studies that show an association between child growth impairment and aflatoxin exposure (the reader is referred to that study for an in-depth explanation of the available studies). They note that studies in Togo and Benin in West Africa (Gong et al. 2002, 2004) show that height and weight for children's ages are lower in a dose-dependent fashion for higher aflatoxin exposures, and children's growth over eight months was also compromised. Two studies of infants and children in The Gambia (Turner et al. 2003, 2007) show that aflatoxin-albumin adduct (AF-alb) levels in maternal blood, cord blood, infant blood, and children's blood are associated with poorer growth indicators. AF-alb is a biomarker of aflatoxin exposure and biological activation in humans. Aflatoxin levels in household flour in Kenya were associated with wasting in children (Okoth and Ohingo 2004). A Ghanaian study (Shuaib et al. 2010) linked mothers' AF-alb levels with low-weight babies at birth. In Iran, two studies (Sadeghi et al. 2009, Mahdavi et al. 2010) showed that aflatoxin M1 in mothers' breast milk was associated with reduced length and weight of infants at birth. Khlangwiset et al. (2011) also provide discussions of animal studies linking aflatoxin exposure with impaired growth outcomes, and of the importance of aflatoxin-free weaning foods.

At the moment, because of the relatively small number of epidemiological studies undertaken and the limited nature of dose-response relationships, it is not possible to conduct a quantitative risk assessment definitively linking an aflatoxin dose with a particular risk of stunting in a population. Further studies to explore the relationship between aflatoxins and childhood stunting are currently underway. However, while causality has not yet been confirmed, the body of evidence consistently shows an association between aflatoxin exposure and growth impairment in children.

Aflatoxins and immune system modulation in humans

Several studies have examined the link between aflatoxin exposure and markers of immune system modulation in humans. Jiang et al. (2008) found that in HIV+ and HIV- study subjects in Ghana, higher levels of AF-alb were associated with lower levels of CD4+ T regulatory cells and naïve CD4+ T cells, as well as lower B-cells—all cells associated with immune responses. In an earlier Ghanaian study, other types of cells involved in immune response were found to be lower in individuals with higher AF-alb (Jiang et al. 2005). Another study showed that Gambian children with higher levels of AF-alb had lower levels of secretory IgA in their saliva, another immune parameter (Turner et al. 2003). Taken together, these few studies indicate that aflatoxin exposure is associated with changes in markers of human immune systems. How these changes actually correlate to disease outcomes, however, is less clear and was beyond the scope of the studies.

Conclusions

Because aflatoxins are one of the most significant risk factors for liver cancer, one of the deadliest cancers worldwide, controlling its presence in the food supply is critical. It is possibly responsible for up to 172,000 liver cancer cases per year, most of which would result in mortality within three months of diagnosis. Possibly even more critical from a global public health standpoint is the link between aflatoxin exposure and childhood stunting, which can lead to a variety of adverse health conditions that last well beyond childhood. However, at the moment there is insufficient evidence for a quantitative risk assessment to evaluate exact daily doses of aflatoxins that lead to particular levels of risk or adverse health outcomes in children. Additionally, while aflatoxins may lead to immunomodulation, not enough information is currently known about how this leads to particular adverse health outcomes in humans. However, the human health evidence points to aflatoxins' association with multiple adverse effects; hence, it is important to reduce human exposures to aflatoxins in the diet to the extent that feasible methods allow.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Child Stunting and Aflatoxins

JEF L. LEROY

Though having steadily fallen over the last decades, linear growth retardation remains a serious problem, with an estimated 170 million children under five years of age being stunted. (A stunted child is too short for its age, having a height below -2 standard deviations of the World Health Organization's reference height for his or her age and sex.) Growth retardation in young children is associated with delays in cognitive development, lower school achievement, and both lower earnings and a higher probability of non-communicable chronic diseases at adulthood. Key then is to make universal improvements to maternal and child health and nutrition in the first 1,000 days (that is, the period from conception to when the child reaches 24 months of life). Providing multiple micronutrient supplementation during pregnancy, improved complementary feeding, and better hygiene would reduce the prevalence of stunting by only an estimated 20.3 percent (Bhutta et al. 2013). Research efforts are therefore focusing on identifying presently unknown causes of growth retardation.

Evidence from human and animal studies and current knowledge of the biological mechanisms of action of aflatoxins suggest that chronic exposure to aflatoxins might lead to stunted growth. This brief summarizes the existing evidence and reviews possible solutions that could be applied if future research confirms the causal relationship between aflatoxin exposure and growth retardation. It begins with an overview of the criteria that must be met to conclude that aflatoxins cause stunting.

Determining causation

To prove a causal relationship between aflatoxin exposure and stunting, four criteria must be met:

1. Aflatoxin exposure and growth retardation must be associated.

2. Exposure to aflatoxins should precede the growth retardation.

3. The effect needs to be biologically plausible.

4. The effect cannot be due to confounding factors.

In terms of the last criterion, one confounding factor particularly challenging to rule out is the socioeconomic status (SES) of the household. Children in poorer households are often fed diets deficient in micro- or macronutrients and suffer from more frequent infections, both of which contribute to growth retardation. If these factors are associated with aflatoxin exposure and are not adequately controlled for in the analysis, the magnitude of the aflatoxin-growth association will be overestimated.

Evidence in humans

While only a small number of observational studies have been carried out, the majority has found strong associations between aflatoxin exposure and stunted fetal, infant, and child growth, thus providing evidence for the first criterion for causality. Some studies have shown the temporal relationship as per the second criterion. Even though the effect is biologically plausible (criterion 3, see "biological mechanisms" below), the possibility that the association is (at least partially) due to confounding factors, as per the fourth criterion, has not been adequately addressed. Findings from published studies addressing at least two causality criteria are summarized below.

In Ghana, women exhibiting high serum aflatoxin levels at delivery—a marker of having been exposed over the last two to three months—were more likely to have a low-birthweight baby; no association was found with having a baby small for gestational age or with preterm birth (Shuaib et al. 2010). The analysis controlled for SES, but no details were provided on how this was done, making it difficult to evaluate if confounding was adequately controlled for.

A study in The Gambia showed that exposure occurred before the linear growth retardation: serum aflatoxin levels in pregnant women and in infants at 16 weeks of age were strong predictors of linear growth during the first year of life. Cord blood levels were not associated with birth weight or length (Turner et al. 2007). The Gambia study did not control for SES.

A study in Benin and Togo found that the serum aflatoxin level was 30–40 percent higher in stunted children one to five years of age than in non-stunted children, after controlling for confounders including socioeconomic status, child age, and sex. Details on the measure of SES were not provided by the authors (Gong et al. 2002). Finally, the same authors studied the linear growth of 200 Togolese children 16 to 37 months of age over an 8-month period. Children in the highest serum aflatoxin albumin quartile grew 1.7 cm less than children in the lowest quartile, after controlling for age, sex, baseline height, and SES. As in the previous study, the authors did not provide details on the SES measure used (Gong et al. 2004).

Although the findings are generally consistent, none of the studies adequately controlled for factors that could potentially confound the association between aflatoxins and child growth—such as household socioeconomic status, child dietary intake, and child morbidity. Another possible confounding factor is child age. Because growth retardation is a cumulative process, stunting increases with age. Exposure to aflatoxins through the diet is also strongly associated with age; thus if age is not properly controlled for in the analysis, the degree to which aflatoxins and child growth are associated will again be overestimated.

Evidence in animals

A large number of studies conducted with different animal species consistently found that experimental exposure to aflatoxins led to reduced weight gain (brief 5). The evidence suggests that this is at least partially due to reduced feed intake and less-efficient feed conversion. A small number of studies further suggest that in utero exposure negatively affected fetal growth (Khlangwiset, Shephard, and Wu 2011). An important remaining question is to what extent

the weight-gain findings in animals are applicable to linear growth retardation in children.

Biological mechanisms

The known biological mechanisms of aflatoxins make an impact on linear growth plausible. Human and animal studies indicate that aflatoxins cause immunosuppression (which in turn can lead to repeated infections and, consequently, growth retardation in young children), impairs protein synthesis, and changes the hepatic metabolism of micronutrients (Khlangwiset, Shephard, and Wu 2011). It has also been suggested that aflatoxins together with fumonisin and desoxynyvalenol (two other mycotoxins commonly found in maize and groundnuts) mediate intestinal damage similar to environmental enteropathy (Smith, Stoltzfus, and Prendergast 2012). Environmental enteropathy is characterized by increased gut permeability, which is a disruption of the tight junctions that allow the membranes of intestinal cells lining the gut to form an impermeable barrier, and villous atrophy, which is erosion of the microscopic, finger-like tentacles that line the wall of the small intestine, reducing the surface area by leaving a virtually flat surface. This condition leads to chronic systemic immune activation and malabsorption of nutrients, which in turn may lead to growth retardation.

Solutions

Human exposure to aflatoxins can be reduced by improved cropping, harvesting, and storage practices and by switching to crops or foods less prone to aflatoxin contamination. The adverse effect of aflatoxins in the body can be mitigated through food additives that bind aflatoxins in the gut and through chemopreventive agents that reduce the toxicity of aflatoxins.

Food additives operate as "enterosorbents" that trap aflatoxins in the gastrointestinal (GI) tract. A well-studied example is calcium montmorillonite clay (marketed as NovaSil), which binds aflatoxins in the GI tract and consequently reduces its bioavailability. A clinical trial in which Ghanaian adults were given a placebo, either a 1.5- or 3-gram clay capsule, daily for three months led to a net reduction in serum aflatoxin levels of 21 percent and 24 percent, respectively, in the low- and high-dose groups (Wang et al. 2008). Whether this reduction is sufficient to result in meaningful improvements in linear growth (should the association between aflatoxin exposure and growth be found to be causal) is unknown. An important concern is the clay's capacity to bind micronutrients, which might reduce their bioavailability in the gut and hence lead to or aggravate micronutrient deficiencies. The treatment in the Ghana study was not associated with reductions in serum micronutrient levels (Afriyie-Gyawu et al. 2008), but the intervention period was relatively short, which might have allowed homeostatic mechanisms to maintain serum micronutrient levels. NovaSil has not been tested in pregnant women and young children who are particularly prone to micronutrient deficiencies.

Chemopreventive agents such as chlorophyllin (a derivate of chlorophyll) and oltipraz (an antischistosomal drug) have been found to intervene in the biochemical pathway linking liver cancer to aflatoxin exposure. To what extent these chemopreventive agents might be relevant in mitigating the effect of aflatoxins on linear growth retardation is not known.

An important consideration when promoting the use of enterosorbents or chemopreventive agents at scale is to make sure that they are not interpreted as a substitute for good crop husbandry and that they do not unintentionally encourage the use of foods not fit for human consumption.

Conclusion

The current evidence suggests that aflatoxins are a likely cause of linear growth retardation in children. Controlled intervention studies are needed, however, to unambiguously establish the causal relationship and to quantify to what extent the current level of aflatoxin exposure contributes to the global burden of stunting. These studies also need to evaluate if reducing exposure remedies the functional correlates of stunting (such as delays in cognitive development and future economic productivity). Given the known carcinogenicity and acute toxicity of aflatoxins, preventive measures aimed at lowering aflatoxin exposure of children in the womb and of young children should be taken irrespective of the findings of these studies.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Animals and Aflatoxins

DELIA GRACE

Aflatoxicosis affects both people and animals. In fact, it was first discovered in 1961 when more than 100,000 turkeys and other farm animals died from a mysterious disease in the United Kingdom. The cause was found to be aflatoxins in the feed.

Sources of mycotoxins in the diet of livestock

Aflatoxins occur in many animal feed concentrates including cereal grains, soybean products, oil cakes (from groundnuts, cottonseed, sunflower, palm, and copra), and fishmeal. Brewers grains (a byproduct from the production of cereal-based alcoholic drinks) can have high levels. Pasture, hay, straw, and silage are more prone to contamination with other types of mycotoxins that will not be considered in this brief.

In general, livestock in intensive systems are at higher risk of dietary exposure than animals in extensive systems. Worldwide, a high and increasing proportion of dairy cattle, poultry, and swine are kept in intensive systems; aflatoxins are thus likely to be an increasing problem.

In countries where regulation for aflatoxins in animal feeds exists, the total permissible aflatoxin levels in animal feeds range from 0 to 50 parts per billion (ppb) with an average of 20 ppb (FAO 2004). (Standards for individual feed components may be higher.) Studies find that in developing countries around 25–50 percent of samples have levels above 20 ppb and contamination of 100 to 1,000 ppb are not uncommon (Binder et al. 2007, Rodrigues and Naehrer 2012).

Susceptibility of livestock

The effects of aflatoxins depend on various factors: genetic (species and breed strain), physiological (age, nutrition, and exercise) and environmental (climatic and husbandry). Fetuses are very susceptible to even low levels, and young and fast-growing animals are more affected than adults. Males are more susceptible than females. There is considerable variation by species. A list of animals in order of decreasing sensitivity runs rabbits>ducks>turkeys>chicken>fish>swine>cattle>sheep. Rats are susceptible and mice are resistant. Ruminants, if old enough to have a functioning rumen, are relatively resistant.

Impacts of aflatoxins on animal health and production

Very high levels of aflatoxins cause acute toxicosis and death in livestock and fish. Chronic consumption of lower levels can cause liver damage, gastrointestinal dysfunction, decreased appetite, decreased reproductive function, decreased growth, and decreased production. In addition, immune-suppression results in greater susceptibility to other diseases. Adverse impacts are more severe when there is co-contamination with other mycotoxins.

Impacts of aflatoxins on the livestock sector

Chronic aflatoxicosis probably has greater economic impacts than acute disease. Numerous studies show a worsening in food conversion ratios, a decrease in average daily gain, and a decrease in body weight for animals experimentally fed aflatoxins (Khlangwiset et al. 2011). Additional losses occur in the livestock sector if grain and feed do not meet standards for animal feed. Moreover, the nutritive value of grains and cereals is reduced by contamination with the mold that produces aflatoxins. Economic loss also occurs if livestock and fish products do not comply with the standards for aflatoxins in human foods.

Impacts of aflatoxins in animal-source foods

Aflatoxin B1 is metabolized to aflatoxin M1 (AFM1) in the liver and excreted in the milk of dairy cows. Because aflatoxins are degraded by flora in the cow's rumen, the amount of AFM1 excreted in milk is only around 1–7 percent of the total amount of aflatoxin B1 ingested. Higher-yielding animals consuming large amounts of concentrates typically have higher levels in their milk. The presence of mastitis may increase the secretion of aflatoxins.

While levels of mycotoxins in cereals may reach thousands of ppb, levels in milk are generally less than 100 ppb. However, aflatoxins in milk are of concern because milk consumption is often higher among infants and children, who are likely to be more vulnerable. Accordingly, many countries set a lower threshold for aflatoxins in milk. AFM1 ranges are between 0.02 and 5 ppb, with 0.05 ppb the most common (Mohammadi 2011).

Aflatoxin levels are around three times higher in soft cheese and five times higher in hard cheese than the milk of origin. But because cheese is more concentrated, using aflatoxin-contaminated milk for cheese production is risk mitigating (for example, if ten liters of milk makes one kilogram of cheese and aflatoxins are five times higher in hard cheese, then the exposure of humans from consuming one kilogram of cheese is half as much as the exposure from consuming ten liters of milk). Aflatoxins may also be present in yogurt and other dairy products. Recent studies have suggested that a related toxin called aflatoxicol may also be excreted in significant amounts in milk, a subject that requires further research.

Trace levels of aflatoxins and their metabolites may also carry over into the edible tissue of meat-producing animals. Poultry feed contaminated at the level of 3,000 ppb may result in levels of 3 ppb in poultry meat. Aflatoxins may be carried over from feed to eggs at ratios ranging from 5,000–125,000 to 1 (Zaghini et al. 2005). These transfer rates are much lower than for milk, and surveys in developing countries typically find levels of less than 10 ppb in meat and offal. Given the relatively low quantities of animal-source food consumed, this is not likely to present a major contribution to overall consumption of aflatoxins in the diet. However, processed fish has been found to be significantly contaminated with aflatoxins (Adebayo-Tayo et al. 2008) and may represent a risk. Mold-fermented foods such as fermented meat may also contain aflatoxins, but there is very little information regarding the level of aflatoxins in traditionally processed foods.

Control of aflatoxins in animal feeds

The general methods of aflatoxin management (plant breeding, biocontrol, pre- and postharvest practices, and nutritional strategies) are discussed in other briefs and here we focus on methods primarily applicable to animal feeds.

Binders: The addition of binding agents such as zeolite clays and aluminosilicates is effective in reducing toxicity. When binding agents are included in feed at a ratio of 200 parts feed to 1 part binding agent, they reduce most of the harmful effects of aflatoxins at levels of 1,000 ppb for pigs and 7,000 ppb for poultry. The cost is around $0.25 per ton of feed.

Blending: One method of reducing moderate levels of aflatoxin contamination is to blend contaminated grain with clean grain (blending one kilograms of grain with aflatoxin contamination five times above the limit with nine kilograms of grain exhibiting no detectable aflatoxins would result in ten kilograms of grain with aflatoxins at 50 percent of the permissible amount).

Decontamination: Ammoniation is a safe and effective way to decontaminate aflatoxins; it has been used with success in many countries, yet is not legal in others. The average costs are 5–20 percent of the value of the commodity. Nixtamilization, the traditional alkaline treatment of maize in Latin America, can reduce toxicity and has potential for wider applications. Other chemical and biological agents have been effective in experiments but are not yet commercially developed.

Feeding aflatoxin-contaminated cereals to livestock

Being fed to appropriate livestock may be the best use of most aflatoxin-contaminated corn. Although there are no currently established levels at which aflatoxins can be guaranteed safe for livestock, many animals, especially mature animals, can tolerate aflatoxins well. Many experimental studies do not show any statistically significant effects from low levels of aflatoxins, and there is a consistent pattern of fewer effects from aflatoxins at lower doses and increasing effects at higher doses. Moreover, there appear to be no scientific papers describing any toxic effects of mycotoxins when present at very low levels (AFSSA et al. 2009). Growth depression associated with aflatoxins is affected by factors other than species and age; for example, rats on high-protein diets with 500 ppb aflatoxins exhibited better growth than rats on low-protein diets without aflatoxins. Exercise and absence of other mycotoxins from the diet are also protective. Depending on species,

TABLE 1	Guidelines for acceptable aflatoxin levels in feed	
Animal	Feed	Aflatoxin level
Finishing beef cattle	Corn and peanut product	300 ppb
Beef cattle, swine, or poultry	Cottonseed meal	300 ppb
Finishing swine of 100 lbs. or greater	Corn and peanut products	200 ppb
Breeding beef cattle, breeding swine, or mature poultry	Corn and peanut products	100 ppb

Source: FDA. 1994. CPG *Sec. 683.100 Action Levels for Aflatoxins in Animal Feeds*, www.fda.gov/ICECI/ComplianceManuals/CompliancePolicyGuidanceManual/ucm074703.htm.

age, and length of trial, experiments have found no effects from aflatoxins at levels from 200 to 5,000 ppb and significant effects at levels from 20 to 10,000 ppb. Table 1 demonstrates the appropriate levels of contaminated foods that may be fed to livestock.

Conclusion

Aflatoxins, like other mycotoxins, can seriously reduce livestock productivity. In poor countries, livestock are often fed highly contaminated grains considered unfit for human consumption and are thus at risk of acute toxicosis. Chronic aflatoxicosis is probably a major cause of economic loss, especially for farmers raising pigs and poultry in intensifying systems. Aflatoxins can transfer from feed to animal-source products, but there is minimal information about or testing of these products in developing countries. Risks are likely to be highest in the case of milk, processed fish, and indigenous fermented meat, fish, and dairy products.

Important information gaps requiring urgent research include the prevalence of aflatoxins in animal feeds, serum, and animal-source foods; the current economic impacts of aflatoxins in animal feed in developing countries; the most cost-effective means of managing aflatoxins in animal feed; and the impacts of aflatoxins in animal source food on human health especially in high-risk communities (such as those with very high consumption or risk-increasing practices such as smoking fish).

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MARKETS

AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Managing Mycotoxin Risks in the Food Industry: The Global Food Security Link

DAVID CREAN

FOCUS 20 • BRIEF 6 • NOVEMBER 2013

In order to bring about true food security, the world must achieve more than the availability of sufficient amounts of affordable and nutritious foodstuffs. It must also ensure that foods are safe. To do so requires going beyond in-factory quality management processes and to instead cover the entire supply chain from "farm to fork." Food safety incidents involving raw materials can be traced back through all key points of the food production system, including growing, harvesting, storage, manufacture, and distribution. Of these incidents, mycotoxin contamination—of which aflatoxin is the predominant concern—represents the largest proportion of raw material–related food safety issues. This paper will discuss the approach that Mars Incorporated, one of the world's largest food manufacturers, takes to managing mycotoxin risks throughout its supply chains. It closes by recommending actions to better manage the global challenges that mycotoxins present.
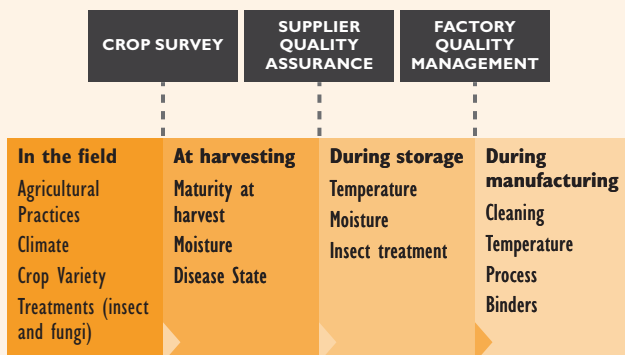
Mars Incorporated's material quality management process

The need for an integrated, holistic approach to reducing the risk of mycotoxins is clear. The approach adopted by Mars Incorporated, as summarized in Figure 1, includes three essential risk-based steps—crop survey, supplier quality assurance, and factory quality management—plus procedures for strategic sampling, testing, and analysis. Each of these rigorous, science-based steps must be applied according to the particular context, be it climate, growing region, disease, pest infestations, seed selection, and adherence (or not) to good agricultural practices (GAP).

STEP 1 AGRONOMIC DATA AND CROP SURVEYS: FOREWARNED IS FOREARMED

Mycotoxin management starts with the collection of crop-specific agronomic data and regional crop surveillance information for each new crop year. This data will provide information on the potential mycotoxin distribution, which can be used to perform quantitative risk assessments to direct purchasing strategies, supplier quality-assurance requirements, and sampling/testing protocols (such as mycotoxin types and levels, risk areas, and crops affected).

STEP 2 SUPPLIER QUALITY ASSURANCE: THE FIRST INTERVENTION

Raw material suppliers must understand the potential mycotoxin risks associated with materials they purchase, store, and later sell for feeds or further processing. This includes a solid understanding of regulatory requirements and customer food safety standards to ensure appropriate levels of monitoring, correct storage, and adequate control procedures. A clear specification is essential. Supplier quality assurance works with the raw material supply base to audit and verify the effectiveness of mycotoxin control programs to ensure that potential food safety risks are appropriately managed before the materials are shipped and subsequently received at production facilities. All of these activities should be audited to ensure compliance.

STEP 3 FACTORY GATE AND FINISHED PRODUCT VERIFICATION: THE LAST OPPORTUNITY FOR FORWARD CONTROL

Mycotoxin risk management at the factory level starts with inbound inspection, sampling, and testing as a means of verifying that deliveries meet quality and food safety requirements. This is also risk-based. Information and data from earlier steps in the process are used to direct the extent of sampling and testing done at the factory gate (for example having all inbound trucks or a lesser number evaluated based on the crop risk evaluation). A point of caution is that solely using factory gate testing to accept or reject inbound loads will fail without an understanding of crop and supplier risks. Finished product verification testing must also be risk based, whereby finished products manufactured from higher-risk materials may be evaluated lot for lot, placed on positive release, and subjected to final verification testing prior to market release. Conversely, finished products manufactured from lower-risk materials may not require positive release and can be evaluated at reduced frequency to verify effectiveness of up-front controls.

SAMPLING, TESTING, AND DATA ANALYSIS

Because mycotoxins are not evenly distributed, the sampling strategy needs to be risk based and designed to increase the chance of detecting "mycotoxin pockets" in or across inbound loads. The sample-preparation steps must also be validated to ensure not only that they are compatible with the mycotoxin quantification method employed (HPLC or ELISA) but also that the results are accurate and reproducible within statistical limits.

The accuracy of sample preparation and testing protocols must be routinely verified by a recognized proficiency authority (such as the Food Analysis Performance Scheme or FAPAS) as a means of

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FIGURE 1 Material quality management process

CROP SURVEY	SUPPLIER QUALITY ASSURANCE	FACTORY QUALITY MANAGEMENT

In the field	At harvesting	During storage	During manufacturing
Agricultural Practices	Maturity at harvest	Temperature	Cleaning
Climate	Moisture	Moisture	Temperature
Crop Variety	Disease State	Insect treatment	Process
Treatments (insect and fungi)			Binders

Source: Author, 2013.

benchmarking results against other testing laboratories with known mycotoxin types and concentrations. Since mycotoxins are not evenly distributed, the probability of detecting pockets of elevated concentrations in a single truck is low.

Sampling should be performed using manual or automated probes that are inserted at ten points. Each probe is inserted from the top to the bottom of the received load and collected as a continuous core of material. Mycotoxin quantification is performed by analyzing a composite of the ten probes taken from across the received load (per USDA GIPSA recommendations).

As such, each of the components explained above are part of a comprehensive quality management process, which at Mars is structured as summarized in Figure 2.

To maximize the value of each test, it is important to trend mycotoxin test data for each raw material/supplier combination across a rolling 30-lot sample size. This helps to normalize the variance within a single truckload, allowing for a better understanding of material risks and comparison between suppliers of the same raw material. Through both leverage of large volumes of data and collaboration with key partners (such as IBM), we have been able to validate and optimize, through statistical analysis, best practices for sampling and mitigation mechanisms. (A list of supporting references can be found in the appendix section of this publication.)
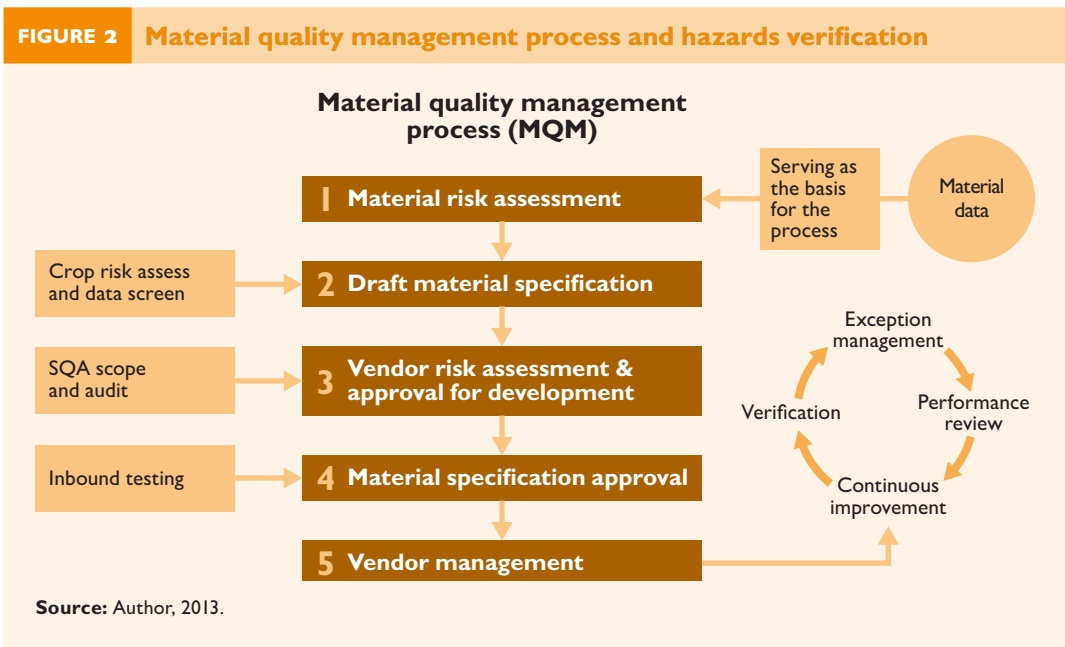
Conclusions and recommendations

Food safety is a high-level concern for food security. Of the many food safety issues, mycotoxins present a specific and significant challenge to global food security, especially for key food crops eaten by hundreds of millions of malnourished people, particularly those in Africa. The consequences of mycotoxin contamination impact the ability of food companies to use local materials, but overcoming this barrier presents an opportunity for all. We will only be able to drive reliability of supply chains if all manufacturers operate to the same standards and risk management assessments. Mars Incorporated believes that many elements of food safety are pre-competitive, and every day the company generates thousands of data points that, aggregated with other industry data, have the potential to strengthen operating practices across food value chains. In order to prevent material rejected by one manufacturer from re-entering another's supply chain, we must create a standardized approach to mycotoxins and ultimately to food safety management.

The material quality management process described in this brief is an example of a well-integrated, holistic process that can significantly better manage the challenges and reduce the barriers and consequences that mycotoxins create. Additional policy recommendations could build the needed framework to significantly increase the value of this process and increase the likelihood of reducing the risk of mycotoxins through multidisciplinary solutions.

Obtaining acceptable improvements will require the coordination of a comprehensive and complex network of actions by a wide range of appropriate players from smallholder farmers to multinational food companies and regulators, supported by a "food safety" scientific and policy research agenda promoted by robust food safety management initiatives. Self-regulation—managed through a real-time, open source platform to be accessed by small, medium, and large manufacturers—seems the most reliable and robust way to ensure that the bar for food safety manufacturing practices is raised across the globe. The pressing need to improve the safety of our food supply is clear, and we should further understand how we can make this a pre-competitive space where experience, knowledge, and research should all be fostered for the common goal of achieving a safe and secure food supply for the benefit of farmers and consumers around the world.

FIGURE 2 Material quality management process and hazards verification

Material quality management process (MQM)

Serving as the basis for the process — Material data

1 Material risk assessment

Crop risk assess and data screen → 2 Draft material specification

SQA scope and audit → 3 Vendor risk assessment & approval for development

Inbound testing → 4 Material specification approval

5 Vendor management

Exception management → Performance review → Continuous improvement → Verification

Source: Author, 2013.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Farmer Perceptions of Aflatoxins: Implications for Intervention in Kenya

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RESEARCH PROGRAM ON
Agriculture for Nutrition and Health
CGIAR
LED BY IFPRI

2020 VISION
FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

In 2004, the Kenyan Ministry of Health invited the US Centers for Disease Control and Prevention and the World Health Organization to investigate cases of high-fatality jaundice in Eastern Province. Testing of the maize food supply found high levels of aflatoxins, suggesting that the 125 lives lost and 317 cases reported were a result of aflatoxin poisoning.

Work began in 2008 to examine the situation on the ground and to develop technologies to reduce the risk posed by aflatoxins to both humans and animals. Surveys were carried out by AflaSTOP, a project—co-funded by USAID and the Bill & Melinda Gates Foundation and implemented by the Meridian Institute in partnership with ACDI/VOCA and Agribusiness Systems International—designed to examine storage and drying technologies that prevent further aflatoxin contamination. These surveys found that while most Kenyan farmers are aware of the dangers of aflatoxins and have ideas about preventing contamination, they still possess misinformation about the ways in which the fungus can be detected, the importance of testing, and what to do with grain when there is a problem. Furthermore, there is currently no premium offered to farmers in the marketplace for "clean" or "aflatoxin-free" maize; there is no simple, cheap testing method; and consumers lack awareness about the dangers of aflatoxins.

Survey background

In early 2012, the International Food Policy Research Institute (IFPRI), the University of Nairobi, and AflaSTOP conducted a storage survey among 50 farmers in Eastern Province's Meru and Makueni counties. Later that year, AflaSTOP carried out a similar survey of 50 farmers in Trans Nzoia county, Rift Valley Province (North Rift). These two provinces were surveyed because they represent very different ecological environments, with Eastern Province being more drought prone, having a higher incidence of aflatoxins, and containing a larger segment of poor farmers. In North Rift, farmers are generally wealthier, less affected by extremes in weather conditions, and experience a lower incidence of aflatoxins. This brief presents the findings of these surveys.

Aflatoxin awareness and understanding

Given that the severe outbreak of aflatoxicosis in 2004 and a second outbreak in 2010 were centered in Eastern province, it is not surprising that 93 percent of farmers surveyed in Meru and 100 percent in Makueni had heard of aflatoxins, while only 48 percent of farmers in North Rift were familiar with the term. Exactly half of the farmers in North Rift who had heard of aflatoxins thought that it was a "poison found in spoiled maize." In comparison, 43 percent of farmers in Meru felt that it was caused by wet or rotten maize. Twenty percent of farmers in Makueni agreed with 25 percent of their counterparts in North Rift that it was a "mold that attacks maize." These insights reveal a limited understanding of what aflatoxins are and how they are formed.

When asked specifically about the causes of aflatoxins, 65–71 percent of farmers in Makueni and Meru and 54 percent of North Rift farmers identified poorly dried and or wet maize as the cause, followed by poor storage (11 percent in Meru, 15 percent in Makueni, and 21 percent in North Rift). Twenty percent of Makueni farmers identified drying maize on the ground as a source of contamination, while 11 percent of Meru farmers identified rain on the grain as a problem. Interestingly, in North Rift, where awareness is lowest, there is a perception among 17 percent of those surveyed that shelling wet maize will cause aflatoxin contamination. Farmers, particularly in Eastern Kenya, clearly have some recognition of the connection between postharvest handling and aflatoxin contamination. In terms of threats to human health, a large percentage of farmers in all provinces agreed that aflatoxins cause death, followed by about 25 percent who felt that it causes stomach problems.

Despite some level of awareness, 57 percent of farmers in Meru stated that they did not know how to tell if maize was affected by aflatoxins, while 60 percent in Makueni and 75 percent in North Rift answered that they could tell, identifying the "discoloration of the maize" as a key tell-tale sign—even though the presence of aflatoxins cannot be detected visually. Moldiness and wetness were other indicators listed by all farmers. In Eastern Kenya, 20 percent of farmers also identified finding insects in their maize as an indicator of aflatoxin contamination. Farmers reported receiving their information about aflatoxins from extension workers and media such as radio, TV, and newspapers. Extension officers played a much more prominent role in Makueni, with 60 percent of farmers indicating that they heard about aflatoxins from this source, while 67 percent of those in North Rift and 50 percent in Meru reported receiving their information from the media.

Prevention of aflatoxins and mold

Almost all farmers in North Rift said that they knew how to prevent aflatoxins—by "drying maize properly" and "storing it properly" on a raised platform in a dry store. The majority of farmers in Eastern answered similarly. Of the farmers in Meru, 18 percent claimed not to know any way to prevent aflatoxins—compared to zero of their counterparts in Makueni. That said, nearly all farmers surveyed were afraid to allow their own families to consume wet or discolored maize, with the majority instead feeding it to their livestock. In terms of family health problems, the majority of farmers did not believe that maize consumption was a culprit.

With regard to mold, about three quarters of farmers from North Rift and almost all farmers in Eastern Province took precautions to prevent it from affecting their maize stores by drying their grain before putting it into storage either as cobs or grain. However, within the first month of storage, 54 percent of North Rift, 50 percent of Meru, and 20 percent of Makueni farmers had mold problems, which raises questions about whether their grain is

actually dry enough for storage. Once mold was detected, farmers dealt with the problem in various ways. Airing the maize was a dominant method in North Rift, compared to Eastern Province where there was not a dominant method. All farmers indicated that they used the damaged crop for animal feed, salvaged what remained for consumption or sale, changed the storage containers used, or aired the maize.

Willingness to pay for solutions

A second aflatoxin-control effort was Aflacontrol. This project was implemented by IFPRI in partnership with the International Maize and Wheat Improvement Center (CIMMYT), the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), ACDI/VOCA, University of Pittsburgh, the Institute d'Economie Rurale (IER), and Kenya Agricultural Research Institute (KARI), and funded by the Bill & Melinda Gates Foundation. Aflacontrol found that consumers were willing to pay a premium of 20–30 Kenyan shillings (KES)—or US$0.25–0.37—per 2kg bag for clean maize over poor quality product (presence of 5 percent moldy grains), and an additional premium of 10–15KES ($0.13 –0.19) /2kg bag for maize that was clean and tested clear of aflatoxins. This willingness was positively influenced by consumer income and negatively by consumer age. The Aflacontrol project concluded that in order to intervene successfully there needed to be a low-cost product differentiation in the market that was also credible with consumers.

The subsequent work of the AflaSTOP project found that 28 percent of farmers in North Rift and about half of the farmers in Eastern Province claimed to be willing to pay for a drying machine or service that cost up to 225KES/90kg bag ($29.41/mt), the higher proportion in Eastern Province perhaps reflecting a higher awareness of the dangers of aflatoxins or difficulties faced when drying wet grains at harvest (current drying costs are estimated at $42/mt).

Implications for interventions

Farmers have demonstrated a willingness to pay for services that improve postharvest handling, but there is limited investment in developing such services that would have the added benefit of helping to reduce aflatoxin levels. Data shows that consumers are willing to pay for food that will not adversely affect the health of their families, but there is no credible method of ensuring that the food they buy is safe.

At the moment there is no clear consumer demand for aflatoxin-free maize. Incentives to change behavior, therefore, need to be centered around household consumption given that farmers consume large quantities of the maize they produce, store their household stocks, and sell this maize into the market. Considering the work of Aflacontrol and AflaSTOP and the respective levels of farmer awareness on the ground, it is thus clear that any intervention to reduce aflatoxin contamination and the consumption of infected grain will require the following:

- Sustained information campaign targeted at farmers via radio and other spoken media

- A comprehensive marketing campaign heightening consumer awareness and the demand for tested and labeled grain

- The establishment of a credible and low-cost system for testing and labeling grain

- Technology effectively commercialized by the private sector that addresses the harvesting constraints of smallholder farming

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Market-led Aflatoxin Interventions: Smallholder Groundnut Value Chains in Malawi

ANDREW EMMOTT

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In the 1960s, Africa south of the Sahara controlled 90 percent of the international groundnut market, valued in today's money at US$220 million annually. Although the market has since rocketed to $1.2 billion, Africa's share has plummeted to just 5 percent. A key factor in this substantial decline in earnings has been the strict food import regulations on safe levels of aflatoxins imposed by highly regulated Western markets.

The World Bank estimates that the EU's tightening of the Maximum Allowable Levels (MALs) of aflatoxins to four parts per billion cost African countries $670 million in annual export losses of cereals, dried fruits, and nuts. Underinvestment in infrastructure and systems, coupled with a lack of incentives and information, has made it difficult for smallholders in Africa to respond to these market demands for better aflatoxin controls. China, Argentina, and the United States have emerged as global leaders by continuously investing and improving aflatoxin management practices.

Aflatoxins are more than a barrier to trade for smallholders—they are a serious risk to public health. The US Centers for Disease Control and Prevention estimate that 4.5 billion people are chronically exposed to the toxin through the consumption of staple foods, leading to cancer and childhood stunting as well as contributing to immune disorders. Over the past decade, efforts to tackle aflatoxin contamination in Africa have focused on practices within formal export value chains. In countries like Malawi, however, 60 percent of groundnuts are sold on poorly regulated local or regional markets, exposing populations to high levels of the toxin and undermining food security and nutrition interventions. Improvements to processing, storage, and trading practices are therefore urgently needed along the smallholder groundnut supply chain in order to sustainably address the economic and health impacts of aflatoxins.

Targeting critical control points with appropriate interventions

Although aflatoxin contamination points have been identified along the supply chain, the key challenge remains the complex set of factors driving inappropriate farming, postharvest, and consumption practices. Any attempts to change practices need interventions that will be accepted, adopted, and maintained by smallholder farmers. A good example is the case of African groundnut farmers who have traditionally shelled groundnuts by hand. This painful and time-consuming task is mostly done by women, who spend an estimated 4 billion hours hand shelling each year. The shells are often softened in water to ease the process, and the shelled nuts are subsequently kept in unsuitable storage conditions on-farm until the crop is taken to market. Moisture introduced during shelling promotes fungal growth on the nuts, and the long storage times in poor conditions further increase the risk of aflatoxin contamination. Hand-operated mechanical shellers make the shelling process ten times faster and remove the need to wet the groundnuts, significantly reducing contamination at the farm level.

Basic equipment, such as mechanical hand shellers, can often be too expensive for individual smallholders to purchase. Twin is working with two partners—Exagris, the UK-based agri-business, and National Smallholder's Farmers Association of Malawi (NASFAM)—to develop sustainable business models for the distribution and maintenance of the technology at an affordable price. Local entrepreneurs could be engaged to establish rental services for equipment with a maintenance contract, or farming organizations could invest in equipment to help their members improve both their labor efficiency and practices for the management and control of aflatoxins. This is but one example of a simple, cost-effective intervention that can significantly reduce contamination at a key entry point, thereby resulting in more reliable access to international markets as well as reducing the levels of aflatoxins entering local food systems via informal markets. To ensure optimal impact, the introduction of new technology should be accompanied by systematic changes, such as buying and storing nuts in shell and improving storage practices.

Developing products and systems that pull aflatoxins out of human food chains

While interventions along the value chain can greatly reduce levels of aflatoxins in formal and informal human food chains, evidence from more regulated value chains suggests some level of contamination may still occur. For example, in 2012 the US maize crop had higher than usual levels of aflatoxin contamination as a result of unusually hot and dry growing conditions. Similar problems occurred in in Germany and Holland in 2013 when milk was found to be contaminated with M1 aflatoxin. The incident, traced to maize grown within the EU, was detected and managed by following standard EU testing procedures. Even if developing countries improve aflatoxin management along their supply chains, the limited testing, consumer awareness, and market regulation in these countries is likely to result in exposure to unsafe levels of aflatoxins, especially among the food insecure.

In order to reduce risk for vulnerable communities in the absence of market regulation, there is a need for innovative, safe, and economically viable uses for contaminated products to be developed in combination with programs to raise awareness. In the case of contaminated groundnuts, the production of groundnut oil is an example of the potential to convert high-risk stock into a safe value-added product. Groundnut oil has been identified by Malawi's National Export Strategy as a key regional export and import-substitution product in the country's effort to diversify from tobacco dependency. Once contaminated nuts have been pressed into oil, a simple filtration process that removes protein can significantly reduce aflatoxins to safe levels. This results in both a nutritious product and access to value-added markets for crops

that would otherwise be considered waste—or irresponsibly dumped on local markets. Groundnut oil is a high-value product in demand both locally and internationally, with global production doubling over the past 30 years. Pilot crushing programs and market research are underway in Malawi to better assess the profitability of large-scale pressing facilities.

The waste product of pressing groundnuts for oil, known as press cake, can be treated with clay for safe use in animal feed. The contaminated press cake is added to normal feed and mixed with clay, which binds with the toxin while the food is digested by livestock. Clay feed additives are already used extensively in the United States and the EU as anti-caking agents to improve the physical properties of feed. That these additives increase health benefits to the animals by binding aflatoxins further strengthens the economic case for the inclusion of the clay. Establishing alternative uses for aflatoxin-contaminated groundnuts reduces waste and prevents dangerous products from entering the food systems of poor and marginalized people. It also provides both access to new markets and more consistent access to value-added international markets, thereby increasing farmer incomes.

Creating incentives to improve the processes for aflatoxin management and control

Currently, there is limited quality grading or price differential for groundnuts sold on Malawi's markets. With little price incentive to produce higher quality products, smallholders consequently choose not to invest their time, energy, and resources in producing quality nuts. Most smallholders also have low awareness levels of the health implications of aflatoxins. Higher awareness may act as an incentive for farmers to change their practices to protect their families and communities. However, even farmers aware of the risks do not have access to affordable, rapid aflatoxin testing equipment to assess quality at either the farm gate or buying station. Therefore, alternative indicators can be used to assess the risk of aflatoxin exposure, such as quality of grading and the presence of moldy nuts.

One viable alternative to testing for aflatoxins is testing moisture content using low-cost portable meters. Twin and NASFAM are piloting a buying system in which smallholders receive a bonus for selling groundnuts with low moisture content. Financial incentives that encourage good drying practices can significantly reduce aflatoxin contamination because fungal growth on groundnuts stops when the moisture content falls below 7 percent. The costs of the bonus scheme are offset by weight savings made at the point of purchase and in transport costs because dry nuts are lighter than wet nuts. Furthermore, by investing at this point in the supply chain, producer cooperatives and processors, who shoulder most of the risk of containers being rejected due to safety regulations in the EU

and elsewhere, can more reliably identify products acceptable to international markets.

Developing collaborative value chains

The complex nature of aflatoxin contamination means a holistic and multidisciplinary approach is required in order to change pre- and postharvest practices. Furthermore, developing innovative market mechanisms to remove aflatoxins from the human food chain may bring sustainability and scale to these interventions. The entire supply chain needs to share the cost of interventions to control and manage aflatoxins, as smallholders—the poorest in the supply chain—cannot bear this financial burden alone. Expertise from a variety of stakeholders must come together to develop and coordinate a system- and industry-wide response to the problem of aflatoxins in smallholder value chains. Agricultural researchers, public health and nutrition practitioners, technical farmer trainers, trading and farmer organizations, and ultimately the companies that purchase the products all have a part to play. Without such a concerted effort, smallholders will continue to lack the necessary incentives and capacity to respond adequately to market demands and thus to compete in the global marketplace.

Key recommendations

Working within market realities and taking a sector-wide approach is essential to addressing the issue of aflatoxin control. Agricultural, health, nutritional, and value chain experts need to work together to:

- raise awareness of the public health impacts of consuming unsafe food,

- improve drying, sorting, and storage both on-farm and throughout the value chain,

- provide training and access to equipment to change inappropriate practices, such as by facilitating access to mechanical shellers to stop hand shelling, and

- research and develop innovative market mechanisms to pull aflatoxins out of human food chains.

FOR FURTHER READING

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Aflatoxin Management in the World Food Programme through P4P Local Procurement

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Aflatoxins are a major concern for the World Food Programme (WFP). The organization procured more than 2.1 million metric tons of mixed commodities from international markets in 2012, including 417,000 metric tons of maize grain and approximately 49,000 metric tons of maize meal. The WFP ranks both commodities as "risky" due to the safety threat posed by aflatoxin contamination. Maize products are deemed less risky than other commodities such as groundnut-based ready-to-eat foods, which in addition to presenting microbiological risks also target the most vulnerable. But given that maize products are widely used commodities within WFP programs, the organization gives the threat of aflatoxins in maize particular attention.

In 2012, 77 percent of the WFP's food procurement came from developing countries (OECD 2013). In order to guarantee that food goods are fit for human consumption, WFP uses independent inspection services to perform end-product testing prior to taking ownership. In 2012, over 388,000 metric tons of maize and 33,000 metric tons of maize meal purchased in Africa had an aflatoxin content that did not exceed the WFP's specification of 20 parts per billion (ppb). With WFP increasingly sourcing locally the food that it distributes, the organization is focusing on addressing food safety and food quality issues upstream. Proper supplier management and support lead to a drastic reduction in the rejection of food by ensuring that the product is up to general safety standards and, particularly, is below tolerated aflatoxin levels.

Purchase for Progress

Purchase for Progress (P4P) is a pilot program that integrates WFP's food purchasing power with the technical expertise of other partners and uses farmer organizations to help connect smallholder/low-income farmers to markets to help raise their incomes. Under P4P over 64,000 metric tons of maize were purchased in 2012 from smallholder farmers from regions in Africa prone to high aflatoxin levels. Yet in 2010 WFP rejected two sets of consignments in Kenya as well as large quantities of India-sourced maize due to high levels of aflatoxins (with levels reaching up to 110 ppb). Following those outbreaks, WFP issued a guidance note that emphasized mandatory aflatoxin testing ands introduced a Standard Operating Procedure for sampling and testing maize grain at the farm gate.

Since then WFP has actively worked to reduce aflatoxin levels through the promotion of good practices. It has offered, through various partners, training across 12 P4P countries, covering practical aspects of postharvest handling (drying, sorting, storage, transport, etc.) and quality control (inspection and testing), thereby building a preventive approach to food quality and safety, particularly in regard to aflatoxins. The WFP, in collaboration with the Natural Resources Institute of the University of Greenwich, published a standardized manual, the *P4P Training Manual for Improving Grain Postharvest Handling and Storage,* which sets out the best training materials and methods. Available in both English and French, this user-friendly manual addresses the specific needs of smallholder farmers and provides instructions for trainers.

Blue Box

WFP is also committed to playing a greater role in terms of pre-inspection with the development of cost-effective solutions for food testing in the field. The Blue Box—a portable 18-gallon aluminium box containing grain-testing tools—allows for on-the-spot screening of food quality parameters and grading at any stage of the supply chain, be it at the farmer, processor, or inspection and procurement levels. The Blue Box was first developed for farmers in Guatemala at a time when WFP was purchasing locally produced fortified blended foods that used ingredients, including maize, sourced locally from smallholder farmers. A first inspection of maize in 2007 led to the rejection of cargos due to non-compliant kernel size. With the rollout of P4P, limiting food rejection became an important focus combining early detection (via Blue Box) and early prevention (via postharvest training). Early detection of suitable lots results in a reduction of rejected consignments and leads to significant savings for the farmers, who do not have to bear unnecessary transport costs. Various parameters can lead to the rejection of an entire lot, and not just for aflatoxin contamination. Parameters controlled for include moisture, defective grains (such as for broken or discolored kernels, mold or insect damage, or extraneous material), and aflatoxin levels.

In areas lacking basic infrastructure, such as in conflict zones, the Blue Box can provide an interim solution that permits WFP to continue operating and procuring locally. In South Sudan, for instance, the absence of inspection services and analytical capacity has resulted in maize samples being shipped to other countries with appropriate equipment for aflatoxin control. On top of the extra cost incurred, the extended lead time for receiving analysis results was also counterproductive, keeping local suppliers from completing transactions in a day. To overcome this situation, WFP's Sudan Country Office provided the government with Blue Boxes to assist them in grading and performing safety controls.

By boosting quality control practices, the Blue Box can help private operators enter markets with more rigorous standards. In Mali, where no legislation regarding aflatoxins exists, WFP's market was targeted by Moulins du Sahel (MdS), a well-established local private processor. High aflatoxin levels, up to 400 ppb, prohibited the procurement of maize by WFP in 2011. The next year MdS decided to use the Blue Box for verifying aflatoxin levels in incoming maize and identifying lots below 20 ppb, which allowed sales to WFP to finally proceed.

The Blue Box is also widely used by WFP procurement officers. In Burkina-Faso for example, joint WFP missions with P4P and procurement officers aim at minimizing food rejection by screening farmer organizations. Commodity quality controls are integrated

into the market research phase, and the selection of grain suppliers is not solely based on price. The Blue Box is used to determine the level of aflatoxins in harvested grains and to identify those meeting WFP contractual specifications. Training of WFP officers provided by the Blue Box supplier also provides the opportunity to bring other key players, such as food inspectors and food suppliers, to the table, thereby contributing to the mutual acceptance of WFP requirements regarding aflatoxin levels and detection means.

Initially developed for farmers, the Blue Box has surprisingly found many applications and users along the supply chain. One reason behind its success is that the Blue Box offers a set of tools that controls parameters directly influencing the price paid to the farmer or even if the consignment is accepted or rejected. However, aflatoxin testing has not been embraced by all. Farmer organizations often find the absence of electricity, the cost per test, and the inconsistent availability of batteries and other consumable Blue Box components to be inhibiting. In response, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has developed a fast, simple, and affordable test kit—a solution that can reduce costs from US$6 down to $1 per sample tested. Receiving the most praise has been the moisture meter, as moisture is often a key price-determining criterion. This portable battery-run device also provides an excellent precautionary check for aflatoxins.

Concluding thoughts

WFP's presence in local markets provides a platform to raise awareness about aflatoxins and food quality. Working with governments, farmers' organizations, and suppliers, WFP can stimulate and support improvements in food quality. The above efforts, combined with WFP's procurement standards, have helped create a spill-over effect of practices enhancing food quality in the markets where WFP operates. Many traders made investments in quality assurance equipment, such as drying and cleaning equipment, in order to meet WFP standards, thereby opening up additional export opportunities (WFP 2013; Wagacha and Muthhomi 2008).

As a major purchaser, WFP plays a leading role in piloting innovative approaches. Its one-two approach of pre-inspection coupled with preventive measures has led to positive results, as shown by local procurement figures for maize products. Switching from end-product testing to preventive measures, not only for aflatoxins but for quality and safety parameters in general, is one area in which WFP can increase cooperation with local authorities and influence policy design and execution. This is already occurring. WFP supports appropriate entities in setting up laboratories and works closely with inspection bodies. In parallel, cooperation with the Food and Agriculture Organization (FAO) is leading to guidance for the design of mycotoxin sampling plans and the interpretation of results. WFP, with its extensive presence in the field and its growing involvement at various levels of the supply chain, is thus an interface that transmits innovative approaches and tools developed for the management of aflatoxins. In the field, WFP provides technical support and rigorous follow up, helping to ensure that preventive approaches are adopted to secure food quality.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Reducing Aflatoxins in Africa's Crops: Experiences from the Aflacontrol Project

CLARE NARROD

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This brief overviews the Aflacontrol project, a multidisciplinary effort from 2009 to 2012 that sought to provide empirical evidence of the cost-effectiveness of aflatoxin risk-reduction strategies along maize and groundnut value chains. The project aimed to assess the potential for farmers, consumers, processors, and traders to uptake and adopt these control strategies and interventions.

Prevalence

Data on aflatoxin levels in maize sampled were collected from 2009 to 2011 at different points along the value chain—at pre-harvest, in storage (at 15- to 30-day intervals), and monthly in selected markets—from three regions of Kenya: Upper Eastern, Lower Eastern, and South Western. Examining maize in Kenya, Mahuku et al. (2011) found a greater than expected prevalence of aflatoxins at levels that were well above the legal limit of ten parts per billion (ppb). Though Eastern Kenya is where the highly publicized deaths associated with aflatoxicosis occurred in 2004, a huge variation of aflatoxin levels above ten ppb was also found in farmers' fields and stores in Western Kenya. Furthermore, the proportion of maize with aflatoxin levels greater than ten ppb was higher in farmers' stores and markets, suggesting that current practices for drying and storing maize do not adequately minimize exposure to aflatoxins.

Groundnut samples were also collected at the same intervals from three regions in Mali—Kayes, Kita, and Kolokani—and aflatoxin prevalence levels were analyzed. Waliyar et al. (2011) found aflatoxin levels in the fields greater than 20 ppb in over 33 percent of the total sample across the study regions. Furthermore, aflatoxin levels in Kenya increased in storage and in the markets, suggesting that, as with maize, current groundnut drying and storage practices are inadequate.

Risk assessment and cost-effectiveness models

Based on this prevalence data, the project used a probabilistic framework to develop baseline risk assessment models that focused on pre- and postharvest prevalence as well as actions that individuals might take at home to reduce aflatoxin prevalence. The output was used to analyze cost-effectiveness. As there were limited data on the effectiveness of implementing control measures in Africa, an expert elicitation was administered to a panel to provide guidance on the potential effectiveness of selected measures to reduce aflatoxin risk for maize and groundnuts. The findings were combined with cost data on different storage methods from unpublished data from the International Maize and Wheat Improvement Center (CIMMYT) and estimated costs of biocontrol from the International Institute of Tropical Agriculture (IITA) in order to facilitate the cost-effectiveness analysis (Narrod et al. 2011a, 2011b).

To assess the cost-effectiveness of combinations of aflatoxin control options, we combined the output of the risk assessment with a cost-effectiveness analysis for a select group of pre- and postharvest technologies. The preliminary findings suggest that treatments that reduce prevalence the most are more costly. When considered in combination, however, groups of less-costly treatments emerged as cost-effective alternatives to single, more expensive options. The differences depended not only on stated costs and revealed effectiveness, but also on the considered option's lifespan (that is, how often it must be repurchased). In the case of maize, for instance, a few low-cost options that need to be replaced on a regular or semiregular basis, such as drying on tarp, were found to be cost-effective, as were more expensive options with longer life spans, such as plastic and metal silos. The lifespan of the biocontrol option is not sufficiently known, yet it is a key factor in determining its cost-effectiveness. The analysis assumed a lifespan of one year, which meant that the full cost of applying this option was borne within a single growing/harvesting cycle, making the approach non-cost-effective. If in reality the lifespan is longer (that is, the treatment does not have to be repeated every year), then biocontrol could be a cost-effective approach. Findings from the cost-effectiveness analysis need to be interpreted with care until both good experimental data on the effectiveness of various measures in the context of Africa and a better understanding of the lifespan of the various methods are available to provide us a true understanding of their costs.

Understanding household practices and knowledge

Our interest in the types of household practices that might reduce aflatoxin levels led us to conduct focus group interviews followed by household surveys in 2010–2011 (Bett et al. 2011; Hellin et al. 2011; Ndjeunga et al. 2011; Tiongco et al. 2011a). We found that basic knowledge of aflatoxins was extremely low in both countries (Narrod et al. 2011c, 2011d). Households in the drylands of Kenya, where aflatoxicosis outbreaks occurred in 2004, had a higher perception of risk, as expected, but low knowledge on the actions needed to minimize exposure to aflatoxins. These observations suggest that a lack of understanding of the problem contributes to poor control of aflatoxins in that region. The survey also showed that most farmers who had heard of aflatoxins obtained that information from local language radio broadcasts and from extension workers. Preliminary research findings suggest that being involved in selling maize has no effect in terms of action to reduce aflatoxin risk in Kenya. Mali households that are more market oriented (that is, sell more than 25 percent of their production) seem to be more likely to take action to ensure better crop management and to mitigate risk by using better storage facilities.

The survey also looked into the influence of behavioral factors on an individual's adoption of strategies to reduce aflatoxin risk. A contingent-valuation method was used to capture the willingness of farmers and other value chain actors to pay for aflatoxin control technologies. Based on preliminary research, Tiongco et al. (2011c

and 2011d) conclude that producers in both Kenya and Mali with more assets were hypothetically more willing to pay for aflatoxin risk-reducing technologies. It is thus important to know what types of information would be needed to get farmers with limited resources to adopt aflatoxin reducing strategies. Furthermore, their findings suggest that in the drylands of Kenya, where outbreaks of aflatoxicosis have occurred, respondents were more willing than those in other regions to pay for improved seeds as well as for tarpaulins and metal silos for drying and storing grain.

Furthermore, about half those surveyed in Kenya reported taking maize home to dry on tarpaulins, which would limit direct exposure of the maize to dirt. Such exposure is problematic because aflatoxins are a toxic substance emitted by fungi that are abundant in agricultural soil in the tropics. Given that poor postharvest practices and storage conditions are also known to increase aflatoxin prevalence, we asked a number of additional questions concerning postharvest practices. About 30 percent reported leaving maize uncovered in the fields, and the most common reported storage practices were either using a room in the house or an improved granary with a wooden wall (Bett et al. 2011). In Mali nearly half of those surveyed reported drying groundnuts in large piles in the field. As in Kenya, few Malian farmers used storage structures; of those that did, traditional granaries were the most common.

Given that aflatoxins can be neither smelled nor tasted and that a laboratory test is needed to determine whether the levels in a product exceed the safety threshold, in the household survey experimental auctions were used for maize and groundnuts certified as being free of aflatoxins (De Groote et al. 2011). Preliminary analyses of collected data suggested that consumers are willing to pay a slight premium for maize labeled "tested" and also that the premium was positively associated with increased schooling and was higher in affected regions. Preliminary results in Mali found people were also willing to pay a premium for groundnuts tested and labeled free of aflatoxins (see Tiongco et al. 2011 b). However, in both cases the premium did not cover the cost of off-the-shelf low-cost testing methods. Currently the typical field-based test methods cost around US$5–7 per test and require expensive chemical readers that cost around $4,000. Because of the costs and complexity of testing for aflatoxins, testing in much of the developing world is therefore limited to commercial establishments and is nonexistent in rural areas.

Conclusions

These findings suggest that rural people still know little about the harmful effects of aflatoxins and ways to reduce it. Though there are currently initiatives that aim to control aflatoxins in developing countries, gaps remain in our understanding of both what will work in a developing country context and whether food-insecure individuals will alter their behavior if given improved information about aflatoxins. Further, as very few of the existing risk reduction methods have actually been deployed in developing countries under nonexperimental methods or nonsubsidized studies, there are still gaps in our understanding of which methods will lead to widespread voluntary adoption by rural populations. Effective low-cost testing methods that will work under rural conditions in developing countries are needed.

To be effective in the long term, aflatoxin risk reduction efforts in developing countries need to also be directed at (1) educating families, farmers, stakeholders along the value chain as well as governments about the health risks associated with mycotoxins and the social and economic costs of reducing this risk; (2) reducing the risk of aflatoxins and other harmful mycotoxins by the application of appropriate agricultural practices; (3) investing in local capacity to support further activities both to reduce mycotoxins in agricultural products and to monitor mycotoxin levels in crops and the local population; and (4) providing the tools (data and risk management capacity) for locally driven policy reform that creates an effective regulatory environment to ensure domestic food safety in rural and urban areas and also facilitates trade opportunities in the region.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Cost-Effectiveness of Interventions to Reduce Aflatoxin Risk

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Many interventions have been developed to reduce aflatoxins or their adverse effects on human health. Often not considered, however, is the likelihood that these strategies will be adopted in the countries that need them most—where aflatoxin-related risks are highest. This brief summarizes two aspects crucial to the adoption of new technologies and methods: the *costs* and the *efficacy* of the different interventions. This brief categorizes aflatoxin risk-reduction strategies into preharvest, postharvest, dietary, and clinical settings, and summarizes the costs and efficacy of each strategy in reducing either aflatoxins in food or their adverse impacts in the body.

Preharvest interventions

Because most mycotoxin problems begin and develop in the field, strategies are needed to prevent toxigenic fungi from infecting growing plants. Developing genetic resistance to Aspergilli in maize and groundnuts is a high priority (Cleveland et al. 2003).

A number of resistant inbred maize lines have been identified (Maupin et al. 2003). Sources of resistance to each of these pathogens have been identified and incorporated into public and private breeding programs, and have also been extended to include germplasm lines from Africa (Brown et al. 2001). Potential biochemical markers and genetic-resistance markers have been identified in crops, particularly in maize, which are now used as selectable markers in breeding for resistance to aflatoxin contamination (Chen et al. 2007). Now that the sequencing of the *A. flavus* genome has been completed and genes that potentially encode for enzymes involved in aflatoxin production have been identified, genomics as a tool for combating aflatoxin biosynthesis has gained ground (Yu et al. 2008). Similar efforts have been made in groundnuts (Holbrook et al. 2006).

Transgenic crops may also play a role in reducing preharvest aflatoxin accumulation. Insect damage is one factor that predisposes maize to mycotoxin contamination because insect herbivory creates kernel wounds that encourage fungal colonization and insects themselves serve as vectors of fungal spores (Munkvold et al. 1999). Bt maize contains a gene from the soil bacterium *Bacillus thuringiensis*, which encodes for crystalline proteins that are toxic to certain members of the insect order Lepidoptera. Earlier Bt events showed only mixed success in controlling aflatoxins in a variety of studies (Wu 2007).

Biocontrol of aflatoxins refers to the use of organisms to reduce the incidence of *Aspergilli* in susceptible crops so as to reduce aflatoxin contamination. The most widely used biocontrol method employs atoxigenic strains of *Aspergilli* that can competitively exclude toxigenic strains from colonizing crops. These biocontrol methods have been used in maize, groundnuts, and cottonseed worldwide (Dorner et al. 1999; Cotty et al. 2007; Atehnkeng et al. 2008).

Cultural practices—including crop rotation, tillage, timing of planting, and management of irrigation and fertilization—can also help to prevent *Aspergillus* infection and subsequent aflatoxin accumulation by reducing plant stress (Munkvold 2003). Ultimately, a combination of preharvest strategies, as described above, may be needed to adequately prevent mycotoxin contamination in the field (Cleveland et al. 2003).

Postharvest interventions

Postharvest aflatoxin accumulation remains a threat in developing countries. Hence, knowledge of the key critical control points during the harvesting, drying, and storage stages in the cereal production chain are essential in developing effective prevention strategies postharvest (Magan and Aldred 2007). Possible intervention strategies include good agricultural and storage practices—including early harvesting, proper drying, sanitation, proper storage, and insect management, among others (Wagacha and Muthomi 2008). This also holds for tree nuts such as pistachios, which have experienced a dramatic drop in aflatoxin reduction in Iran due to improved drying and storage conditions over the past decade (Wu 2008).

An effective way to remove existing aflatoxin contamination is by sorting aflatoxin-contaminated kernels from relatively cleaner ones. This can be done by either simple physical methods (such as handsorting) or flotation and density segregation methods (Kabak et al. 2006). After sorting, steps to further reduce aflatoxin risk include controlling moisture levels in stored crops, temperature, and insect pests and rodents. Combinations of these methods to reduce postharvest aflatoxins have been tested for efficacy in rural village conditions. Turner et al. (2005) describe a postharvest intervention package to reduce aflatoxins in groundnuts that was tested in Guinea. The package consisted of education on hand-sorting nuts, natural-fiber mats for drying the nuts, education on proper sun drying, natural-fiber bags for storage, wooden pallets on which to store bags, and insecticides applied to storage floors.

Dietary and food processing interventions

A variety of dietary interventions can reduce aflatoxin-related health risks. One simple dietary intervention, where feasible, is to consume less maize and groundnuts in favor of other food crops that have significantly lower aflatoxin contamination, such as rice, sorghum, and pearl millet (Bandyopadhyay et al. 2007; Chen et al. 2013). Where it is not easy to make such a dietary shift, however (such as where maize and groundnuts have traditionally been staples), other dietary interventions may prove helpful.

One class of dietary interventions involves adsorption of aflatoxins. Adsorbent compounds, such as NovaSil clay (NS), can prevent aflatoxicosis in many animal species when included in their diet. They do so by binding aflatoxins with high affinity and high capacity in the GI tract (Phillips et al. 2008). Green tea polyphenols (GTPs) have been shown to inhibit chemically-induced cancers in animal and epidemiological studies (Fujiki et al. 2002). Chlorophyllin

sequesters aflatoxins during the digestive process and hence impedes its absorption (Egner et al. 2001).

A variety of substances have the potential to reduce aflatoxin-induced liver cancer by inducing phase 2 enzymes that convert aflatoxins' carcinogenic metabolite into a less harmful form that can be excreted (Kensler et al. 2005).

There is recent evidence that some lactic acid bacteria have the ability to bind aflatoxin B1 (Hernandez-Mendoza et al. 2009). Hence, inclusion of culturally appropriate fermented foods in the diet may be a feasible method of partially reducing aflatoxin risk. Other methods of food processing, such as extrusion processing at temperatures greater than 150 degrees Celsius, can moderately reduce aflatoxins and other mycotoxins (Bullerman and Bianchini 2007).

Hepatitis B vaccination

Vaccinating children against the hepatitis B virus (HBV) has been shown to significantly decrease HBV infection (Zanetti et al. 2008). Though having no impact on actual aflatoxin levels in diets, the vaccine reduces aflatoxin-induced hepatocellular carcinoma (HCC) by lowering HBV risk, thereby preventing the synergistic impact of HBV and aflatoxins in inducing liver cancer.

Costs and efficacies of interventions to reduce aflatoxin risk

Khlangwiset and Wu (2010) have summarized the cost–effectiveness information for different interventions to reduce aflatoxin–induced adverse health effects. These findings are summarized below and placed in the context of usefulness in resource-poor settings.

Estimates hold that aflatoxin-resistance breeding in crops can reduce aflatoxins up to 70 percent in groundnuts in both high- and low-income nations, where the cost would be calculated in terms of research and development while the benefits would be reaped by growers. Transgenic Bt maize has been shown in various studies to be cost-effective in reducing aflatoxins and other mycotoxins, but this option is not feasible in many parts of the world—including most African nations—where transgenic crops are not approved for commercialization. Costs of biocontrol methods have a range of US$42–79/hectare, and depending upon the severity of aflatoxin contamination in a given year, could range from hardly any aflatoxin reduction to reductions of up to 80 percent under

preharvest conditions. Unless subsidized, the costs would most likely be borne by growers, who would also reap the benefits of aflatoxin reduction. The feasibility of biocontrol use would depend upon biosafety regulations in nations as well as the ability to harness local resources to develop and maintain biocontrol strains. Irrigation and insecticide use can also effectively reduce aflatoxin levels in crops and generally meet with regulatory approval. Simple postharvest interventions to improve drying and storage conditions of food crops can be a cost-effective way to reduce aflatoxin contamination in resource-poor settings.

Dietary interventions to reduce adverse effects of aflatoxins in the human body are less definitive in terms of costs and effectiveness in reducing harmful effects. While NS, green tea polyphenols, chlorophyllin, and other dietary constituents have been shown to reduce aflatoxin bioavailability or markers of adverse effects in animals and humans, less information is available regarding how much constitutes an "effective" dose, how frequently they must be taken to effectively reduce risk, how they should be formulated for consumption, and hence what the accompanying costs and efficacies are. Moreover, their acceptability in different parts of the world where populations are at high risk of aflatoxin exposure would depend upon the specific cultural context.

Discussion

This brief has sought both to describe the scientific knowledge base (efficacies) and economic factors (costs and stakeholders) concerning aflatoxin risk-reduction strategies that could be deployed worldwide and to highlight the importance of economic feasibility. Policymakers can use this information to decide (1) whether the benefits (market and health) outweigh the costs of implementing the strategies; and (2) if so, then which stakeholders would pay the costs and which would benefit in the long run, to resolve potential mismatches in economic incentives (Wu et al. 2008). This information can also help researchers who are developing further aflatoxin control strategies to roughly position their interventions among various existing strategies in terms of economic feasibility.

Understanding the costs, efficacy, and affected stakeholders of different aflatoxin control interventions could potentially help decision-makers—be they government policymakers or farmers or consumers—to optimally allocate resources, with the ultimate aim of improving public health.

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Policy

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According to World Trade Organization (WTO) rules, countries can choose their own Sanitary and Phyto Sanitary Standards (SPS) to protect human, animal, and plant health as long as they are nondiscriminatory and justifiable by science. This discretion has resulted in regulations that can serve as a significant barrier to trade, as revealed by numerous disputes within the WTO (Josling, Roberts, and Orden 2004).

Aflatoxin regulations have attracted notice for their potential role in restricting trade. For example, total peanut meal imports by European Union (EU) countries fell from more than one million tons in the mid-1970s to just 200,000–400,000 tons annually after 1982, the year mycotoxin regulations were first tightened in the EU. In 2002, the EU further tightened standards, leading to concern about the impact on exports from Africa. Two groundbreaking papers on the trade impact of aflatoxin regulations (Otsuki et al. 2001a, 2001b) examined cereals and groundnuts, respectively. Their large estimates of the negative effects of aflatoxin regulations on African trade (greater than US$750 million dollars annually in the two trades combined) received much attention. Even UN Secretary General Kofi Anan, at the time, cited these numbers when he called for a balance between the potential public health benefits of stringent aflatoxin standards and the economic pain that African countries experienced as a result.

For several reasons, however, assessing the effects of SPS standards is extremely difficult. First, standards can vary in intensity, which can be difficult to measure. In this context, aflatoxin regulations are somewhat easier to measure since they are specified as parts per billion (ppb) and hence do directly measure the intensity of product standards. A restriction of 4 ppb is clearly more restrictive than 20 ppb and is likely to create a bigger trade barrier. Second, standards do not change often and do not change across exporters to any particular market. Empirical estimations produce robust results only when there is sufficient variation in the data to identify the effects of one variable on the other. Hence, many studies have focused on the significant changes implemented in the EU in the early 2000s. Finally, as other factors influence trade over time, it can be difficult to isolate the impact of standards on trade in any given commodity market.

Given these difficulties in measuring the impact of standards on trade, it is not surprising that the findings of subsequent research on the impact of aflatoxin regulations have been more mixed than those reported in the two papers by Otsuki et al. Using a different empirical model and ex post data, Xiong and Beghin (2012) show that the tightened EU regulations did not significantly further reduce African groundnut exports, contradicting the ex-ante analysis of Otsuki et al (2001b). Furthermore, based on interceptions data (export rejections at the border), Diaz Rios and Jaffee (2008) argue that the contamination levels from many exporters are much higher than the limits imposed by European standards. The variations in standards, therefore, do not alter trade because contamination levels are usually so high that many exporters would find it difficult to meet even less-restrictive standards. This means that while standards are a potential barrier to trade, relatively small changes in standards may not visibly impact trade.
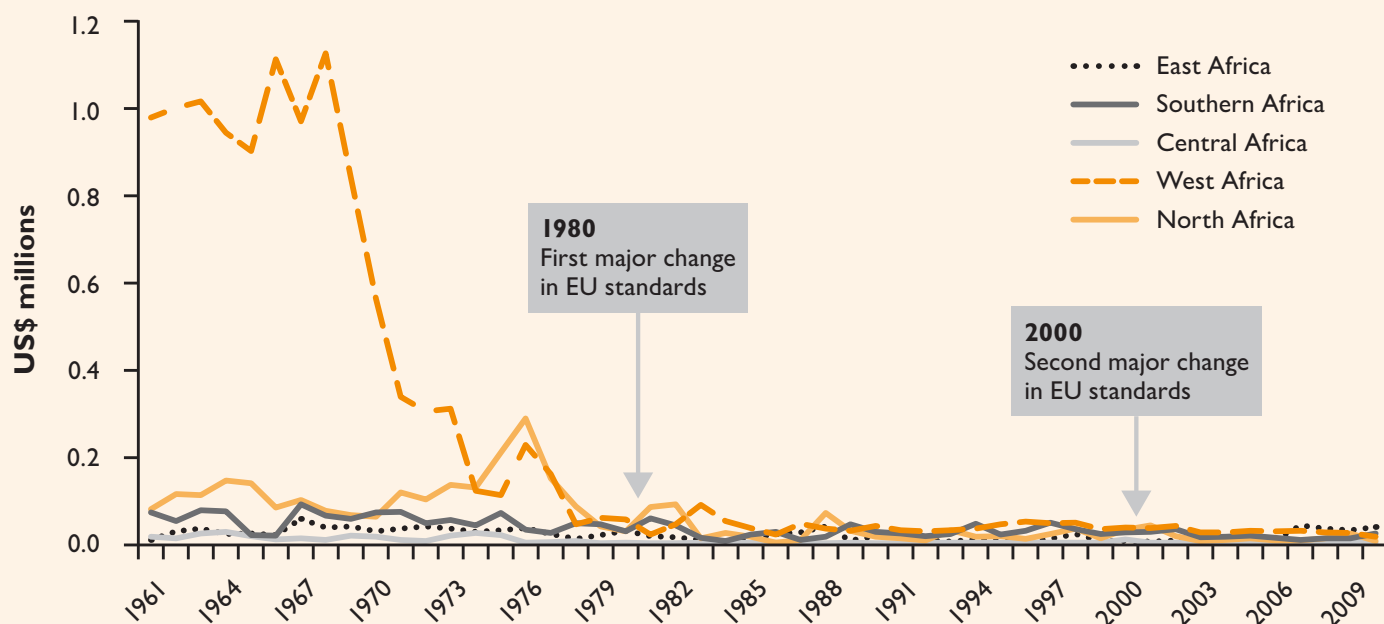
The maize market also provides evidence on the market losses from aflatoxin regulations. Maize, one of the most highly traded staples, is highly prone to aflatoxin contamination. Thailand was regularly ranked among the top five maize exporters during the 1970s and 1980s. But partly due to aflatoxin problems, Thai maize is regularly sold at a discount, having cost Thailand about $50 million per year in lost export value (Tangthirasunan 1998). According to the Food and Agriculture Organization of the United Nations (FAO), the direct costs of mycotoxin contamination of maize and peanuts in Southeast Asia (Thailand, Indonesia, and the Philippines) has amounted to several hundred million dollars annually (Bhat and Vasanthi 1999). More recently, preliminary results of research by Munasib and Roy (2011) suggest that a 10 percent increase in the gap between standards of importers and exporters is associated with as much as a 4.4 percent decline in maize exports from low-income countries.

One issue is just how big the differences in standards may be. Considering a set of 48 countries with established limits for total aflatoxins in food, Dohlman (2003) found that standards varied widely, ranging from 0 to 50 parts per billion. Preliminary research by Munasib and Roy (2011) suggests that maize regulations in different countries have become increasingly stringent over time. The EU harmonized its regulations in 2002, and members joining since then have been required to apply these new regulations. In the Czech Republic, for example, the permissible limits on aflatoxins went down to 2 ppb from 5 ppb when it joined the EU in 2004. Hence, both the harmonization of standards in 2002 as well as the entry of new members into the EU implies that globally the average level of regulation related to aflatoxins has increased. It can thus be expected that standards will play a growing role in restricting trade.

More than a decade has passed since the implementation of harmonization by the EU. African exports of groundnut products had already declined to modest levels before this harmonization, and fluctuations in trade over the last decade cannot be directly associated with these recent changes in European standards (Figure 1). African exports, particularly of groundnuts, experienced a secular decline since the 1970s because of several other factors, including changes in preferences in importing countries and increases in domestic demand in Africa. African exports were declining anyway, and African exporters who were unable to meet the new higher standards in 2002 would likely not have met the earlier less restrictive standards either.

Standards remain a potentially important barrier to trade, and meeting them is a necessary, but not sufficient, condition for market access for many exporters in low-income countries.

FIGURE 1 Value of shelled groundnut exports from African regions

Legend:
- East Africa
- Southern Africa
- Central Africa
- West Africa
- North Africa

1980 First major change in EU standards

2000 Second major change in EU standards

Y-axis: US$ millions (0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2)

X-axis: 1961, 1964, 1967, 1970, 1973, 1976, 1979, 1982, 1985, 1988, 1991, 1994, 1997, 2000, 2003, 2006, 2009

Source: Author's calculation, 2012.
Note: The high correlation (r = 0.99) reveals the reliability of enzyme-linked immunosorbent assay (ELISA) to detect and quantify aflatoxins in breeding programs.

Reducing domestic levels of contamination and improving effective standards domestically in low-income countries could set the stage for greater market access for exports. Improving domestic standards (in line with health and other benefits) could reduce the SPS barrier for exporting countries and increase exports of aflatoxin-affected products.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Codex Standards: A Global Tool for Aflatoxin Management

RENATA CLARKE AND VITTORIO FATTORI

Aflatoxin contamination of food commodities poses major challenges to both public health and trade. It remains a global problem in part because of the attention given to it over the past decades has been insufficient both quantitatively and qualitatively. Reducing aflatoxin contamination in a sustainable manner requires a new approach. What is required is a holistic understanding of the public health, social, market, and technological dimensions of the problem in order to construct effective solutions. This brief focuses on one of the key aspects of any solution for reducing public health and trade risks due to aflatoxin contamination: the setting and implementation of internationally agreed standards.

The Joint FAO/WHO Food Standards Programme, established by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) and implemented through the Codex Alimentarius Commission (CAC), establishes international standards, guidelines, and codes of practice that provide a basis for food safety management in all countries. Codex standards are explicitly recognized by the World Trade Organization as the reference for food safety in international trade. Several Codex texts refer specifically to the management of food safety risks due to aflatoxin contamination. Effective national programs for reducing aflatoxin contamination require an awareness of these international standards and how they are developed, an adequate regulatory framework that enables implementation and enforcement of relevant standards, and the necessary support to facilitate uptake of good practices by value chain operators.

Setting Codex standards: A science-based, global process

FAO and WHO provide neutral and independent scientific advice that serves as the foundation of Codex's work. Based on the risk assessments of the Joint FAO/WHO Expert Committee on Food Additives and Contaminants (JECFA), a number of Codex standards on mycotoxins have been developed, including standards for the maximum levels for aflatoxins in a number of commodities and codes of practice for preventing contamination.

Codex maximum levels (MLs) for aflatoxins in food or feed are the maximum concentration recommended by the CAC to be permitted in that commodity. These MLs are an important tool that both regulators and industry can use to demonstrate that levels of aflatoxin present in a commodity do not exceed tolerable risk. Codex establishes MLs on the basis of assessments carried out by JECFA that determine both population risk for given exposures to aflatoxins over a lifetime and the difference in the levels of public health protection afforded by different regulatory scenarios. In carrying out its evaluation, JECFA considers all available information regarding: the toxicity of the contaminant; the levels and patterns of contamination at various stages of production, handling, and marketing; and the dietary exposure of the population, including consideration of subpopulations that might be particularly vulnerable. Given the variability in production systems—both within and among countries—it is important that data reflecting the range of realities be considered when arriving at conclusions on tolerable levels that then become the objective determinant of acceptability of consignments on the market.

It is essential that more developing countries recognize the value of contributing to setting global standards by generating data that reflects the realities of their national context. For example, FAO and WHO are currently working with the governments of Sudan, Ethiopia, Burkina Faso, and Mali to generate data on levels and patterns of mycotoxin contamination in sorghum to contribute to deliberations within the Codex Committee on Contaminants in Foods. Strengthening the technical capacities within developing countries to generate, collect, and analyze reliable data on the public health and economic impacts of aflatoxin contamination and to communicate effectively with policymakers on related risk-management options would enable these countries to take a more proactive role in determining priorities for setting Codex standards. A 2010 FAO report noted that the organization's Codex-related capacity-development program had so far succeeded in improving the involvement of developing countries in decisionmaking within Codex but less so in "decision-shaping."

Codex Codes of Practice: An emphasis on prevention

As outlined in the previous section, MLs are essential regulatory tools for protecting public health. It is widely recognized, however, that reliance on testing is an inefficient and ineffective approach to the control of food contaminants (FAO 2003, 2008). In particular, aflatoxin contamination is notoriously heterogeneous, which increases the difficulty of estimating true contamination levels of affected lots. Adopting good practices at all stages of the food chain to minimize infection by toxigenic molds and the accumulation of mycotoxin contamination is the best way to reduce levels of these fungal toxins in the food supply.

Recognizing this, Codex has placed emphasis on the development of Codes of Practice to guide countries in the adoption of good practices—both pre- and postharvest—in order to prevent contamination. These Codex codes are developed through expert input and are based on available evidence of hazard reduction or hazard accumulation at various points of the food chain for different production systems. The plurality of Codex guarantees an opportunity for all countries to ensure that these Codes are relevant to their particular national situation; harnessing that opportunity requires a commitment from countries to participate effectively within the Codex "system."

Codex standards are not enough

Codex MLs and Codes of Practice are essential tools for building a shared global view of acceptable practice. Addressing the

problem of aflatoxin contamination requires that countries actually *adopt* Codex MLs into national legislation and also that they *adapt* Codes of Practice to the local context to facilitate uptake of good practices by value-chain operators. Countries may adopt standards that differ from Codex recommendations if such action can be justified by a risk assessment and if the same level of protection applies to imports as well as to local production. Effective regulatory oversight to ensure that foods reaching the market are within established regulatory limits depends on the political will both to develop technical capacities and facilities in the country and to provide the financial resources necessary to run monitoring and surveillance programs. Furthermore, modern food control systems are based on the notion that the producers, traders, processors, and retailers have the primary responsibility for ensuring the safety of the foods they market by implementing the necessary controls at all stages of the food chain. Governments cannot address the problem of mycotoxin contamination without considering the question of how food businesses can be enabled to operate profitably while being in compliance with existing codes and limits.

Little will be gained by countries establishing food safety regulations that can neither be implemented by industry nor enforced by regulators. Key then is to determine when it is appropriate to make a requirement less stringent and when it is imperative to set ambitious goals for raising critical capacities that allow necessary requirements to be met.

In many countries, an impact assessment of regulations is an integral part of the process for proposing new or revised regulation. The high public health burden caused by aflatoxin contamination adds great urgency for governments to raise their country's respective capacities to meet internationally agreed-upon regulation. In many developing countries diets of the poor and vulnerable tend to be less varied than diets of more affluent consumers. Consumption of staples, such as maize, that are susceptible to aflatoxin contamination is much higher in some developing countries. For example annual per capita consumption of maize in Lesotho is 150 kg compared to only 1 kg in Sweden. This fact, along with the efficacy of aflatoxin control programs, contributes to the observation that while aflatoxin exposure in Africa ranges from 10 to 180 ng/kg body weight/day, exposures in Europe and North America range from 0 to 4 and from 0.26 to 1, respectively. Correlated factors render the public health implications in Africa even more serious

(Liu and Wu 2010). If the only consideration was public health, logic would support the promotion of more-stringent aflatoxin control in some low income, less developed countries.

Looking ahead

This brief underlines the fundamental role of Codex standards and well-functioning systems of food control in reducing population exposure and related public health and trade risks associated with aflatoxin contamination. There are a number of requirements to creating sound regulatory frameworks at both the international and national levels:

- Broad international commitment to contributing to the work of Codex is required to ensure that these international standards that are the reference for food safety in international trade fully consider the realities of production systems in developing countries.

- "Rational" support for developing national capacities for effective implementation of national standards and Codes of Practice is required. Such rational decisions must come from consideration of all available evidence regarding the public health, social, and economic implications of possible action or inaction regarding aflatoxin control. To this end, emerging evidence on newly recognized public health impacts of aflatoxins, such as in the area of stunting, needs to be closely considered.

- National authorities must pay careful attention to the practicability of their national regulations. Countries that recognize the imperative to reduce population exposure to aflatoxins should not only limit their attention to the ability of regulators to enforce regulation but should also consider the local industry's ability to meet requirements while still being able to compete successfully on the market.

- There is need for foresight in understanding and reacting to the new challenges and opportunities provided by changing technological and physical environments. Climate change, for instance, is likely to lead to increased occurrence of aflatoxins and other mycotoxins (and possibly their increased co-occurrence) in many countries just as new technologies may prove effective in contributing to future efforts at aflatoxin control.

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Risk assessment is a powerful tool for helping risk managers and policymakers to understand risk, evaluate risk control options, and make decisions that balance the benefits of risk reduction with the costs of mitigation. This brief shows how the principles of risk assessment and risk management could be applied to aflatoxins to support public health policy. It first describes risk assessment, then discusses some of the insights provided by risk assessment that are relevant to aflatoxins, and finally considers the key implications for aflatoxin policy.

What is risk assessment?

In risk assessment terminology, risk is defined as the combination of adverse impacts on human health and the likelihood of their occurrence. The principles of risk assessment apply to any substance or process that adversely affects human health, but food risk assessments are typically applied to physical, chemical, or microbiological hazards. (Hazards, defined as anything that can harm human health, are often categorized as physical, chemical, or biological.)

A risk-based approach to food safety focuses on the severity and likelihood of human health impacts. Risk assessment helps answer the questions that matter to policymakers and the public: "Is this dangerous?" "Is it a big or small problem?" and "What can best be done about it?" Risk assessments may be qualitative (where risk is categorized by descriptors such as "low," "moderate," or "high") or quantitative (where risk has numerical values).

Quantitative risk assessments typically provide a point estimate with a measure of uncertainty (for example 50 deaths in Kenya per year due to a given hazard with a 95 percent confidence interval of 40 to 60 deaths). Risk assessments can identify the actors or conditions that generate most risk and hence allow risk targeting. They can identify control points where risk may be most effectively reduced. These features make risk assessments useful for decisionmakers.

Because hazards can decrease or increase along the pathway from production to consumption, and because risk is dependent on exposure, the level of a hazard at a given point in the value chain is not always a good indicator of risk to human health. Risk will depend on the amount consumed, duration of consumption, hazard levels in the food at final point of consumption, as well as vulnerability of the person ingesting the hazard. Hence risk-based approaches that take into account these determinants to impute net impacts on human health are useful for targeting risk reduction efforts.

Insights from risk assessment useful for understanding aflatoxins

Only a limited number of risk assessments have been conducted for aflatoxins. Acute toxicity may result in tens to hundreds of deaths per year (brief 3). Aflatoxins are potent hepato-carcinogens,

especially in people infected with hepatitis B and C. Most assessments take a broad scope with many assumptions (JECFA 1998; Shepherd 2008; Wu et al. 2010). Risk assessments suggest a substantial proportion of the global health burden of hepatocellular cancer is attributable to aflatoxins. There is a strong association between aflatoxins and both stunting and immunosuppression in children (briefs 3 and 4). However, a causal relation has not been established, making this risk difficult to quantify.

Even when quantitative assessments are limited, important insights can be garnered by applying the principles of risk assessment to the problem of aflatoxins. A starting insight is that eliminating all risk is usually prohibitively expensive or completely infeasible. The public and policymakers often demand "zero risk" but an axiom of risk assessment is that "there is no such thing as zero risk." Especially when hazards are natural and widespread (as is the case for aflatoxins), their total elimination is unfeasible. It is important to educate stakeholders on the nature of risk and the frequent need to accept a negligible, low, or acceptable level of risk.

The acceptable level of risk is a societal decision, one that should take into account the costs of risk management as well as the potential public health benefits. In developing countries, the potential costs of aflatoxin reduction can be a relatively high percentage of current food prices (briefs 10 and 11). Furthermore, the costs of determining aflatoxin levels may be high when diagnostic tools are not available. This means that enforcement of standards that demand very low levels of aflatoxins, such as those in the EU and the US, may not be feasible under current conditions in many developing countries.

Another principle of risk assessment is that risk is multi-source; in the case of aflatoxins several different foods have been associated with high levels of contamination. Hence food safety risks need to be addressed using a dietary rather than a commodity perspective.

Risk is not the same for everyone. In the case of aflatoxins, diet and hence exposure tend to vary in predictable ways by gender, age, socioeconomic status, and agroecosystem, suggesting that some subpopulations are more vulnerable. In the EU, for example, the standard for aflatoxins in milk is stricter than for other foods because milk is consumed by infants and children who, because of their rapid growth, are especially vulnerable to aflatoxins. Because people in developing countries often eat large quantities of a small number of staples (for example, maize in East Africa), they may be more at risk than people who have more diversified diets. A corollary is that exposure levels and sources will change as diets become less staple-based; evidence suggest that this is already occurring in China.

Risk is often heterogeneous, and targeting "hot spots" is an effective use of scarce resources. Aflatoxin risks are not only heterogeneous over space (in terms of agroecosystems and crops)

but also over time (for example, risks are higher under drought conditions), requiring flexibility in response. It is important to identify the minority of producers who are creating most of the risk and the minority of consumers who are bearing most of the risk. These need to be the first target of interventions.

Risk management is incremental and cumulative, with farm-level actions, such as drying, storage, and handling, all potentially contributing to reducing aflatoxins. Risk management takes a whole value chain or "farm to fork" perspective and because hazards such as aflatoxins are costly to reduce and may increase between production and final consumption, preventive measures can be the most important means of risk mitigation. Identifying critical control points where prevention is most effective can focus efforts to mitigate risks. In the case of aflatoxins, elimination is challenging and people are not widely treated for aflatoxicosis, so control at the beginning of the supply chain is likely to be most efficient and cost-effective.

Risk management includes the appropriate management of contaminated crops. Because risks differ depending upon use, diverting crops with higher levels of aflatoxins to certain uses, such as animal feeds or brewing, can reduce human exposure. However, animal feed use will pose a different set of risks when humans consume animal source foods (brief 5). Moreover, market segmentation requires some means to determine levels of aflatoxins, and such tests are not yet in wide use in developing countries, limiting the ability of market actors to sort for aflatoxin levels. Technologies for decontamination also exist—with associated risks, costs, and benefits.

Messages for policymakers

Much of the motivation for aflatoxin control has emerged from concerns about market access and the development of commercial food and feed markets. The value of risk assessment is to reframe policy efforts with a focus on public health. The above insights from risk analysis provide some guidance for emerging health-oriented policies to address aflatoxin contamination.

Basic data on the prevalence of aflatoxins and associated risk are largely lacking for developing countries. Specific risk assessments for developing countries, crops, and animal-source foods are a useful first step to support policymaking and risk communication. It is important that these be accompanied by economic studies on the costs of mitigation and social (including gender) studies on the feasibility, sustainability, and differential impacts of mitigation.

One of the key messages for policymakers is the need to consider the role of international standards carefully. This evaluation should take into account the realistic trade opportunities, costs of risk reduction, and domestic public health priorities. Policies need to encourage risk reduction without setting up standards so costly to meet that they discourage compliance, especially among poor farmers and consumers. On the other hand, formal adoption of international standards can prevent "dumping" of sub-standard products from other countries, and this may be a motivation for their adoption in commercial markets. Collective adoption of regional standards by groups of trading partners that reflect the realities of production conditions and mitigation costs may be a reasonable step towards promoting regional trade.

For many developing countries domestic and regional markets are much more important than export markets for the food crops most affected by aflatoxins. For foods consumed on the farm or sold on informal markets of developing countries where most poor farmers sell their products and most poor consumers buy their products, regulation has little reach. In these markets value chain actors are the primary risk managers, and risk communication will be important for motivating changes in practices. (Risk communication is defined as an interactive process of information and opinion exchange on risk among risk assessors, risk managers, and other interested parties.) Policymakers need to support such risk communication, including information about simple risk-reduction measures. Over the longer term, the development of rapid diagnostics and new control technologies through research can support the development of market incentives to reward aflatoxin control.

FURTHER READING

FoodRisk.org has a wide range of material on risk assessment at http://foodrisk.org.

WHO has resources on microbial risk assessment at www.who.int /foodsafety/micro/about_mra/en/index.html and together with FAO offers a selection of tools at http://www.fstools.org/index. html.

FAO has several documents on risk assessment including www.fao .org/docrep/012/a0822e/a0822e00.htm and www.fao.org /docrep/005/y1579e/y1579e05.htm.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Mobilizing Political Support: Partnership for Aflatoxin Control in Africa

AMARE AYALEW, WEZI CHUNGA, AND WINTA SINTAYEHU

Aflatoxins are highly toxic fungal metabolites produced by certain strains of *Aspergillus flavus* and related species in diverse foods and feeds. These toxins have wide-ranging impacts on human and animal health, trade, and food security. Tropical regions between 40°N and 40°S of the equator, which include the entire African continent, are chronically affected by aflatoxins.

Furthermore, traditional crop-production practices that are widely used in Africa expose crops to stress and fungal invasion. The harvesting, drying, and storage practices expose produce to pest attack, soiling, and increased moisture, further increasing risk of contamination of food and feed produce. The problem of aflatoxin contamination, moreover, disproportionately affects the resource-poor segments of society.

The heavy reliance on single dietary staples, such as maize, subjects African populations to increased risks of aflatoxin exposure. In addition, aflatoxins adversely affect African countries' access to bigger export markets by making it harder for them to meet the regulatory standards of developed importing countries. These toxins also undermine efforts at regional integration, particularly the free trade agreements of Regional Economic Communities (RECs) in Africa.

Due to the complex nature of the problem, prevention and control of aflatoxin contamination requires a comprehensive, systematic approach involving a broad range of stakeholders in Africa and beyond. A prerequisite to this approach is institutional support and political will at the country, regional, continental, and global levels. This policy brief provides an overview of how the Partnership for Aflatoxin Control in Africa (PACA) is mobilizing political support for actions to address the aflatoxin problem on the continent. The brief provides background on PACA and highlights five approaches that PACA uses to win support to advance its objective of abating the aflatoxin challenge in Africa.

What is PACA?

PACA is an innovative consortium aimed at coordinating aflatoxin mitigation and management across the health, agriculture, and trade sectors in Africa. It seeks to provide consistent coordination and coherent leadership for the continental efforts on aflatoxin control.

In March 2011, stakeholders from African governments, the private sector, funding organizations, farmers' organizations, and other civil society groups met at the seventh Comprehensive African Agriculture Development Program (CAADP) Partnership Platform meeting. Recognizing the need for an Africa-wide approach to the prevention and control of aflatoxins, the participants urged the African Union Commission (AUC) to oversee the establishment of a continental Sanitary and Phytosanitary (SPS) Working Group and to explore a partnership for aflatoxin control in Africa. The AUC, working with partners representing interests across relevant sectors in Africa, developed structures and approaches for the effective functioning of what would become PACA. On October 31, 2012, PACA was formally launched and a Steering Committee was inaugurated by the AUC.

Generation and dissemination of knowledge to inform policy

PACA is dedicated to accuracy in data and information gathering, including in the realm of aflatoxin contamination, consumption, and exposure patterns as well as subsequent impacts across the African continent. To that effect, PACA will commission country assessments to achieve fast–track, country-specific, multisectoral understanding of the aflatoxin situation. PACA and its partners will use regional and national stocking studies and stakeholder consultations to generate baseline information on aflatoxin prevalence and impact. Scoping studies are also planned to survey research facilities and expertise on the continent as well as available technologies and their suitability for adoption in the African context. Such information is vital to inform policymakers and regulatory bodies of the burden the aflatoxin problem poses and how it is handled on the continent. Stakeholders engaged in promoting food safety also require evidence to determine their areas of prioritization.

PACA also compiles and reviews existing data and information and makes them available for wider use. PACA is initiating independent expert panel reviews of aflatoxin control technologies as a basis for regional and country-level scaling-out and scaling-up. In addition, PACA will assess the credibility of critical data by evaluating the soundness of methodology used in data collection and analysis. PACA is working on establishing an electronic data management system, including an online aflatoxin prevalence map for Africa. Initially, this will be hosted in the Animal Resources Information System (ARIS 2) of AUC. In collaboration with partners, country teams will be trained on data collection methods and will be responsible for entering data. PACA also supports capacity building through strengthening laboratory testing capacity and promoting standardized protocols. Currently many African researchers focusing on aflatoxin management lack suitable laboratory facilities. PACA has thus started brokering linkages between these researchers and institutions such as CGIAR centers that have state-of-the-art facilities both in and outside of Africa.

Building regional and national capacity for policy formulation and review

Effective aflatoxin mitigation efforts require enabling policy and institutional environments. PACA seeks to thoroughly understand the existing policy landscape in Africa through both scoping studies and gap analysis. Surveys are being initiated to assess the policies, regulations and standards, institutional settings, and regulation-enforcement challenges that currently exist in African countries. Needs for policy or policy reforms will also be assessed.

Aflatoxin regulation can be achieved within a comprehensive framework of food safety policy. PACA will assist countries by supporting policy development, guiding policy reviews, and catalyzing regional cooperation. To improve the policy landscape, PACA will facilitate independent technical reviews, expert support, training, and experience-sharing between countries.

Embedding PACA in the CAADP framework

From the outset, PACA has been conceived to fit into the CAADP framework. This framework was endorsed by African heads of state in 2003 as the primary continental program to guide agricultural growth, food security, and rural development. CAADP operates through investments under four inter-related pillars. PACA has particularly been considered as an important program contributing to accelerated growth in the agricultural sector by raising capacities to meet the increasingly complex requirements of three of the pillars: (1) food security; (2) domestic, regional, and international markets; and (3) research and technology.

Embedding PACA within the CAADP implementation mechanism will allow review of National Agriculture and Food Security Investment Plans, which are implementation plans prepared by countries after signing on to a CAADP compact or agreement, to include aflatoxin control components. This, in turn, would allow resources for aflatoxin control to be committed at the country level. Initially, PACA will develop guidelines for review of Investment Plans (IPs) in order to mainstream aflatoxin control. Countries with evidence of not only a severe aflatoxin problem but also a well-developed investment plan will then be chosen to initiate high-level engagement with countries and RECs through the AUC. The resulting technical review report and its recommendations endorsed by country-level deliberations will then form the basis for modifying IPs and mobilizing resources to implement aflatoxin control initiatives based on the newly agreed upon country IP. PACA will also use other existing mechanisms and institutions to work with RECs and countries on the continent.

Mainstreaming aflatoxin control in the continental SPS agenda

PACA supports mainstreaming of aflatoxin issues into SPS activities at continental, regional, and national levels. Aflatoxins, being a complex multisectoral food safety issue, should be addressed in a holistic manner and could get support from policymakers and regulatory authorities by aligning continent-level coordination with the broader SPS frameworks through PACA. Moreover, regional aflatoxin standards and regulations could be promoted through the harmonization efforts that are underway by RECs. Therefore,

strengthening SPS systems through the CAADP process, RECs, and national regulatory agencies in Africa would contribute to aflatoxin control by directly promoting regulation enforcement and by creating incentives via increased trade and reduced transaction costs.

Harmonization of SPS measures is vital to the improvement of market access and both interregional and international trade. SPS capacity is unevenly distributed across Africa. Countries with weaker SPS capacity will find it more difficult to trade with countries whose SPS capacity is stronger. Uneven trade relationships will tend to widen if SPS barriers are not addressed. PACA advocates stronger SPS capacity and a harmonized approach to SPS issues across regions in Africa.

Adopting a three-track coordinated approach

From the outset, PACA was born from recognition of the need for holistic and coordinated approaches to addressing the complex problem of aflatoxin contamination in Africa. PACA pursues three-levels of coordination: (1) working toward coordinated continental, regional, and national efforts and impact; (2) addressing the effects of aflatoxins across the sectors of agriculture and food security, trade, and health; and (3) integrating policy and advocacy, capacity building, preharvest and postharvest measures, and regulations and standards. Such a holistic approach is the most viable way for the continent to address the aflatoxin problem.

The way forward

PACA employs multiple approaches to mobilizing support for achieving regionally harmonized standards and regulations, for the generation and dissemination of suitable technology-based solutions, for the generation and dissemination of knowledge and information to inform policy, and for increased investment in aflatoxin control initiatives. PACA's strategic plan for 2013–2022 has been endorsed by the PACA Steering Committee in August of 2013 and is already being implemented. PACA plans on fully utilizing events during the Year of African Agriculture (2014) to showcase its strategic thrust areas and aflatoxin control activities on the continent. Direct engagement with PACA will ensure that stakeholders involved in funding and implementing aflatoxin research, prevention, and control activities in Africa align their efforts with the continental strategic plan and the AUC frameworks while both avoiding overlaps and building on synergies.

FOR FURTHER READING

Aflatoxin Health Sheet, Aflatoxin Literature Review, Aflatoxin Trade Sheet, and PACA Brochure, all accessible at www.aflatoxinpartnership.org.

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IFPRI

TECHNOLOGY

AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Biological Controls for Aflatoxin Reduction

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Aflatoxin exposure is frequent and widespread in most African countries where the key staples, maize and groundnuts, are particularly vulnerable to aflatoxin contamination. *Aspergillus flavus* is the major cause of aflatoxin contamination although other aflatoxin producers are less frequently implicated. These fungi are ubiquitous in Africa where they occupy soil, colonizing diverse organic matter, and produce spores that associate with crops leading to aflatoxin formation in both fields and crop stores.

Exposure to aflatoxins can be reduced, at considerable cost, with monitoring and crop destruction. Effects of preharvest and postharvest interventions have thus far proved to be inconsistent, continuing to leave farmers vulnerable to contamination. Furthermore, although storage conditions are generally good in advanced agriculture systems, aflatoxins frequently form prior to harvest. Nevertheless, integrated aflatoxin management practices are recommended to reduce contamination. Preharvest crop contamination with aflatoxins costs farmers in the United States hundreds of millions of dollars annually (Robens 1988). In 1988, major US crop organizations joined the US Department of Agriculture (USDA) to form the Multi-crop Aflatoxin Working Group to increase research toward ending repeated epidemics of aflatoxin contamination; the development of resistant crops through breeding and transgenics were major emphases for the twenty years of this effort. However, when the program was discontinued in 2008, commercially useful resistant crops had not been developed (Brown et al. 2013), indicating that the pursuit of host resistance is a risky research strategy not guaranteed to succeed.

Fortunately, there was an unexpected and different kind of advance: a biological control technique that greatly reduces aflatoxin contamination of all susceptible crops across broad areas in a cost effective manner. This biocontrol, which is manufactured and marketed to scale in the United States as either Afla-guard® or Aspergillus flavus AF36, has been proven to be safe and environmentally sound with over a decade of testing and commercial use on cottonseed, groundnuts, maize, and pistachios. The technique reduces the aflatoxin-producing potential of fungal communities associated with crops by over 80 percent with a single application (Cotty 2006). These biocontrol products reliably reduce aflatoxins during crop development and maturation and remain the most effective aflatoxin prevention tools available in the United States. The biocontrol approach has been adapted to African environments.

Biocontrol principles

Aspergillus flavus occurs in nature in complex communities composed of diverse genetic groups called vegetative compatibility groups, which vary widely in aflatoxin-producing capacity. Some produce variable amounts of toxins (called toxigenic strains) while others produce none (called atoxigenic strains). Communities in different locations vary in composition and, as a result, in average aflatoxin-producing potential. This potential to produce aflatoxins influences the extent to which crops become contaminated. Modulating the structures of fungal communities in favor of atoxigenic strains can drastically reduce aflatoxins because the causal agent of contamination is reduced. Application of carefully selected atoxigenic strains at appropriate stages in crop development (just before resident *Aspergillus* populations begin to increase) shifts the community composition within the production area from one dominated by aflatoxin producers to one in which beneficial atoxigenic strains dominate. This results in decreased crop aflatoxin contamination. Changes in the *A. flavus* community structures induced by atoxigenic strain applications occur without increases to the overall amount of *A. flavus* in the environment and without increases in the amount of the crop infected.

Aflatoxin-producing fungi infect crops in the field. Although contamination frequently occurs prior to harvest, aflatoxin producers stay with crops during harvest, transport, and storage. If the storage environment is humid and warm, crop infection and the contamination process continue. Similarly, use of atoxigenic strains to competitively exclude aflatoxin-producers in the field provides carryover benefits in storage. One is that there are fewer aflatoxin-producers moving into storage. A second is that the atoxigenic strains stay with the crop and continue to protect against contamination until use.

Biocontrol strain identification

Biocontrol technology with atoxigenic strains uses native strains of *A. flavus* to competitively exclude both aflatoxin-producing *A. flavus* and other aflatoxin producers from the crop environment. These strains are selected from nature through an intense process using microbiological, DNA, and field-based methodologies to ensure that they are environmentally safe and adapted to provide effective, long-lasting, and area-wide reductions in aflatoxins (Mehl et al. 2012).

Biocontrol products and efficacy in Africa

The International Institute of Tropical Agriculture (IITA), the Agricultural Research Service (ARS) of USDA, and partners have successfully adapted this competitive displacement technology for use on maize and groundnuts in various African countries, developing biocontrol products with the trade name Aflasafe™. Aflasafe™ consists of a mixture of four native atoxigenic strains specifically targeted for a particular country or agroecosystem. Multistrain products such as Aflasafe™ may be superior to single-strain products because they display both immediate and long-term efficacy in diverse environments (Probst et al. 2011).

The method of production and application of atoxigenic strain–based biocontrol products can be fairly simple. A mixture of spores of biocontrol strains can be coated on a grain carrier (such as sorghum), which also serves as a food source. The atoxigenic strains grow and

multiply on and disperse from the carrier to initiate displacement of aflatoxin-producers in the field. The product is applied 2–4 weeks prior to crop flowering. For small fields, the product can be tossed onto crop and soil by hand at an application rate of 10 kg/ha.

Field testing of distinct biocontrol products in Burkina Faso, Kenya, Nigeria, and Senegal is producing extremely positive results (albeit as yet not peer reviewed or formally published; IITA 2013). The products have reduced aflatoxin contamination of maize and groundnuts consistently by 80–90 percent, and even as high as 99 percent, both at harvest and after poor storage. Product development is currently also underway in Ghana, Mozambique, Tanzania, and Zambia. The products in each country contain unique strains native to the target country and are developed in close collaboration with national institutions. National capacity building in all aspects of biocontrol product development is a key component of this collaboration. More recently, IITA and USDA-ARS have begun to develop regional products that will contain atoxigenic strains co-occurring in all target countries in the region. Regional products will reduce the burden of costly biopesticide registration processes and increase market reach.

With approval from national regulatory agencies, farmers have applied Aflasafe™ products in more than 3,000 ha in Kenya, Burkina Faso, Nigeria, and Senegal. In the countries where aflasafe development is most advanced (Nigeria, Senegal, and Kenya), farmer need and demand for Aflasafe™ will likely far exceed supply from the current lab-scale manufacturing method. A demonstration-scale manufacturing facility with a production capacity of five tons of Aflasafe™ per hour will be operational in October 2013 at IITA in Ibadan, Nigeria.

Advantages of biocontrol

Modifications to fungal communities caused by application of biocontrol strains carry over through the value chain, discouraging contamination in storage and transport even when conditions favor fungal growth. Unlike other methods of aflatoxin management requiring many time-consuming actions at various critical control points, biocontrol is a simple intervention in the field that by itself dramatically reduces aflatoxin contamination in crops from harvest until consumption.

Positive influences of atoxigenic strain applications carry over between crops and provide multiyear benefits. A single application of atoxigenic strains may benefit not only the treated crop but also rotation crops and second season crops that miss a treatment. Additionally, because fungi can spread, as the safety of fungal communities within treated fields improves, so does the safety of fungal communities in areas neighboring treated fields. For this reason, registration of the atoxigenic strain Aspergillus flavus AF36 by the US Environmental Protection Agency is classified as in the public interest.

Challenges and opportunities

Prior to large-scale use in a target country, biocontrol products must be registered with the respective national biopesticide regulatory agency. Registration is based on efficacy, safety, quality, and social/economic value of a product. Several efficacy, toxicology, and eco-toxicology parameters must be satisfied prior to registration. Gathering such data is expensive. For biopesticide registration in some countries, a fast-track system is in place that allows requests for science-based waivers for some registration data requirements. Negotiations for such waivers for registration are a significant challenge. To overcome this problem, regulatory agencies and key senior policymakers are consulted and sensitized before biocontrol product development begins in each country. These agencies are considered partners in the development process, and their advice is incorporated into research. For example, Nigeria's National Agency for Food and Drugs Administration and Control required a poultry-feeding study with Aflasafe™ to determine the safety of the product and waived other toxicity data requirements when the product was found safe in the study. Except in a few African countries, the biopesticide registration procedure is not well developed. Efforts are underway to develop regional guidelines for biopesticide registration to enable use of biopesticides in all countries in the region when approved by the regional regulatory agency.

Although Aflasafe™ is available for purchase, there may be other mechanisms for supplying farmers with Aflasafe™ either on an emergency basis or through the development of nonprofit governmental or nongovernmental organizations. In the United States., a governmental organization (The Arizona Cotton Research and Protection Council) supported by a crop tax distributes the atoxigenic strain product, Aspergillus flavus AF36 to farmers in Arizona at cost.

Biocontrol technologies, in conjunction with other aflatoxin-management tools, can profitably link farmers to markets, improve health of people and animals, and increase food safety. Technology has a high cpacity to reduce aflatoxins. Widespread biocontrol adoption cannot occur, however, without first creating a flexible and enabling system for biopesticide regulation in tandem with other policy and institutional support. Licensing and stewardship of biocontrol products must receive attention to ensure that the quality and affordability of the products are not compromised.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Managing Aflatoxin Contamination of Maize: Developing Host Resistance

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Aflatoxins are toxic and highly carcinogenic secondary products produced by the *Aspergillus flavus* (*A. flavus*) and *Aspergillus parasiticus* family of molds. When produced on a susceptible crop, aflatoxins contaminate maize grain products, threatening human and animal health. *A. flavus* is an opportunistic pathogen occurring with higher incidence on maize grown under stressed conditions, including late-season drought and high temperatures during kernel filling. Insect or mechanical damage to kernels can increase the infection rate of *A. flavus* and aflatoxin levels, which can also worsen with poor harvesting and storage conditions because grain that is insufficiently dried prior to storage provides an ideal environment for fungal growth. In addition to proper storage conditions, management strategies to reduce aflatoxin contamination also include biological control: the use of non–toxin producing *A. flavus* strains to prevent further infection by toxin-producing strains. Additionally, decontamination is sometimes possible, although the decontaminating agents themselves may be harmful and expensive. An important, safe, and preventative strategy for aflatoxin elimination is the development of host-plant resistance in order to inhibit fungal colonization or toxin production. Host resistance is an economical approach that is easy to disseminate, requires no additional production or management resources, leaves no harmful residues, and is compatible with other control measures, including proper storage and biological control. This brief highlights the advances that have been made to date in the identification of host resistance to *A. flavus* and aflatoxin accumulation while also laying out the breeding requirements for developing resistant maize cultivars.

Aflatoxin detection

Because aflatoxins are toxic at very low levels, detection methods must be sensitive and accurate. Although different methods can be used to detect and quantify aflatoxins, an inexpensive, robust, and high-throughput method is needed for large-scale breeding programs. The bright greenish-yellow fluorescent (BGYF) light technique can quickly detect maize lines supporting high fungal growth. This method uses a black light assay to observe fluorescence from kojic acid, a secondary metabolite produced by *A. flavus* in grain. Lines that show fluorescence are eliminated, and those with no fluorescence must be assayed using the more sensitive enzyme-linked immunosorbent assay (ELISA), high performance liquid chromatography or ultra-performance liquid chromatography (HPLC or UPLC), or affinity columns to determine aflatoxin levels. A cost-efficient ELISA technique is used at the International Maize and Wheat Improvement Center (CIMMYT) for routine detection and quantification of aflatoxins in breeding programs, providing results that correlate well with UPLC (Figure 1).

Tools to identify resistant germplasm

Maize kernel infection by *A. flavus* is highly variable under natural conditions. Selection of resistance genes relies on the ability to subject all plants both to equally high levels of active fungal infection to avoid escapes (plants that look resistant because they have not been infected) and to high-throughput phenotypic screening capacity. Aflatoxin trials must be carried out in replicated field plots over multiple years and locations because resistance is highly affected by the environment in which the infected plants are grown. Several techniques for mass inoculation of maize germplasm under field and laboratory conditions have been developed and are available (Brown et al. 1993). Standardized systems for data acquisition and exchange among breeding programs, such as those developed by CIMMYT, also help to accelerate both the identification of *A. flavus*– and aflatoxin-resistant germplasm and the development of tolerant maize cultivars.

Generation of resistant germplasm

Methods to achieve resistance to *A. flavus* and aflatoxin accumulation include (1) prevention of fungal infection of maize, which is especially important under stressed environmental conditions; (2) prevention of subsequent growth of the fungus once infection has occurred; (3) inhibition of aflatoxin production following infection; and (4) degradation of aflatoxins by the plant or fungus. Development of aflatoxin-resistant varieties is thus a complex process that may include direct selection for resistance to fungus and aflatoxin accumulation, indirect selection for resistance or tolerance to biotic and abiotic stresses, or selection for morphological traits such as ear, kernel, and husk characteristics that impede or delay fungal introduction or growth. Breeders at CIMMYT are evaluating known sources of aflatoxin resistance under drought conditions, as well as drought- plus heat-tolerant germplasm for possible resistance to *A. flavus* and aflatoxin accumulation. Sources of resistance to many of these factors have been identified and are now being combined to develop aflatoxin-resistant maize germplasm adapted to various agroecologies. Doubled haploid (DH) technology produces new pure breeding lines in a very short time as compared to the several generations needed to create pure lines via traditional self-pollination. DH technology is being used at CIMMYT to rapidly develop inbred lines combining *A. flavus* and aflatoxin resistance with other important agronomic traits. These DH lines are now being evaluated to identify new superior lines combining aflatoxin resistance, drought and heat tolerance, and good agronomic performance.

Quantitative trait loci (QTL) for both fungal and aflatoxin accumulation resistance have been mapped, and the transfer of these QTL into new elite germplasm is underway. This is a challenge for breeders, as *A. flavus* and aflatoxin resistance is controlled by a large number of genes with small effects whose performance varies by environment. Markers linked to QTL or genes associated with aflatoxin resistance may enable rapid selection gains for resistance. The recent elucidation of the fungal aflatoxin biosynthetic pathway and the regulatory genes for this pathway provide the

potential for developing kernel mechanisms that directly inhibit aflatoxin biosynthesis.

## Promising new technologies to speed up aflatoxin resistance

Genes, QTLs, and genetic mechanisms contributing to *A. flavus* and aflatoxin resistance are being identified using new tools and techniques. Next-generation sequencing and association mapping is being used to identify DNA and RNA sequences involved in resistance. Final confirmation of genomic regions providing improved resistance using near lisogenic lines is nearing completion for several QTL and gene sequences at CIMMYT and the US Department of Agriculture's Agriculture Research Service (USDA-ARS). Finally, new techniques involving RNA interference (RNAi) gene silencing may allow transgenic maize plants to resist infection by *A. flavus*, using DNA sequences from the fungus itself to allow recognition and prevent growth of the fungus in the plant.

Technology-implementation challenges

Accumulation of aflatoxins in maize occurs following a complex series of interactions among maize, the environment, the pathogen, insects, and crop-management practices. Selection must be done simultaneously for multiple stresses in order to combine drought and heat tolerance, resistance to insects (especially ear-feeding insects), and resistance to the pathogen. These stress tolerances must be combined with improved agronomic performance in new maize varieties for adoption of aflatoxin-resistant cultivars to occur, as farmers will not grow low-yielding varieties regardless of aflatoxin resistance. The negative impacts of aflatoxin consumption are generally slow and difficult to recognize, while hunger due to insufficient food is immediate and pressing. The challenge is to systematically identify the best sources of resistance, introduce them into adapted maize germplasm, and make the germaplasm available in areas where aflatoxin contamination is a problem. Established procedures for field inoculation, measurement of aflatoxin levels, and generation of doubled haploids, together with new techniques for implementation of marker-assisted breeding, gene expression studies, proteomics, and RNAi, will lead to more opportunities for efficient development of aflatoxin-resistant elite maize cultivars. Work has progressed on the development of resistant maize varieties, and resistance is being pyramided and combined with other disease

FIGURE 1 Relationship between aflatoxin quantification using ELISA and UPLC

$y = 1.661x - 0.4924$
$R^2 = 0.98901$
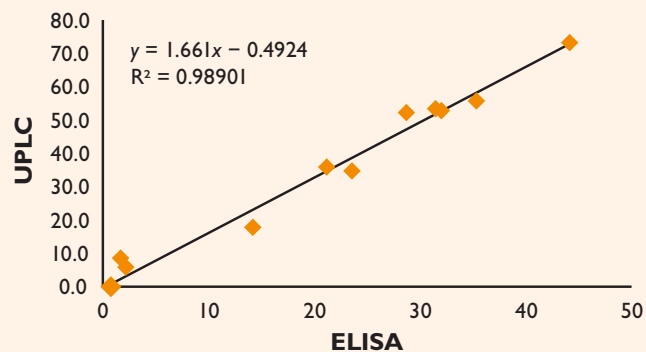
Source: Author's calculation, 2012.
Notes: ELISA = enzyme-linked immunosorbent assay. UPLC = ultra-performance liquid chromatography. The high correlation (r = 0.99) reveals the reliability of ELISA to detect and quantify aflatoxins in breeding programs.

and abiotic (heat and drought) stress-resistance genes by several collaborating institutions. Because this is a long-term process, no new cultivars are yet ready for release. Good progress has been made, yet final testing of new breeding lines must be performed in replicated field trials before release. Support for aflatoxin resistance breeding must continue in the meantime.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Reducing Aflatoxins in Groundnuts through Integrated Management and Biocontrol

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The groundnut, or peanut (*Arachis hypogaea* L.), is an important food and fodder crop in the farming systems of developing countries. The seed is high in oil (close to 50 percent for many varieties) and protein (~26 percent) and an important source of vitamins and dietary fiber. Groundnuts, like all legumes, are also important due to their ability to fix atmospheric nitrogen, a critical and often limiting nutrient for crops in degraded soils. Global groundnut production is concentrated in Africa (40 percent) and Asia (55 percent). As discussed in other briefs in this series, high aflatoxin levels pose human health risks and are also a barrier to expanding trade in and commercial use of groundnuts and other crops.

Aflatoxins in groundnuts

Aflatoxins are chemical metabolites naturally produced by the soilborne saprophytic fungi *Aspergillus flavus* (*A. flavus*) and *A. parasiticus* (or less commonly by *A. nomius*) that contaminate groundnuts and other crops in the field or during post-harvest handling. Contamination varies from year to year as well as within the field and is particularly high when plants are exposed to stresses toward the end of the growing season. Preharvest infection and aflatoxin contamination often occur when the plant is exposed to moisture and heat stress during pod development, when pods are damaged by insects or nematodes or when they are mechanically damaged during cultural operations. Due to the reliance on rainfall for watering crops and the recent variations experienced with weather patterns, these conditions commonly occur. Postharvest infection in groundnuts is influenced by shelling methodology, relative humidity, temperature, and insect damage. Some strains of *A. flavus* also produce cyclopiazonic acid (CPA), a harmful mycotoxin that is currently not regulated (Abbas et al. 2011). In most developing countries the level of aflatoxin contamination is extremely high. For example, results of recent studies in Mali have

shown levels of contamination in groundnuts in excess of 3,000 parts per billion (ppb) with a mean contamination of 164 ppb (Waliyar et al., forthcoming). These levels are much higher than international standards allow for human consumption (4 ppb in the EU and 20 ppb in the United States). Results from Mali have revealed that only 30–55 percent of all groundnut products are safe to eat by EU standards (Waliyar et al., forthcoming). Further, results from our studies in Mali show that granaries have a significantly higher aflatoxin load during the storage period (October to June) due to high moisture and temperatures recorded during this time of year (IFPRI 2012). It is thus imperative to improve management of aflatoxins in groundnuts for food, health, and nutritional security.

Management of aflatoxins

Several approaches to reducing aflatoxin contamination have been proposed (Table 1). The rationale for most aflatoxin management practices relates to the effective management of moisture, particularly after the cessation of rains, to ensure that plants will not undergo moisture stress. It is also important to ensure that pods are well formed and not breached by pathogens or insects. On-farm tests have been conducted in several countries in Asia and Africa to investigate not just technologies, such as the use of varieties that are tolerant of or resistant varieties to *A. flavus*, but also cultural practices, such as the use of soil amendments, and postharvest handling on yield and aflatoxin contamination.

Tolerant varieties

Rural farmers in developing countries are often resource poor and have a limited ability to implement integrated management approaches. Host plant resistance, when combined with pre- and post-harvest strategies, is thus often the most practical and effective approach. For the past decade, breeding groundnut varieties resistant

TABLE 1	Good agricultural practices (GAPs) for aflatoxin management
Preharvest GAPs	**At–harvest and postharvest GAPs**
• Use of *A. flavus* resistant/tolerant varieties	• Harvesting the crop at the correct maturity
• Selection of healthy seeds	• Use of water-harvesting to preserve available moisture
• Early planting	• Use of *A. flavus* resistant/tolerant varieties
• Avoidance of mono-cropping	• Avoidance of damage to pods during harvest
• Application of *Trichoderma* at 1 kilogram/hectare	• Drying seed to 8 percent moisture level
• Plowing before sowing	• Stripping the pod immediately after drying
• Appropriate weeding	• Removing immature pods attached to the haulms
• Application of farmyard manure at 2.5 tons/hectare before planting	• Removing damaged, shriveled, and immature pods
• Treatment of foliar diseases using 1–2 sprayings of Kavach	• Not mixing clean harvested pods with gleaned pods
• Application of lime or gypsum at 400 kilogram/hectare at flowering	• Avoidance of re-humidification of pods during shelling or in storage
• Mulching with crop residues at 40 days after planting	• Fumigation of pods with insecticide to avoid insect damage during storage
• Maintenance of optimal density of plants in the field	
• Avoidance of end-of-season drought through irrigation (if possible)	
• Removal of dead plants from the field before harvest	

Source: Authors' compilation, 2013.

to *A. flavus* infection has been a focus of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). A number of varieties with resistance to or tolerance of *A. flavus* infection and aflatoxin contamination have been released or are in various stages of testing. Study results indicate that, despite high variation in *A. flavus* infection and subsequent aflatoxin incidence, significant improvement in the level of varietal resistance (less than 20 ppb contamination) is possible because we were able to identify varieties that showed less than 4 ppb aflatoxin—in comparison to susceptible varieties with more than 2,000 ppb. Breeding efforts have focused on reducing groundnut maturity periods to escape end-of-season drought, and the emphasis has been on the identification of short-duration farmer-preferred lines with resistance to or tolerance of *Aspergillus* spp.

Preharvest management

A number of agronomic practices minimize preharvest infection by *A. flavus* (Table 2). Among them are the applications of lime (or any calcium source) and farmyard manure (FYM). Studies have shown that application of lime alone can reduce aflatoxin contamination by 72 percent, while application of FYM reduces aflatoxins by 42 percent under field conditions. When combined, the two treatments result in aflatoxin contamination being reduced up to 84 percent.

At-harvest and postharvest management

Cultural practices, starting with harvesting the crop at the right maturity and wind row drying, have been shown to be effective in reducing aflatoxin contamination in groundnuts. In addition, management practices—such as using appropriate drying techniques (including drying on raised surfaces or on mats), reducing kernel moisture content to 8 percent, proper threshing methods, and sorting the kernels before sale or consumption—significantly influence the level of aflatoxin contamination. Aflatoxin reduction under these practices can vary from 63 to 88 percent depending on location. Practices such as wetting groundnut shells to facilitate shelling increase the risk of aflatoxin contamination.

Biocontrol agents

A biocontrol agent refers to a microbial antagonist that keeps the disease-causing agents in check by reducing their populations to economically insignificant levels around the susceptible or target host organ/tissue, resulting in no disease incidence. Several bacterial and fungal biocontrol agents have already been screened all over the world to identify potential antagonists to *A. flavus*.

Although promising biocontrol agents have been identified for groundnut aflatoxin management, research is more advanced on

TABLE 2	Percent reduction in aflatoxin contamination by single or multiple agronomic practices

Agronomic practice	Aflatoxin reduction
Cereal crop residues	28
Farmyard Manure (FYM)	42
Combination of FYM and residues	53
Lime	72
Combination of lime and residues	82
Combination of FYM, lime, and residues	83
Combination FYM and lime	84

Sources: Waliyar et al., 2006, 2007.

other crops such as maize (brief 16). In terms of the peanut, one commercial non-toxigenic *A. flavus* strain, NRRL 21882, has been commercialized (as Afla-guard®) thus far in the United States (Dorner 2005). However, its efficacy in multi-environment and multi-state conditions and under longer time horizons has yet to be understood. ICRISAT has identified a host of potential biocontrol agents that work against aflatoxin-producing molds in groundnuts, including antagonistic bacteria (*Pseudomonas* spp), fungi (*Trichoderma* spp), and actinomycetes (*Streptomyces* spp) strains. Promising biocontrol agents tested under greenhouse and field conditions in Africa and Asia proved to be very effective in reducing aflatoxin contamination by 79 percent (Harini et al. 2011). Efficacy demonstrations in the field with these biocontrol agents also were effective. ICRISAT is working with commercial providers to assess the potential of making the biocontrol agents more widely available to small-scale farmers.

Conclusions

There are various simple cultural and other practices that can be used to manage aflatoxins in groundnuts. To enhance the management of aflatoxins in groundnuts, it is recommended that locally adaptable practices be identified, tested on-farm, and scaled up for groundnut farmers. Biocontrol is also a promising strategy for future development. Challenges to the adoption and use of good practices for aflatoxin management include lack of farmer knowledge, little market reward for quality due to a lack of standards and diagnostics, and little attention to this issue from policymakers.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

Improving Diagnostics for Aflatoxin Detection

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Researchers, donors, and governments are calling for the scale of the response to the aflatoxin problem to be informed by the scope of the risks involved. While current research establishes that a great deal of the global food supply is at risk, especially in developing countries, information on aflatoxin contamination and potential interventions is far from comprehensive, hindered in large part by a lack of information on the quantitative, geographic, and temporal occurrence of the toxins in various commodities. A set of diagnostic solutions is required that can span the dimensions of both scale (from smallholder farmer bags to large silos) and setting (from smallholder farms and village mills to large commercial mills). Of particular need is a new generation of inexpensive and portable diagnostics for testing on the front lines, particularly at the farm and village mill. These diagnostics must be underpinned both by sampling methods appropriate to developing countries and by reference labs accessible to key partners along the value chain on the ground.

The problem: Lack of diagnostics for use in the field

Two broad types of information are needed about aflatoxins: one is the scope and severity of the problem, as well as potential solutions, and the other is the quality, end use, and price differences of at-risk commodities. The aflatoxin problem cannot be addressed with the current network, which largely comprises a few minimally equipped laboratories using a non-standardized set of procedures.

A number of ongoing initiatives seek to address this lack of accessible, affordable, and context-appropriate diagnostics. One effort is the Australian Agency for International Development (AusAID)-funded Biosciences eastern and central Africa (BecA)-Commonwealth Scientific and Industrial Research Organisation (CSIRO) CAAREA project, encompassing a multidisciplinary team focused on diagnostics as one part of a multi-pronged approach to reducing aflatoxins. The project has established an aflatoxin research and capacity-building platform at the BecA-International Livestock Research Institute (ILRI) Hub in Nairobi, Kenya, which is open to biosciences researchers focused on improving food security in Africa.

Sampling issues

Aflatoxin risks are related to the concentration of mycotoxins in food commodities consumed by both humans and production animals. The first consideration for the development of appropriate diagnostics is sampling and scale. Measuring aflatoxin levels in grain products is complicated by the extremely skewed distribution of mycotoxin. Consequently sampling/sub-sampling is widely recognized as the largest source of error in aflatoxin measurement—accounting for up to 90 percent of the error in testing the variance in aflatoxin levels between the measured sub-sample and the whole sample, compared to variance from the analytical test itself (Whitaker 2003). Less than 1 percent of kernels may be contaminated, but these kernels can contain extremely high aflatoxin levels: up to

1,000,000 nanograms per gram (ng/g) for individual peanuts (Cucullu et al. 1986) and 400,000 ng/g for individual maize kernels (Shotwell, Goulden, and Hesseltine 1974). It is thus critical for the accuracy of any analysis that a "representative" sample is obtained for testing. Various sampling and sub-sampling protocols exist (Richard 2006), but these have generally been designed for container and truckload sampling and are not readily applicable to Africa's small-scale farming and village mills. Even the sampling of truckloads of 20 kg bags of grain is complicated when these bags have not originated from a single source, as occurs often with deliveries to commercial mills in Africa. Research efforts are underway to test a range of samples along the less-studied smaller end of the scale, from single kernels to ears in a field, to develop context- and diagnostic test–appropriate sampling procedures. Such sampling strategies are as important as the tests themselves.

Available diagnostic technologies

A number of established diagnostic technologies are already available. However, as shown in Table 1, they are typically expensive, have lower throughput, and are not portable and therefore not available for use in the field.

Available methods of analysis range from the in-field rapid diagnostic strips such as AgriStrips used in rapid test kits to competitive enzyme-linked immunosorbent assay (ELISA) with colorimetric detection to spectroscopic methods.

Aflatoxins possess significant ultraviolet (UV) absorption and fluorescence properties, and chromatographic methods—either high performance liquid chromatography (HPLC) or thin layer chromatography (TLC) with UV or fluorescence detection—are widely used. Such methods require sample extraction and extract clean-up by solid-phase extraction (SPE) or immunoaffinity chromatography (IAC) followed by chromatographic separation and aflatoxin detection. Total aflatoxins can also be measured by direct fluorescence measurements of these purified extracts (for example, VICAM).

Liquid chromatography-mass spectrometry (LC-MS) technology offers the advantage of "dilute and shoot" techniques where simple sample extracts are analyzed without clean-up, and with the added advantage of multi-mycotoxin analysis whereby a range of mycotoxins can be analyzed in the same sample analysis run (Sulyok et al. 2006).

A new generation of cheap and portable diagnostics is needed so researchers, regulators, the private sector, extension agents, and others can address the problem in developing countries. A few promising technologies under exploration include near infrared spectroscopy (NIR), electronic nose (e-nose), and paper microfluidics.

NIR is a rapid, non-destructive, predictive technology that has long been used routinely in plant breeding and in industrial applications to simultaneously predict multiple parameters. NIR can be used with solid or milled material and on liquids such as milk. NIR has identified correlation with aflatoxin levels and could

TABLE 1   Diagnostic technologies available commercially and under development

Diagnostic technology	Technology cost	Sample cost ($)	Prep time (+)	Portable?	Discrimination at regulatory limits (10 ppb)?	Multi-mycotoxin analysis in same run?	Potential use for milled grain?	Potential use for whole grain?
VICAM	$	$$$	+++	No	Yes	No	Yes	No
ELISA	$	$$	+++	No	Yes	No	Yes	No
UPLC	$$	$$	+++	No	Yes	No	Yes	No
LC-MS	$$$	$$	+	No	Yes	Yes	Yes	No
TLC	$	$$	++	No	Yes	No	Yes	No
NIR (proof of concept underway)	$$	$	+	Yes	No	Potentially	Potential application > 200 ppb (in progress)	Potential application in kernel sorting (in progress)
E-Nose (proof of concept underway)	$	$	+	Potentially	No	Unknown	(In progress)	No
AgriStrips and other dipsticks	$	$$	+	Yes	Yes	No	Yes	No

Source: Authors' calculations, 2013.
Note: $ = low/$$$ = High cost (relative within column); + = low effort/ +++ = high effort.

possibly be used in the screening of high levels of aflatoxins (above 200–500 parts per billion or ppb) in milled grains—though so far they have not been proven able to detect levels at regulatory limits for human consumption (10–20 ppb). Some developed countries have different limits for feeds (up to 300 ppb) for which NIR may be suitable. NIR may help in the removal of extremely contaminated kernels (above 1,000 ppb) via single-kernel sorters that have been developed based on spectral sorting (Pearson et al. 2004); spectral sorting for aflatoxins is already done commercially for groundnuts in the United States. Wet chemistry suggests that, if successfully developed, this approach could reduce the contamination levels of bags of maize grains from almost 100 times the legal limit to below the legal limit by removal of as little as three percent of the contaminated grains (Turner et al. 2013).

E-nose is a technology that uses an array of sensors to detect volatiles emanating from a sample. Like NIR, wet chemistry measurements are used to calibrate e-nose to predict a given chemical. E-nose, which is currently being used in a project designed to detect diseases in human breath (Berna et al. 2013), is also being adapted for possible use in aflatoxin detection. Advantages include that it could largely overcome sampling issues because the headspace is produced by the entirety of a sample; there is no sample preparation required, except for milling; and it could potentially be as portable and cheap as an inexpensive mobile phone.

Other recent developments include an immunoassay-based lateral flow device that can quantitatively determine four major aflatoxins in maize in only ten minutes (Anfosi et al. 2011). Paper microfluidics are also being developed for various food safety issues by organizations such as Diagnostics for All, and may provide inexpensive and rapid point-of-use diagnostics.

Challenges to policy and technology implementation

A wide range of potential diagnostics needs to be explored so that the right suite can be selected for use in the network of reference labs and field networks. Diagnostics need to be part of a system for monitoring and managing aflatoxin risk at all critical points, enabling the systems in developing countries to address the aflatoxin issue the way systems in the more-developed countries have largely addressed it. Decontamination procedures and changing regulations for variable limits according to use are also required to complement diagnostics. Otherwise, contaminated commodities are either stored in a state of limbo or re-enter the market via avenues that skirt monitoring and regulation, ultimately reaching the most vulnerable consumers whom the diagnostics were designed to protect in the first place.

In conclusion, a strategic and systemic approach is needed to ensure safe food for all citizens of the world.

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AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY

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NOTE: A full summary of the project and its activities, and background on the team members whose work contributed to this summary work, is available at http://programs.ifpri.org/afla/afla.asp.

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FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

AFLATOXINS: FINDING SOLUTIONS FOR IMPROVED FOOD SAFETY
Edited by Laurian Unnevehr and Delia Grace

Aflatoxins are a naturally occurring carcinogenic byproduct of common fungi on grains and other crops, particularly maize and groundnuts. They pose a significant public health risk in many tropical developing countries and are also a barrier to the growth of domestic and international commercial markets for food and feed. In recent years the aflatoxin problem has garnered greatly increased attention from both policy and donor communities around the globe.

What can be done to reduce the detrimental impacts of aflatoxins? Because growth of the molds that produce aflatoxins is caused by multiple factors, and because they must be controlled along the entire value chain from production to consumption, only a robust multifaceted approach to controlling aflatoxins is likely to be effective.

The nineteen briefs in this set thus provide different perspectives on aflatoxin risks and solutions. The analyses fall under four broad themes: (1) what is known about the health risks from aflatoxins; (2) how to overcome market constraints to improved aflatoxin control by building new market channels and incentives; (3) what is the international policy context for taking action in developing countries; and (4) what is the state of research on new aflatoxin control technologies, including new methods for aflatoxin detection, crop breeding, biological control, food storage and handling, and postharvest mitigation.
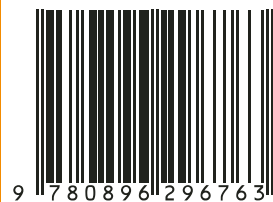
These briefs collectively provide a much clearer picture of the state of current efforts at combatting aflatoxins. They also identify what gaps loom particularly large—including the need for contry-specific risk analysis and for testing integrated solutions for the entire supply chain—in our global efforts to effectively reduce human exposure to aflatoxins and increase the economic returns to smallholders in agriculture.

This entire publication and each individual brief are available online: www.ifpri.org/publication/aflatoxins-finding-solutions-improved-food-safety.

Aflatoxins: Finding Solutions for
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