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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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**Felicia Wu** ([fwu@msu.edu](mailto:fwu@msu.edu)) is a professor of agricultural, food, and resource economics at Michigan State University, East Lansing.



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A member of the CGIAR Consortium | A world free of hunger and malnutrition

2033 K Street, NW, Washington, DC 20006-1002 USA | T. +1.202.862.5600 | F. +1.202.467.4439 | Skype: IFPRIhomeoffice | [ifpri@cgiar.org](mailto:ifpri@cgiar.org) | [www.ifpri.org](http://www.ifpri.org)

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