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EVALUATING THE RISK OF CLIMATE CHANGE–INDUCED AFLATOXIN CONTAMINATION IN GROUNDNUTS AND MAIZE

Results of Modeling Analyses in Six Countries

Timothy S. Thomas, Richard Robertson, and Kenneth J. Boote

Aflatoxins are fungal metabolites—mainly produced by *Aspergillus flavus* and *Aspergillus parasiticus*—that occur naturally in agricultural fields, generally at low concentration levels. These levels can increase under certain weather conditions that cause plant stress, such as drought. Levels can also increase in response to insect damage or when crops are stored, processed, and transported postharvest. Aflatoxins have serious health implications for humans when consumed directly as food or indirectly through products like milk from animals exposed to contaminated feed. Aflatoxins threaten food safety in many countries, especially in tropical and subtropical climates, but also in temperate climates where water stress is a factor during warm growing seasons. At very high levels of contamination, aflatoxin exposure can cause death shortly after consumption. At habitual low levels of exposure, contamination can lead to liver cancer and immune suppression, and it is strongly associated with childhood stunting, which increases vulnerability to infectious diseases and can cause cognitive impairment. Particularly challenging is the fact that aflatoxins are not destroyed when crops are cooked or when products like milk are processed (although contaminated peanuts can still be used for peanut oil because filtration removes most of the aflatoxins). Livestock can tolerate higher contamination levels than humans, but high levels of contamination also affect animal health, growth, and productivity (that is, yields of meat, milk, and eggs). From an economic perspective, concerns over aflatoxin contamination have effectively stymied exports of certain crops, such as maize and groundnuts, from affected countries.

This policy note summarizes research that assessed (1) the likely impact of climate change on aflatoxin contamination in groundnuts (in Burkina Faso, Niger, and Nigeria) and in maize (in Burkina Faso, Honduras, Guatemala, Nepal, Niger, and Nigeria), and (2) the impact of temperature, precipitation, and soil types on aflatoxin contamination. A future goal is to improve the calibration of the modeling software utilized to enable its use as an early warning tool for aflatoxin hotspots.

The Projected Impact of Climate Change on Aflatoxin Contamination in Maize and Groundnuts

Groundnuts

For groundnuts, the simulated baseline frequency of aflatoxin contamination in harvests is comparatively high for both Burkina Faso and Niger (39 and 56 percent of area, respectively), whereas it is comparatively low for Nigeria, which has significantly more area planted to

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TABLE 1. The projected frequency of aflatoxin-contaminated groundnut harvests by country and climate model, 2050

Country	Area (hectares)	Baseline frequency of contaminated harvests, 1960–1990 (%)	Projected frequency of contaminated harvests in 2050 (%)				
			GFDL	HadGEM	IPSL	MIROC	NorES
Burkina Faso	312,780	38.8	42.7	34.3	42.5	3.8	11.6
Niger	322,613	55.7	85.4	60.6	74.4	29.7	41.9
Nigeria	2,169,602	14.0	25.0	16.9	18.5	5.5	11.0

Source: Thomas, Robertson, and Boote (2019).

Note: The frequency of contamination is determined as the share of harvests with aflatoxin concentrations of 4 parts per billion or higher.

DATA AND METHODOLOGY

The study utilized two new models developed by a team from the University of Florida and subsequently tested by a team from the International Food Policy Research Institute (IFPRI) with the support of University of Florida researchers. The models form components of the Decision Support System for Agrotechnology Transfer (DSSAT) package of crop simulation software (Jones et al. 2003), which is recognized as one of the most accurate tools for biophysical analysis of crop growth. The models simulate crop growth at the pixel level (every five arc-minutes, which is roughly 9 kilometers at the equator) in daily increments of time over a window of possible planting dates. Changes in yields and contamination are also calculated at the pixel level, and then aggregated to the national level using weighted estimates of harvested area (You et al. 2014). The groundnut aflatoxin model was designed to predict aflatoxin contamination based on soil temperature, crop water stress, and pod-zone soil water status (a 5-centimeter-deep zone that drives aflatoxin synthesis in groundnuts). The maize aflatoxin model was designed to predict contamination based on air temperature and crop water stress.

The IFPRI research team used these aflatoxin models to simulate contamination levels for the baseline period 1960–1990 and under five future climate change scenarios in 2050 (using the 2041–2070 period) as delineated by five different global climate models: (1) General Fluid Dynamics Laboratory (GFDL); (2) Hadley Centre Global Environmental Model (HadGEM); (3) Institut Pierre-Simon Laplace (IPSL); (4) Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (University of Tokyo), and National Institute for Environmental Studies; and (5) the Norwegian Climate Model (NorES). All five models assume a high emissions scenario (Representative Concentration Pathway 8.5).

Results indicate the frequency of contaminated harvests over a given timeframe—1960–1990 for baseline comparison levels (that is, without climate change), and 2041–2070 for future projections (that is, with climate change). Contamination is defined as aflatoxin concentrations of 4 parts per billion or higher. For more detailed information on the data and methodology underlying the study, see the discussion paper on which this policy note is based (Thomas, Robertson, and Boote 2019).

groundnuts (Table 1). This difference can be explained by the hotter, drier conditions in the northern two countries compared with Nigeria. Projected increases in the frequency of contamination under climate change are fairly moderate for both Burkina Faso and Nigeria, with the MIROC model projecting a comparatively low incidence of contamination in 2050 (3.8 percent for Burkina Faso, and 5.5 percent for Nigeria). On the other hand, three of the five models project a substantial increase in the frequency of contamination in groundnut harvests in Niger in 2050.

Maize

Niger only produces a small amount of maize, but the projected baseline frequency of contaminated harvests is 43 percent (Table 2). Three of the climate models project an increase in this frequency in 2050, and two of the models project a decline. Burkina Faso and Nigeria have low baseline contamination (8 and 9 percent of harvests, respectively). All five climate models project increases for Nigeria in 2050, and four of the five models project increases for Burkina Faso. Under the MIROC model, which predicts higher precipitation levels but only a modest increase in temperature, the frequency of aflatoxin contamination in 2050 is projected to decline to comparatively small shares of harvests in both Burkina Faso and Niger (2.3 and 1.5 percent, respectively).

TABLE 2. The projected frequency of aflatoxin-contaminated maize harvests by country and climate model, 2050

Country	Area (hectares)	Baseline frequency of contaminated harvests, 1960–1990 (%)	Projected frequency of contaminated harvests in 2050 (%)				
			GFDL	HadGEM	IPSL	MIROC	NorES
Burkina Faso	419,938	7.6	22.1	18.5	16.3	2.3	10.9
Niger	7,496	42.8	62.1	54.1	48.2	1.5	27.9
Nigeria	3,623,435	8.9	18.0	15.3	13.8	11.5	12.5
Nepal	268,459	0.2	7.2	1.0	2.0	0.8	0.6
Guatemala	687,515	4.4	6.0	27.6	28.8	15.9	14.6
Honduras	283,202	9.5	11.4	43.4	46.1	41.8	33.2

Source: Thomas, Robertson, and Boote (2019).

Note: The frequency of contamination is determined as the share of harvests with aflatoxin concentrations of 4 parts per billion or higher.

The simulated baseline frequency of contamination in Nepal is atypically low (0.2 percent), as are the 2050 projections from four of the five climate models (Table 2). Analysis of the country's climate trends indicates a notable decline in yearly precipitation, and an increase in mean daily maximum temperature during 1980–2010. Since the baseline data are for 1960–1990, it is conceivable that contamination was not previously a problem but has become one over time due to climate change. The GFDL model projects an increase in contamination to 7.2 percent of harvests in 2050; this suggests that—had the simulations incorporated the lower precipitation and higher temperatures Nepal appears to have experienced in recent decades—the study results would have more closely matched levels reported in localized field studies.

Baseline contamination in both Guatemala and Honduras is comparatively low (4.4 and 9.5 percent of harvests, respectively), but all five models indicate higher frequencies of contamination for both countries in 2050, ranging from 6.0 to 28.8 percent for Guatemala, and 11.4 to 46.1 percent for Honduras (Table 2).

The Projected Impact of Precipitation, Temperature, and Soil Types on Aflatoxin Contamination

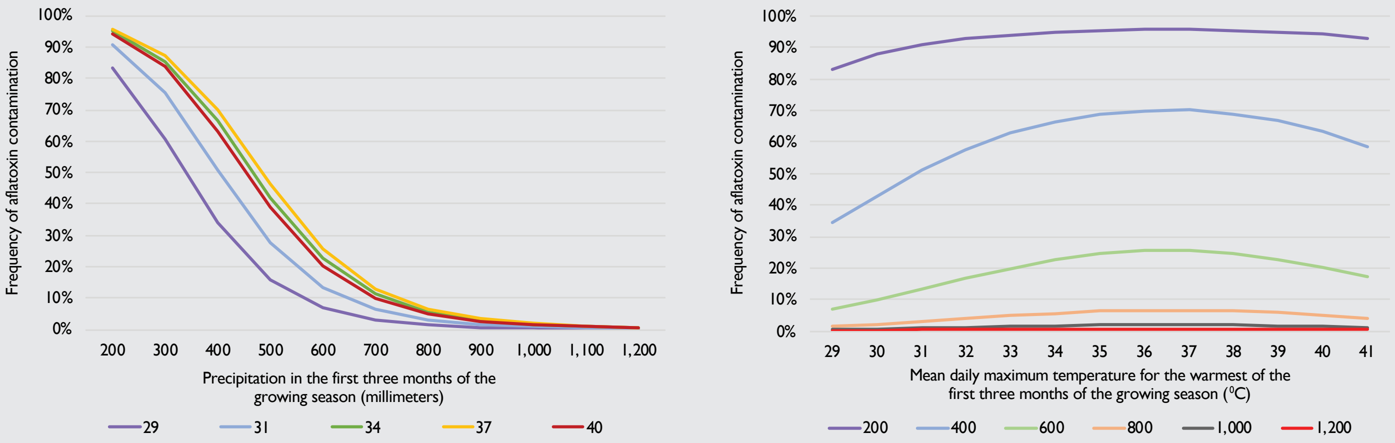
The Impact of Precipitation and Temperature on Aflatoxin Contamination in Groundnuts

Results from DSSAT's aflatoxin model for groundnuts show that, when precipitation levels are above 800 to 900 millimeters during the first three months of the growing season, the frequency of aflatoxin-contaminated harvests is very low (Figure 1a). Relatedly, when precipitation in the first three months of the growing season is low, the frequency of aflatoxin contamination in groundnuts is very high because the non-irrigated crop is water stressed—that is, 80 percent or higher for all temperatures in the range observed for the country in question (Figure 1b). Third, groundnut contamination declines steeply when precipitation increases from 200 millimeters to around 600 millimeters (Figure 1b). Finally, contamination is lower in cooler climates, peaking when daily maximum temperatures reach the mid-to-high 30s (Figure 1b).

The Impact of Precipitation and Temperature on Aflatoxin Contamination in Maize

According to the DSSAT aflatoxin model for maize, the frequency of aflatoxin contamination varies greatly with temperature when precipitation levels are low (Figure 2a).

FIGURE 1. The projected effect of precipitation and mean daily maximum temperature on aflatoxin contamination in groundnuts, 2050



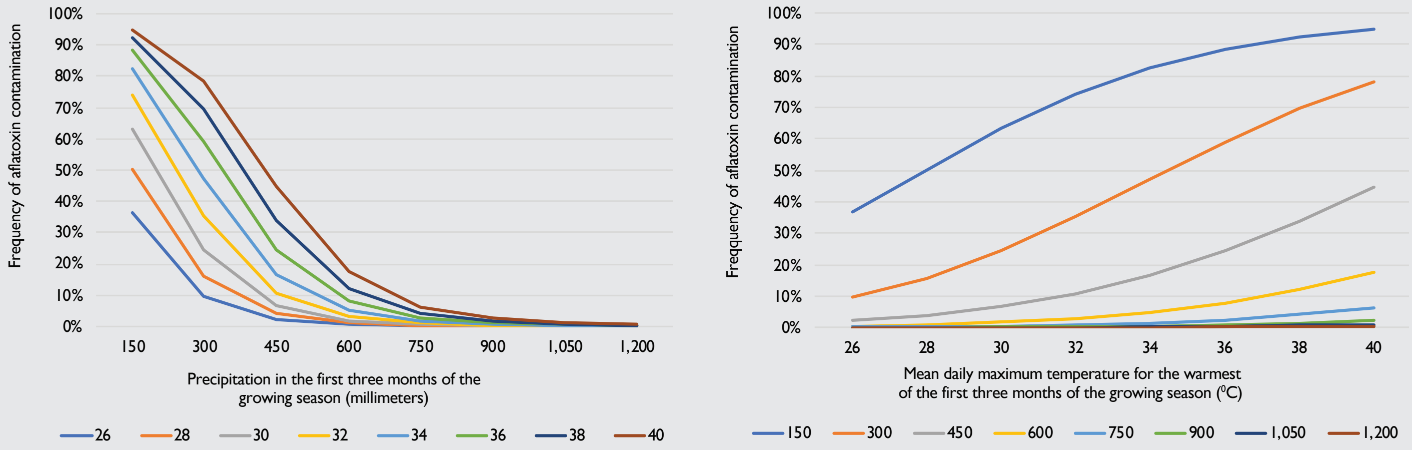
Panel a. The effect of precipitation on the frequency of aflatoxin contamination at different mean daily maximum temperatures (⁰C)

Panel b. The effect of temperature on the frequency of aflatoxin contamination at different levels of precipitation (millimeters)

Source: Thomas, Robertson, and Boote (2019).

Notes: The frequency of contamination is determined as the share of harvests with aflatoxin concentrations of 4 parts per billion or higher. Analysis was undertaken for one historic and five different future climates and was limited to Burkina Faso, Niger, and Nigeria.

FIGURE 2. The projected effect of precipitation and mean daily maximum temperature on aflatoxin contamination in maize, 2050



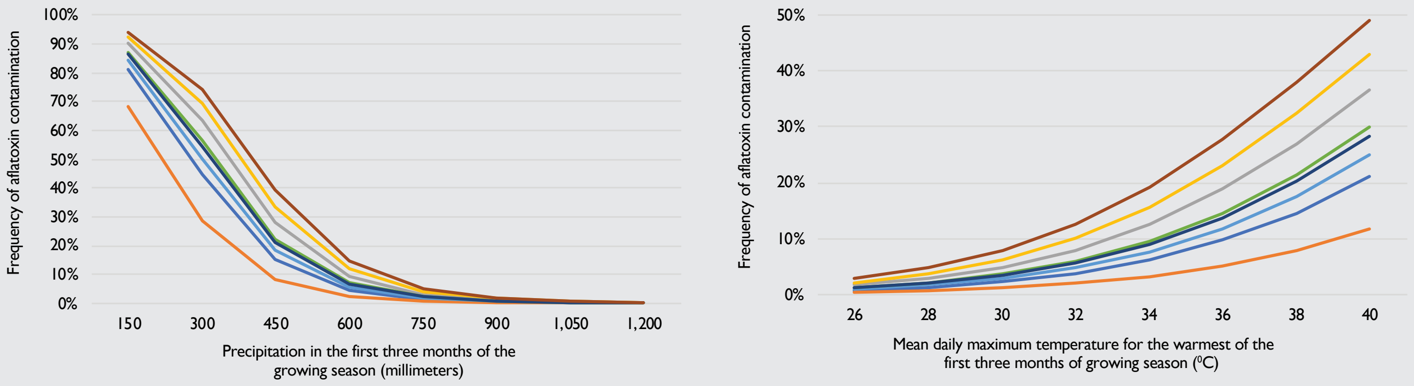
Panel a. The effect of precipitation on the frequency of aflatoxin contamination at different mean daily maximum temperatures (⁰C)

Panel b. The effect of temperature on the frequency of aflatoxin contamination at different levels of precipitation (millimeters)

Source: Thomas, Robertson, and Boote (2019).

Notes: The frequency of contamination is determined as the share of harvests with aflatoxin concentrations of 4 parts per billion or higher. Analysis was undertaken for one historic and five different future climates and includes all six study countries. Projections are based on median elevation and the most widely observed soil type in the sample.

FIGURE 3. The projected effect of precipitation and mean daily temperature on aflatoxin contamination in maize for the major (unspecified) soil types in the study area



Panel a. The effect of precipitation on the frequency of aflatoxin contamination for major soil types

Panel b. The effect of temperature on the frequency of aflatoxin contamination for major soil types

Source: Thomas, Robertson, and Boote (2019).

Notes: The frequency of contamination is determined as the share of harvests with aflatoxin concentrations of 4 parts per billion or higher. Analysis was undertaken for one historic and five different future climates and includes all study countries. Projections are based on median elevation and median precipitation and temperature, as appropriate.

When precipitation levels are above 750 millimeters in the first three months of the growing period, contamination remains very low, even at temperatures above 36^0C (Figure 2b).

The Impact of Soil Types on Aflatoxin Contamination in Groundnuts and Maize

While soil types are an important explanatory variable in the modeling analysis, their variation added very little to explain the contamination in groundnut harvests. For maize, however, at lower precipitation levels, soil type can lead to a difference in contamination of more than 20 percentage points, and at high temperatures to a difference of more than 35 percentage points (Figure 3). This is because water retention—and hence soil moisture levels—differ by soil type, and insufficient soil moisture (brought about by low precipitation or higher temperatures/evaporation) stresses plants and makes them susceptible to higher concentrations of aflatoxins.

Implications and Recommendations for Countries Susceptible to Contamination

Results clearly show that water stress greatly increases aflatoxin contamination in both groundnuts and maize. Contamination in groundnuts is associated with changes in temperature, but this was not consistent across all levels of precipitation. Contamination in maize, however, clearly increases at higher temperatures. While different climate scenarios suggest quite different results, near-term forecasting of aflatoxin hotspots is feasible using adapted modeling techniques developed for this study.

For countries facing significant issues with aflatoxin contamination, the following approaches should be considered:

1. Switching planting months to reduce aflatoxin concentrations, if the shift does not lead to significant, negative impacts on yields.

2. Where possible, water should be applied during the driest growth period. The analysis underlying this study suggests days 30 to 60 after planting might be the most critical in terms of minimizing aflatoxin contamination.

3. Improving water retention would be a good long-term strategy, perhaps through bunds or investments to improve soil organic matter.

4. Another potential solution is the use of biocontrol, which involves introducing nonharmful fungi to out-compete the aflatoxins. The effect lingers for more than one season and potentially helps neighbors as well.

5. Some studies have found that liming soils reduces aflatoxin concentrations.

6. Since aflatoxin contamination is worse when crops are damaged by insects, techniques to reduce their impact can be very helpful.

7. To date, success has not been great in developing aflatoxin-resistant varieties, but this may change in the future given the recent introduction of new breeding techniques.

8. Switching to crops that do not have significant aflatoxin issues should be presented as an option to farmers—despite the significant market development and behavioral/dietary changes required.

Since aflatoxins can continue to be synthesized postharvest, care also needs to be taken to make a number of improvements in harvesting, processing, and storage practices, such as appropriate drying of the crops after harvest (see Brown 2018 for more information). New and faster testing for aflatoxin contamination should be developed so that farmers (or buyers) would know whether they have a problem postharvest. Even if the levels of contamination made the crop unfit for human consumption, alternative uses can still generate income without negative health implications. For example, infected crops can be used as livestock feed when treated with binding or decontaminating agents, and, as previously mentioned, contaminated peanuts can still be used to make peanut oil.

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Timothy S. Thomas *(tim.thomas@cgiar.org) and* ***Richard Robertson*** *(r.robertson@cgiar.org) are employed in the Environment and Production Technology Division of the International Food Policy Research Institute, Washington, DC.* ***Kenneth J. Boote*** *(kjboote@ufl.edu) is employed in the Agricultural and Biological Engineering Department of the University of Florida, Gainesville.*

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