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## **Effectiveness of Aflatoxin Biocontrol**

**Evidence from Kenyan Smallholders under Varied Levels of Technical Support**

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## INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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## **Abstract**

Agricultural technologies shown to be highly effective in research trials often have a lower impact when utilized by smallholder farmers. Both heterogeneous returns and suboptimal application are believed to play a role in this efficacy gap. We provide experimental evidence on the impact of a biocontrol product for the control of aflatoxin, a carcinogenic fungal byproduct, as applied by smallholder farmers in Kenya. By varying the level of external support across farmers, we investigate the role of misapplication in the effectiveness gap. We find that the provision of biocontrol together with a one-time training on application reduces aflatoxin contamination in maize relative to a control group by 34 percent. Additional training to the farmers in the form of a call to remind them of the correct time of application in the crop cycle increases the reduction to 52 percent. Our findings indicate that farmers can achieve meaningful improvements in food safety using biocontrol even with minimal training on its use and that additional support at the recommended time of application can strengthen its impact.

**Keywords:** Agricultural technology; Aflatoxin contamination; Smallholder farmers

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## **1. Introduction**

Both observational analysis and tightly controlled experiments may overstate the impact of agricultural technologies. Highly able farmers are likely to be early adopters of new technologies. Supported field trials, even those conducted on farmers' own land and with their participation, may overstate efficacy if it does not represent farmers' application practices in the absence of this support (Duflo, Kremer, and Robinson 2008). Experimental evidence on the impact of agricultural technologies as applied by farmers on their land and without external support is thus critical to understanding benefits of adoption, but often unavailable.

In this paper, we examine the impact of a biocontrol technology for aflatoxin control as applied by Kenyan smallholder farmers on aflatoxin levels in maize samples collected from farmers' fields. Maize farmers in 120 villages were randomized into a treatment or control group. Those in the treatment group were instructed on the use of the technology during a one-time training session and provided enough of the product to treat one acre of their land. To test the hypothesis that application errors reduce benefits, half of the farmers in the treatment group were randomly assigned to receive follow-up calls were visited in-person at the optimal application time to ensure the product was used correctly.

Fungal toxins (mycotoxins) are a prevalent food safety hazard in certain crops, notably maize and groundnut. Aflatoxin is a mycotoxin of particular concern due to its known carcinogenicity and suspected role in child stunting (Gong et al. 2002; Hoffmann, Jones, and Leroy 2018; IARC 2015; Liu and Wu 2010; McMillan et al. 2018; Turner et al. 2007). Ingestion of high levels of aflatoxin has resulted in several outbreaks of acute poisoning and resulting deaths in eastern Kenya, a global aflatoxin hotspot (Azziz-Baumgartner et al. 2005). In addition to the health burden, aflatoxin contamination is associated with trade-related losses through the disposal of contaminated food and restricted access to high-value markets (Bandyopadhyay et al. 2016; EAC 2017).

Maize is the primary staple crop in Kenya, where most farmers primarily cultivate the crop for their own consumption and, to a lesser extent, for sale when there is a surplus. Previous research has documented that both maize which is grown for home consumption and that which is traded in formal and informal markets frequently contains aflatoxin levels exceeding the Kenyan regulatory standard (Daniel et al. 2011; Hoffmann and Moser 2017; Omara et al., 2021; Barasa et al. 2023). Premium prices for aflatoxin-safe grain are typically not available to smallholder farmers due to the high cost of testing relative to the value of the crop (Hoffmann et al., 2023), though there are reports of millers in aflatoxin-prone regions sourcing preferentially from farmers who adopt practices to manage the toxin (Andae, 2019). Some large-scale maize mills screen for aflatoxin prior to purchase, with rejected lots going to less-discerning mills or the informal sector (Hoffmann and Moser, 2017).

As aflatoxin contamination begins while maize is growing in the field, effective management strategies during production are essential for its effective control. This is particularly crucial for maize grown for home consumption or distributed through informal market channels as such maize does not pass through the formal quality assurance and processing systems that may include aflatoxin testing or industrial processing steps, such as dehulling, which can reduce contamination.

Biological control (biocontrol) is a promising approach for reducing aflatoxin contamination in food crops. This technology involves the use of naturally occurring atoxigenic (i.e., unable to produce aflatoxin) strains of the fungus *Aspergillus flavus* to competitively displace aflatoxin-producing fungi in the soil, thus reducing aflatoxin levels in the treated crop. Biocontrol products are applied when the crop is in the field and protect the crop both before and after harvest (Bandyopadhyay et al. 2019; Senghor et al. 2020). This technology was developed in the early 1990s, and has been used in the United States for almost two decades (Cotty, Antilla, and Wakelyn 2007; Dorner 2009). Similar products, developed with native

atoxicogenic fungal strains, have recently been developed and commercialized in several African countries, Italy and Pakistan over the last decade.

Precision in the application of the biocontrol product, in terms of both timing and dosage, is key to its effectiveness (Weaver et al. 2015). The product should be applied two to three weeks before the crop flowers, prior to the stage at which the target crop is typically colonized by toxin-producing fungal strains (Bandyopadhyay et al. 2019), and should be broadcasted evenly in the field at a rate of 10 kg per hectare (Bandyopadhyay et al. 2016). Once applied, the active ingredients (atoxicogenic *Aspergillus flavus* L-strains) grow, sporulate, and disperse to the target crop. Favorable conditions, including adequate soil moisture and absence of flooding, enable sporulation within a few days (Bandyopadhyay et al., 2016; Pitt, 2019). Under dry conditions, the active ingredient remains dormant on carrier grains until moisture levels improve (Bandyopadhyay et al., 2016). To maximize efficacy, agronomic practices such as weeding, fertilizer application, and pesticide use should be avoided during and immediately after biocontrol application (Atehnkeng et al., 2018). For example, weeding may lead to product loss through burial or trampling, and pesticides may inhibit the growth and sporulation of the biocontrol agent (Garber and Cotty, 2006). Additionally, measures should be implemented to minimize losses from predation by birds, poultry, insects, or rodents (Moral et al., 2020).

Through this study, we contribute to three distinct strands of literature. The first is a growing literature in economics on returns to agricultural technologies as used by farmers. This body of work is motivated by questions having to do with potential heterogeneity across farms or farming conditions, and behavioral factors that could affect the efficacy of technologies. Duflo, Kremer, and Robinson show that the profitability of fertilizer is highly sensitive to dosage, with an optimum below the standard recommended level in their study context of western Kenya (Duflo, Kremer, and Robinson, 2008). Another study, also conducted in western

Kenya, found that the yield response to fertilizer is influenced by ex-ante soil conditions, particularly soil organic matter levels (Marenya and Barrett 2009). Beaman and coauthors note that farmers provided with free fertilizer adjust other inputs in response, confounding the estimation of the impact of fertilizer alone (Beaman et al. 2013). Magnan et al. (2021) similarly find that providing farmers with tarps for drying crops leads to the adoption of complementary storage practices.

A second, related body of work uses experimental methods to test the impact of disseminating agricultural recommendations to farmers on their knowledge, practices, and yields. Impacts on one or more of these outcomes in diverse settings indicate that information constraints significantly impede the productivity of smallholder farmers (Van Campenhout, Spielman, and Lecoutere 2021; Casaburi et al. 2019; Cole and Fernando 2021; Fabregas, Kremer, and Schilbach 2019; Gandhi et al. 2009). Within this literature, two studies test the impact of providing additional post-training support, specifically through post-training text message reminders, delivered at the time when a specific practice should be implemented (Larochelle et al. 2019; Van Campenhout, Spielman, and Lecoutere 2021). The use of these follow-up messages is motivated in part by the hypothesis that attention constraints may pose an additional barrier, beyond that of information, to the correct use of agricultural recommendations. Evidence on the effectiveness of such reminders is mixed. In a study of Ugandan maize farmers, timely text message reminders had no additional effect on farmers' knowledge, practices, or yields beyond those achieved through a video-based training intervention. In contrast, a study in Ecuador found that text message reminders complementing a one-day integrated pest management workshop increased potato farmer's knowledge and adoption of promoted practices (Larochelle et al. 2019). Impacts were strongest for complex practices, as well as time-sensitive practices and those not requiring input purchase, suggesting that the reminders worked both by strengthening farmers' assimilation of new knowledge, and

by triggering them to attend to practices at the appropriate time. These inconsistent results indicate the importance of context and the need for additional research on the effect of post-training support in diverse settings. By testing the impact of such support on farmers' knowledge, and the timing and quality of input application, the present study addresses this need, and sheds light on the mechanism through which additional technical support was effective in the context of applying an unfamiliar input.

Finally, we contribute to a more specific body of work testing the effectiveness of aflatoxin biocontrol in the African context. Several researcher-administered experimental trials of this technology have been conducted, and both observational and experimental evidence is available in the context of contract farming (Bandyopadhyay et al. 2019). Three studies of which we are aware present evidence on the efficacy of aflatoxin biocontrol as applied by small-scale farmers in Africa. The first study uses observational data from a vertically integrated poultry feed value chain in Nigeria to compare contamination in treated versus untreated grain, and finds reductions in toxin concentration of between 72 and 94 percent (Bandyopadhyay et al. 2019). Off-takers in this supply chain typically provide farmers with guidance or assistance in applying the biocontrol product to ensure the crop meets quality and safety standards. In the second study, the Aflasafe manufacturer in Nigeria trained lead farmers of the national maize association and area extension agents who then selected and trained farmer members of the association on the correct method of using Aflasafe, monitored biocontrol treatment, sporulation, and general operations of these farmers, and ensured that farmers followed recommended land preparation and herbicide application practices. The mean reduction in contamination across regions was 62%, and the maize of all farmers who used Aflasafe met the stringent aflatoxin standard of 4 ppb (Ola et al. 2022). In a third study, on-farm trials were conducted in which application was performed by farmers, with timing and rate of application controlled in order to test efficacy (Senghor et al., 2020).

A question left unaddressed by these studies is the importance of assistance during product application. Further, the efficacy of aflatoxin biocontrol may depend on environmental conditions – in particular, soil moisture – after product application. As soil quality and water retention may be correlated with scale of production and market participation, the effectiveness of biocontrol for semi-subsistence farmers who do not sell through an organized, vertically integrated supply chain, and who are not purposively selected by extension agents for participation in a trial, may differ from what has previously been reported in the literature.

## **2. Materials and methods**

### **2.1. Biocontrol product**

The product, Aflasafe KE01, used in this study was manufactured in Kenya at the KALRO/IITA Aflasafe Modular Manufacturing Plant at Kenya Agricultural and Livestock Research Organization (KALRO) Katumani Research Station. Aflasafe KE01, a multi-strain product, has been registered for use in Kenya since 2015 and is constituted with four *Aspergillus flavus* L-strains—C6-E, C8-F, E63-I, R7-H (Moral et al. 2020). Spores of the four atoxigenic strains were coated on sterile sorghum grain that acts as a carrier and a source of nutrients for the fungi, together with a blue dye to distinguish it from consumable sorghum, and a polymer that binds the spores on the grain (Bandyopadhyay et al. 2022).

### **2.2. Population and sample**

The study was carried out in six counties in the Eastern region of Kenya: Meru, Tharaka Nithi, Embu, Machakos, Makueni, and Kitui. A list of villages in maize-growing sub-counties within these counties was generated using data from the authors' previous research, with help from local agricultural extension officers. To avoid both the potential influence of previous training on farmers' behavior, and the biological effects of prior application of biocontrol on or near farmers' fields, villages involved in a previous study on the adoption of biocontrol or located within 2 km of these, were removed from the sampling frame. The remaining list of 729 villages

was stratified by county or subcounty and a random sample of 120 villages was selected for inclusion in the study. Because biocontrol spores may be spread by wind from a treated field to nearby fields (Bock, Bruce, and Cotty 2004), a 2 km minimum distance constraint was imposed between selected villages.

Community leaders were asked to list all the households in their respective villages that grew between 0.5 and 5 acres of maize. Just one farmer was then randomly selected per village (again to avoid spillovers across treatment groups) using a randomly ordered list with a predetermined starting position and direction (ascending/descending). If the selected farmer indicated that he or she grew less than 0.5 or more than 5 acres of maize, or had previously used Aflasafe, that farmer was excluded and replaced with the next farmer on the list.

### **2.3. Experimental design and interventions**

Random assignment of villages to one of three experimental groups was conducted prior to the selection of farmers. Of the 120 villages, 60 were assigned to the control group, while 30 were assigned to each of the two treatment groups. As for sample selection, randomization was stratified at either the county or the sub-county level.

Farmers in villages assigned to the control group did not receive any intervention and were visited for data and sample collection only. All farmers assigned to the treatment group were visited in November 2019. During this visit, treatment group farmers were trained on aflatoxin risk and management strategies, and on the use of biocontrol, by staff from the International Institute of Tropical Agriculture (IITA) and the Ministry of Agriculture. The trainers used the IITA farmers' training manual for aflatoxin biocontrol (Atehnkeng et al. 2018) and a pictorial flyer that illustrated the method and timing of application, as well as post- and pre-application instructions. The flyer is attached as an Appendix. After the training, each farmer was given enough biocontrol product to treat their maize field at the recommended rate of 10 kg/hectare (4 kg per acre). Farmers assigned to the first treatment group were then left to

use the biocontrol product according to the instructions provided during the training. We refer to this group as the biocontrol and training treatment group (T1).

Farmers assigned to the second treatment group received the same training as those in the biocontrol and training treatment group. In addition, these farmers received additional support from research staff. First, they were assisted to monitor their crop to determine the correct stage for application through follow-up calls by the trainers. Once the correct stage of maize growth was reached, based on information collected through these calls, trainers revisited farmers to support and supervise their application of the biocontrol product. For the handful of farmers whose maize was not, upon inspection, at the correct stage for application of biocontrol, an additional visit was conducted, during which the product was applied. We refer to this group as the biocontrol, training, and follow-up treatment group (T2).

#### **2.4. Data**

A baseline survey was conducted prior to the training of treatment farmers, at the beginning of the 2019/2020 season (from 12 September to 18 October 2019). Each of the selected farmers was visited at their home and administered an informed consent procedure prior to enrolment in the study. After obtaining consent, a short survey was administered that included questions on farmers' knowledge about aflatoxin and the biocontrol product, and maize practices including the date at which maize had been planted, or, if not yet planted, the date at which the farmer expected to plant maize.

The second round of data collection was conducted in December 2019 among the farmers assigned to both treatment groups, but not the control group. The timing of this survey was such that biocontrol should have recently been applied, and so would still be visible in the fields of at least some farmers. Two activities were conducted during this round: a follow-up survey and monitoring of the field where the farmer indicated the biocontrol product had been applied.

The follow-up survey was used to collect data on three outcomes of interest: farmers' knowledge of biocontrol and its correct use, date of application, and the stage of maize development at application. Field monitoring involved inspecting the field for the presence of the biocontrol product and the sporulation of the active ingredients (atoxicogenic *Aspergillus* strains). The number of granules with visible sign of *Aspergillus* spore mass was assessed within four one-meter squares in each quadrant of the biocontrol-treated field, and the mean across squares was calculated.

A final round of data were collected for all of the farmers in the study (including control farmers) toward the end of the season, January through March of 2020. During this round, maize samples were collected from farmers' fields for aflatoxin quantification. Twenty to twenty-nine kg of mature maize cobs were harvested from each field in a zig-zag manner. The cobs were shelled by hand, grains mixed, and subdivided by quartering method to obtain approximately 1.5 kg samples for aflatoxin analysis. The samples were packed in khaki kraft papers and transported to the Regional Mycotoxin laboratory in KALRO, Katumani for aflatoxin analysis.

In the lab, the samples were sun-dried for 3 days, and then oven-dried at 45°C for 48 hours to obtain a requisite moisture content of less than 13%. The samples were then ground to a fine powder using a coffee mill grinder (Bunn-O-Matic Corp., Springfield, IL, United States), weighed, and stored at -20 °C prior to aflatoxin analysis. Aflatoxin analysis was conducted using Neogen Reveal Q+ strips and Accuscan Pro reader according to the manufacturer's instructions.<sup>1</sup> The samples were mixed by hand shaking for homogeneity. Ten grams of each maize sample were added to 50 ml of 65% ethanol: water (v/v) and shaken in an orbital shaker (HS501 IKA-WERKE, Germany). The mixture was filtered through Whatman No. 4 filter paper and the filtrate was collected in a Tripour beaker from which 100 µL of sample extract was collected and mixed with 500 µL of sample diluents. Diluted sample extract (100 µL) was

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<sup>1</sup> <https://www.neogen.com/categories/mycotoxins/reveal-q-plus-aflatoxin/>

transferred into a new clear sample cup and a Reveal Q+ strip was placed into the clear sample cup and incubated for six minutes, following which the test strip was read within a minute. Aflatoxin levels were expressed in parts per billion (ppb). The Accuscan Pro reader's lower limit is 2 ppb and the upper limit is 150 ppb total aflatoxins. Samples with above 150 ppb total aflatoxins were further diluted in 65% ethanol at the ratio of 1:9 and an additional test was performed.

### **3. Results**

#### **3.1. Farmers' knowledge and maize practices at baseline**

We begin by describing the maize farming practices and knowledge of aflatoxin and of biocontrol among participating farmers. Table 1 reports means and standard deviations of variables collected through the baseline survey, both overall (Column 1) and per treatment group (Columns 2-4). In Columns 5-7, we present p-values for differences in means of each variable between each treatment group and the control group, and between the two treatment groups. Farmers' maize practices and knowledge were generally similar across the three groups.

The size of the land under maize in the current season ranged from 0.5 to 5 acres (reflecting eligibility criteria), with a mean of 1.69 acres and a median of 1.38 acres. Maize was intercropped with at least one other crop in 68% of the farms. Over 90% of farmers used fertilizer on their maize.

Knowledge about aflatoxin was high among farmers in the study sample. Ninety-five percent of farmers indicated that they had heard of aflatoxin before. When asked to describe aflatoxin, 73% described it as poison, 20% described it as a disease, and 8% did not know how to describe it. Almost all the farmers (95%) identified maize as one of the crops affected by aflatoxin. Beans were the next most frequently reported crop affected (mentioned by 34% of farmers), followed by sorghum (21%). Only 3% of farmers identified groundnuts as affected

by aflatoxin, notable as this is one of the crops most susceptible to contamination, though not widely grown in the study area.

Awareness of biocontrol for aflatoxin was low. Fewer than a fifth of farmers (18%) said they had heard about the biocontrol product at baseline. The primary source of information on the product was radio, mentioned by 68% of those who had heard of it. Other sources of information included extension officers (18%) and other farmers (9%). None of the farmers had used the product before.

**Table 1.** Farmer's knowledge of aflatoxin and biocontrol and their maize practices at baseline

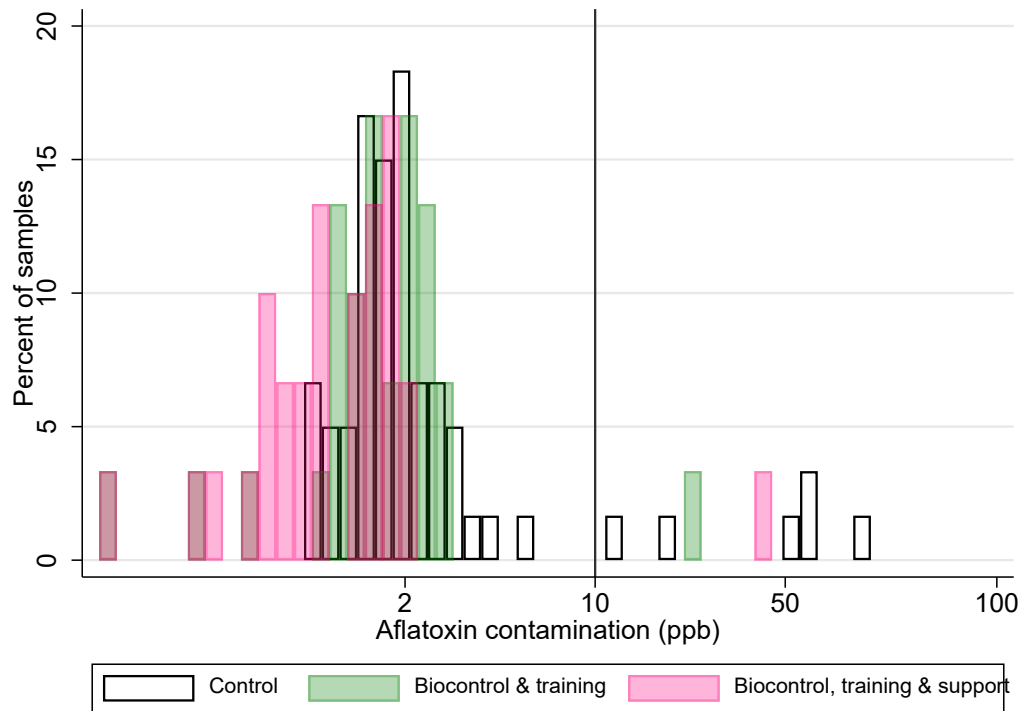
	1		2		3		4		5	6	7
	All		Control		Biocontrol and training		Biocontrol, training, and follow-up		3-2	4-2	3-4
	mean	sd	mean	sd	mean	sd	mean	sd	p-value	p-value	p-value
<i>Maize practices</i>											
Land under maize current season (acres)	1.69	1.14	1.42	0.93	1.88	1.23	2.03	1.34	0.047	0.012	0.653
Maize intercropped with another crop	0.68	0.47	0.70	0.46	0.73	0.45	0.57	0.50	0.746	0.214	0.182
Used fertilizer in maize	0.93	0.25	0.93	0.25	0.90	0.31	0.97	0.18	0.583	0.521	0.309
<i>(Expected) maize planting date</i>											
Late Sept/Early Oct	0.17	0.38	0.20	0.40	0.07	0.25	0.23	0.43	0.102	0.719	0.073
Mid Oct	0.66	0.48	0.67	0.48	0.70	0.47	0.60	0.50	0.753	0.539	0.425
Late October	0.17	0.37	0.13	0.34	0.23	0.43	0.17	0.38	0.235	0.676	0.527
<i>Aflatoxin knowledge</i>											
Have heard of aflatoxins	0.95	0.22	0.95	0.22	0.90	0.31	1.00	0.00	0.376	0.217	0.078
Describes aflatoxin as:											
Poison	0.73	0.45	0.68	0.47	0.70	0.47	0.83	0.38	0.874	0.132	0.229
Disease	0.20	0.40	0.22	0.42	0.20	0.41	0.17	0.38	0.857	0.581	0.744
Does not know	0.08	0.28	0.10	0.30	0.13	0.35	0.00	0.00	0.640	0.074	0.039
Aflatoxin is caused by:											
Moisture	0.57	0.50	0.60	0.49	0.53	0.51	0.57	0.50	0.551	0.765	0.799
Fungi	0.08	0.26	0.08	0.28	0.03	0.18	0.10	0.31	0.376	0.796	0.309
Bacteria	0.02	0.13	0.03	0.18	0.00	0.00	0.00	0.00	0.317	0.317	
Do not know	0.20	0.40	0.18	0.39	0.30	0.47	0.13	0.35	0.214	0.554	0.121
Crops affected by aflatoxin:											
Maize	0.95	0.22	0.95	0.22	0.90	0.31	1.00	0.00	0.376	0.217	0.078
Beans	0.34	0.48	0.23	0.43	0.37	0.49	0.53	0.51	0.187	0.004	0.201
Sorghum	0.21	0.41	0.18	0.39	0.27	0.45	0.20	0.41	0.367	0.851	0.549
Groundnuts	0.03	0.18	0.05	0.22	0.00	0.00	0.03	0.18	0.217	0.721	0.321
<i>Aflasafe knowledge</i>											
Have heard of Aflasafe	0.18	0.39	0.15	0.36	0.13	0.35	0.30	0.47	0.834	0.096	0.121
Observations	120		60		30		30		90	90	60

### 3.2. Impact of biocontrol, training, and follow-up on total aflatoxins

We now turn to our main results, on the impact of providing biocontrol and training, with and without additional support, on aflatoxin contamination in maize. Table 2 shows summary statistics for this outcome in freshly harvested maize samples collected from farmers assigned to each of the three experimental groups, and the distribution of the natural logarithm of aflatoxin concentration in each group is shown graphically in Figure 1. Aflatoxin contamination in samples from the control farms ranged from 0.85 to 89.4 ppb, with an arithmetic mean of 6.58 ppb, and a geometric mean of 2.39 ppb. Aflatoxin concentration in samples from the biocontrol and training group ranged from 0.15 to 22.60 ppb, with an arithmetic mean of 2.35 ppb (geometric mean of 1.58 ppb). Finally, contamination in samples from the biocontrol, training, and follow-up group ranged from 0.15 to 42.10 ppb, with an arithmetic mean of 2.52 ppb (geometric mean of 1.13 ppb). For all three groups, measures of central tendency were below the Kenyan regulatory limit of 10 ppb, but some observations far exceeded this limit.

**Table 2.** Aflatoxin contamination by treatment group at harvest

	N	min	max	Proportion of samples > 10 ppb	Geometric mean	95% Confidence interval of the geometric mean	
Control group	60	0.85	89.4	10	2.39	1.83	3.13
Biocontrol and training only (T1)	30	0.15	22.6	3.3	1.58	1.17	2.13
Biocontrol training plus support, T2	30	0.15	42.1	3.3	1.13	0.81	1.59



**Figure 1.** Histogram showing the distribution of aflatoxins by treatment groups. The x-axis is shown on a logarithmic scale.

Next, we compare contamination across treatment groups through a multivariate linear regression. We regress the logarithm of aflatoxin concentration at harvest on binary indicators for assignment to each treatment group and indicators for the randomization strata. We show results both from a model without additional baseline covariates, and one in which covariates are chosen from among those shown in Table 1 via post-double selection LASSO (Belloni, Chernozhukov, and Hansen 2014), as implemented through Stata’s `pdlasso` command. This procedure selects covariates that are both correlated with the independent variable (aflatoxin concentration), and the independent variables of interest (treatment indicators), thus adjusting the estimated treatment effects for pre-existing differences across groups and increasing the statistical precision with which these are estimated. The method is particularly useful in small samples where the inclusion of more controls may result in a loss of precision due to reduced degrees of freedom.

Coefficients estimated through the parsimonious model without additional baseline covariates are shown in column 1 of Table 3, while post-double selection LASSO adjusted results are reported in column (3). Exponentiating the coefficients on treatment effects in the model with baseline controls indicates that aflatoxin is reduced by 34% in the group provided with aflatoxin biocontrol and a one-time training on its use (column 4). The group to whom technical assistance for biocontrol application was additionally provided saw a greater reduction, of 52% relative to the control group. The difference between treatment groups is marginally statistically significant ( $p = 0.08$ ). The results are nearly identical when baseline controls are not included, though estimated with less statistical precision.

**Table 3.** Impact of biocontrol treatments on total aflatoxins

	1	2	3	4
	Log total aflatoxin	Reduction relative to control group	Log total aflatoxin (adjusted)	Reduction relative to control group
Biocontrol and training only (T1)	-0.433** (0.194) [0.028]	35%	-0.411** (0.185) [0.026]	34%
Biocontrol training plus support (T2)	-0.702*** (0.205) [0.001]	50%	-0.730*** (0.182) [0.000]	52%
Baseline controls	No		Yes	
P-values T1 = T2	0.237		0.080	
Observations				
Mean of the control group	2.394		2.394	

Values shown outside parentheses are coefficients on treatment indicators. Those in parentheses are standard errors, and those in square brackets represent p-values for the test of equivalence of the coefficients for each treatment with the control group. Adjusted coefficients include baseline controls selected via post-double selection LASSO. \*\* indicates  $p < 0.05$ , \*\*\*  $p < 0.01$ . Strata fixed effects are included in both regressions.

### 3.3. Mechanisms

The additional support provided to farmers in T2 consisted of two components: phone calls through which farmers were asked to report on maize growth in order to identify the correct time for biocontrol application, and direct support during application. These two aspects of the support intervention address distinct potential constraints to farmers' optimal use of the technology. Phone calls target potential attentional constraints that might cause farmers to forget to apply the product at the optimal time. Technical assistance during application, on the other hand, ensures that farmers apply the product correctly, addressing the risk that they have not fully assimilated the instructions provided during training. To understand the mechanism through which the additional support intervention acted, we examine the effect of training and follow-up on farmers' *knowledge* about biocontrol application, their *timing* of application, and their *quality* of application.

We use regression analysis to test the impact of the two treatments on each of these intermediate outcomes, adjusting for stratification dummies. In Table 4, we present results without additional baseline controls in odd-numbered columns and including baseline covariates selected through post-double-selection LASSO in even-numbered columns. First, we investigate the effect of additional training on farmers' knowledge of biocontrol and its correct use. Seven statements, listed in Appendix Table 1, were used to assess this knowledge. First, farmers were asked to describe the biocontrol product. Second, farmers were asked to state the stage at which the product should be applied. All farmers in both treatment groups stated the correct stage of maize development during which the biocontrol should be applied, that is, 2 to 3 weeks before flowering or at the 6<sup>th</sup> to 7<sup>th</sup> leaf stage. The third statement asked about the rate of application. A majority of farmers, almost equal across the two treatment groups (80% in T1 versus 77% in T2), were able to state the correct rate of the biocontrol use (4 kg/acre). The next three statements related to protecting the applied product against loss

through poultry and farmer activities such as weeding, and how its effectiveness was affected by the use of other inputs such as herbicides. Lastly, farmers were asked about the toxicity of the biocontrol product. A knowledge index was created from these seven statements by assigning the value of 1 to correct responses and summing these values. The index, which ranged from 0-7, had mean values of 6.73 and 6.90 in T1 and T2, respectively. The difference in knowledge scores between groups is statistically indistinguishable from zero. These results indicate that the one-time training was sufficient to transfer knowledge about the technology to the farmers in our sample, and that the follow-up calls and visit had no additional impact on knowledge.

Next, we turn to the timing of application. First, farmers were asked, using pictures of maize at different stages of growth, to indicate the stage at which they had applied biocontrol. Results show that farmers in the biocontrol, training and support group were 22-23 percentage points more likely to indicate having applied at the correct time, compared to farmers who received only one-time training. This difference is statistically significant in the model that does not include the controls. We additionally test for differences between treatment groups in the time between planting and application of biocontrol based on farmers' reported dates of planting and application. Planting dates were estimated from the baseline data, which includes farmer reports of the month and week of planting. A mid-week date was assigned as the planting date based on the indicated week and month of planting. Farmers in the biocontrol and training group applied the product 52 days after planting on average while farmers in the biocontrol, training, and follow-up group applied the product three to five days earlier on average, a statistically significant difference. These two sets of results indicate that additional support led farmers to apply biocontrol earlier, at the optimal time.

Finally, we present results from the field monitoring exercise. The number of sporulated granules observed per square meter is slightly higher, but not significantly so, among farmers

who received in-person support during application. Adjusting for baseline covariates reduces this difference to nearly zero. In sum, analysis of intermediate outcomes suggests that post-training reminders and technical assistance increased the likelihood that farmers applied the product at the correct time but had no additional impact on their understanding of how to use the technology or the quality of application.

**Table 4.** Impact of follow-up on intermediate outcomes

	1	2	3	4	5	6	7	8
	Knowledge index at follow-up		Biocontrol applied at the correct stage		Days between planting and application		Sporulated granules per square meter	
Biocontrol, training plus support	0.190 (0.339) [0.577]	0.303 (0.329) [0.357]	0.221*** (0.081) [0.009]	0.227*** (0.081) [0.005]	-4.84** (1.82) [0.011]	-2.89** (1.35) [0.011]	1.43 (2.42) [0.557]	-0.004 (2.01) [0.999]
Observations	60	60	60	60	60	60	60	60
Baseline controls	no	yes	no	yes	no	yes	no	yes
Mean of the comparison	6.733	6.733	0.800	0.800	52.0	52.0	7.212	7.212

The table presents coefficients from OLS regressions. Stratification dummies added in all models. \* = p-value <0.10, \*\* = p-value<0.05 and \*\*\* = p-value<0.01.

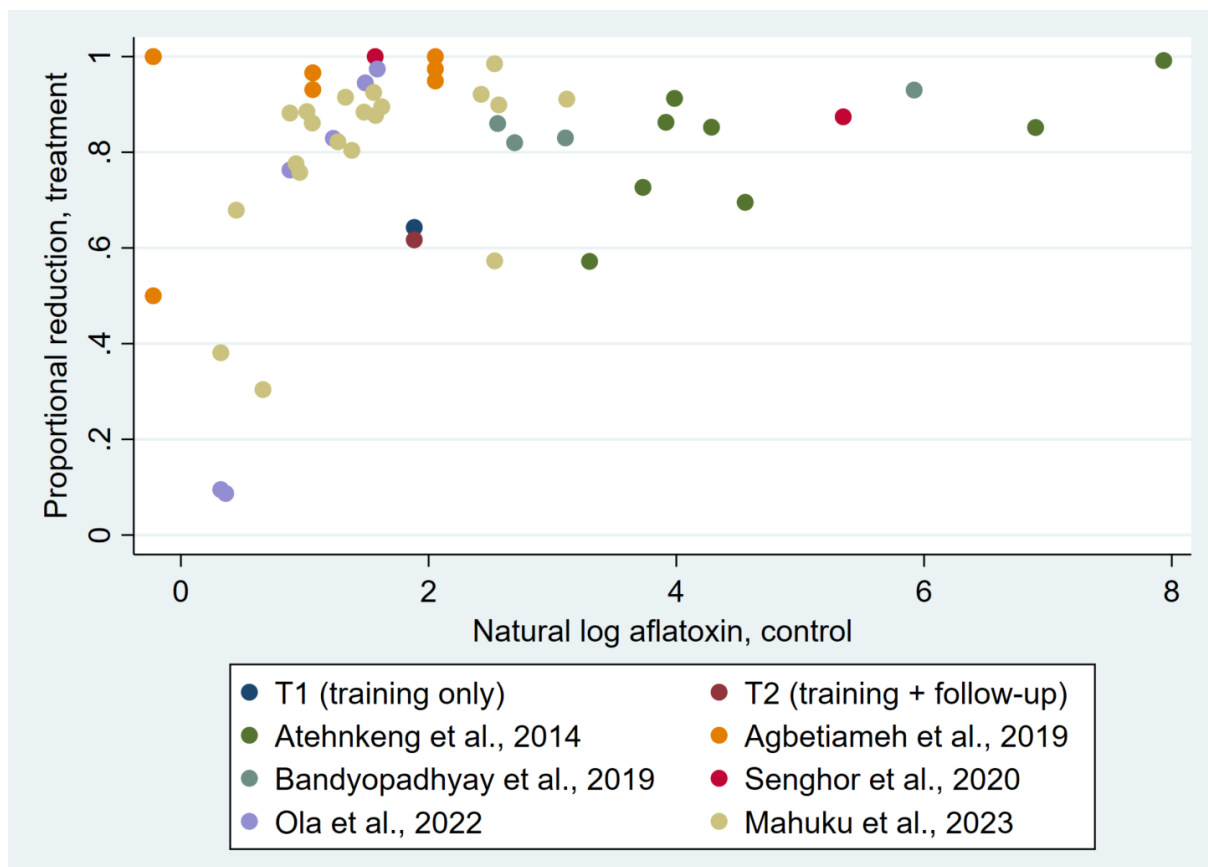
The values in parentheses are the standard errors while those in the square brackets are p-values.

### 3.4. Discussion

The reduction in aflatoxin observed due to biocontrol application in the present study is lower than has been observed in researcher-administered and researcher-assisted field trials in Nigeria, Senegal, and Ghana (Agbetiameh et al. 2019; Atehnkeng et al. 2014; Bandyopadhyay et al. 2019; Mahuku et al. 2023; Senghor et al. 2020), and similar to results reported in farmer-administered field trials in Nigeria (Ola et al. 2022). The relatively modest impact we observe could be partly attributed to the fact that aflatoxin contamination in control farms was generally low during the study season. Figure 2 presents the mean proportional reduction in the arithmetic mean of aflatoxin concentration reported per location and year in the efficacy studies cited above, and for T1 and T2 in the present study, against the logarithm of aflatoxin observed in control fields. Adjusting for study fixed effects,<sup>2</sup> these data show a significant positive association ( $p < 0.01$ ) between log aflatoxin in control fields and the magnitude of the reduction achieved by application of Aflasafe, with a seven percentage-point additional reduction in contamination for a unit log increase in the background concentration of aflatoxin. Atehnkeng et al. (2022) and Ola et al. (2022) also reported a positive relationship between the level of aflatoxin in control fields and the efficacy of Aflasafe.

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<sup>2</sup> Inclusion of study fixed effects is necessary due to the fact that different biocontrol products, tailored to local conditions, were used in the various trials.



**Figure 2.** Reduction in arithmetic mean of aflatoxin concentration vs. natural logarithm of aflatoxin in maize harvested from control fields, in previous trials, T1 and T2.

Differences in application practices by experts versus farmers also appear to play a role. The geometric mean of aflatoxin contamination at harvest among farmers who in addition received post-training phone calls and support during application was 52% below that seen in control fields, whereas farmers given only a one-time training saw a reduction of 34%.

Analysis of differences across treatment groups in intermediate outcomes shows that the additional post-training support did not serve to improve farmers’ understanding of how to use the biocontrol technology. Nor do we find evidence that supervision during application led to improved use of the technology, as measured by the number of sporulated granules per meter square. Rather, the post-training follow-up calls and visit at the time of application appeared to serve as a reminder to farmers to monitor the stage of their crop and apply the biocontrol product at the correct time. Our results concord with previous studies showing that timely reminders of

recommended practices can improve practices and increase agricultural yields (Casaburi et al., 2019; Larochelle et al. 2019). These authors have noted that such reminders, in addition to reinforcing the transfer of information, can focus farmers' attention on a task at the time it should be completed, addressing the cognitive cost of processing and attending to this information (Handel and Schwartzstein 2018).

We note that participants in this study had never previously used aflatoxin biocontrol. However, our findings are likely to be relevant beyond the first application, as aflatoxin contamination is a hidden trait that can only be detected via relatively expensive tests. This lack of observability limits the extent to which farmers can learn about proper use of the technology through their own experience or that of other farmers. This is especially true for maize consumed by farming households, which may never be subject to aflatoxin testing, but which could negatively affect the health of farming families.

#### **4. Conclusion**

The current study has demonstrated that when smallholder, rainfall dependent maize farmers in eastern Kenya apply aflatoxin biocontrol after receiving a one-time training on its use, the impact on contamination is significant. The effectiveness of this technology is amplified by additional post-training support, apparently due to improved timing of application.

Households in sub-Saharan Africa, and in particular Kenya, have among the highest global rates of exposure to aflatoxin, a naturally occurring carcinogenic hazard (Xu, Gong, and Routledge 2018). Cost-effective methods are not available for reducing aflatoxin contamination in whole grains once it is present. Further, the highest levels of contamination are found in grain produced and consumed by farm households (Daniel et al. 2011). Acute exposure to highly contaminated maize has led to hundreds of fatalities in Eastern Kenya over the past four decades (Wangia 2017). Expanding farmers' adoption of technologies for on-farm control of aflatoxin in highly affected regions such as eastern Kenya is thus critical. Further, addressing aflatoxin

contamination can potentially expand farmers' access to higher-value markets (Hoffmann et al. 2022).

Aflatoxin contamination varies from year to year and place to place. When levels of the toxin are lower, the percentage reduction in contamination due to application of biocontrol tends to be less dramatic. Total aflatoxin levels in samples collected from control fields are similar to those seen in maize collected from farmers in the same region through a previous study, during what the authors refer to as a 'non-outbreak year' (Daniel et al. 2011). Our results thus shed light on typical impacts of aflatoxin biocontrol in a high-prevalence region during a relatively low-contamination year.

Our findings suggest the need for caution in using efficacy results from agronomic trials to project the effect of aflatoxin biocontrol technologies at scale. While biocontrol can achieve significant reduction in aflatoxin in crops, previous work has demonstrated that returns to other agricultural technologies depend critically on the quality of land (Marenya and Barrett 2009), and that profitability can hinge on optimal rates of application (Duflo, Kremer, and Robinson, 2008).

The results also shed light on the supports needed to facilitate farmers' optimal use of agricultural technologies more generally. The importance of application timing is not unique to biocontrol. Effectiveness of fertilization and pest control measures are similarly sensitive in this regard. Our study adds to a growing body of evidence on the effect of reminders to encourage timely use of recommended agricultural practices (Casaburi et al., 2019; Larochelle et al. 2019). Such reminders can be very low-cost, at pennies per farmer, if delivered through recorded voice or text messages. Mobile phone-based support for optimal use of agricultural technologies has the potential to bring farmers closer to realizing the enormous – yet often elusive – gains described in agronomic trials.

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**Appendix Table 1: Aflasafe knowledge at follow-up, by treatment group**

Variable	Biocontrol and training				Biocontrol, training and support		
	1	2	3	4	5	6	7
	N	Mean	SD	N	Mean	SD	p-value (5-2)
Describes Aflasafe correctly: <i>A product with living good fungus</i>	30	0.77	0.43	30	0.90	0.31	0.287
Describes correct stage of application: <i>2-3 Weeks before flowering/ 6-7th leaf stage</i>	30	1.00	0.00	30	1.00	0.00	
Describes correct rate of application: <i>4kg/acre</i>	30	0.80	0.41	30	0.77	0.43	0.615
Describes correct reason for guarding against poultry: <i>poultry will feed on the product</i>	30	0.97	0.18	30	0.87	0.35	0.180
Describes correct reason for not applying together with other inputs: <i>Other inputs may interfere with Aflasafe KE01 activity</i>	30	0.73	0.45	30	0.70	0.47	0.936
Describes correct reason for not weeding immediately: <i>not to bury Aflasafe grains under the soil</i>	30	0.83	0.38	30	0.73	0.45	0.435
States Aflasafe not harmful	30	0.83	0.38	30	0.93	0.25	0.142

# aflasafe KE01

Guide for aflasafe KE01 application to control aflatoxin contamination in maize



## What is aflasafe KE01?



aflasafe KE01 is a natural product that suppresses the growth of the aflatoxin - producing fungus. Aflatoxin contamination of crops can therefore be reduced with the use of aflasafe KE01.

## Before applying aflasafe KE01 to your farm

- Prepare your farm and plant the appropriate maize seed variety.
- For aflasafe KE01 to work effectively it is best applied when the soil is wet.

1



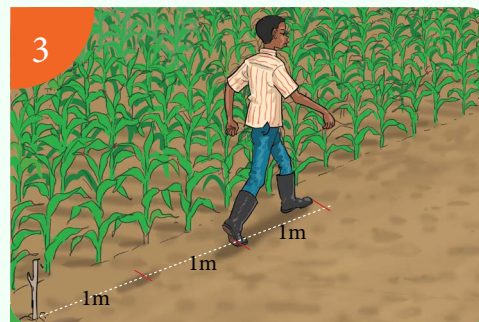
Good farm preparation ensures healthy crops.

2



Weed your maize and apply fertilizer where necessary before application of aflasafe KE01 to avoid trampling of the aflasafe KE01 grains.

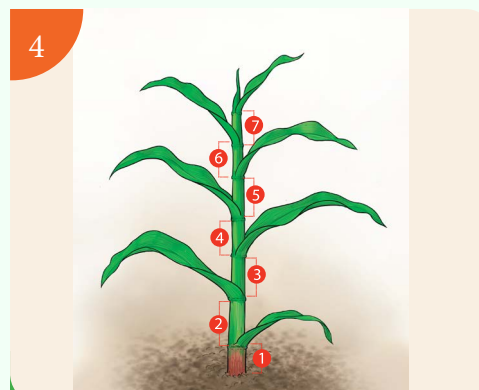
3



Measure the farm where you will apply aflasafe KE01. This is to determine the amount of aflasafe KE01 grains to be applied on the farm. 1 acre = 63.6m x 63.6m

## During application of aflasafe KE01

4

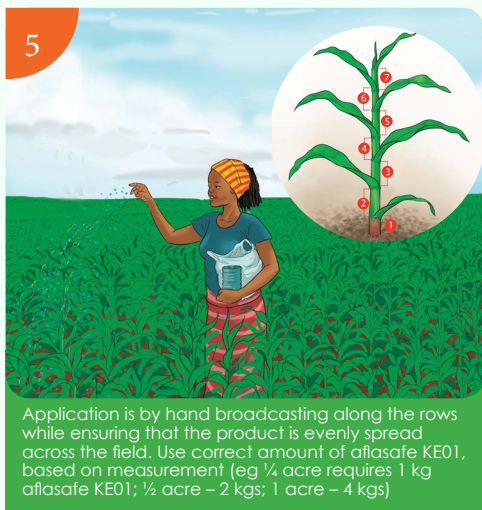


Apply aflasafe KE01 to your farm at 6th to 7th leaf stage. This is around 2-3 weeks before flowering (approximately at the knee or waist level depending on your height). Timing of application of aflasafe KE01 is critical. It will not work if you apply too early or too late

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Application is by hand broadcasting along the rows while ensuring that the product is evenly spread across the field. Use correct amount of aflasafe KE01, based on measurement (eg ¼ acre requires 1 kg aflasafe KE01; ½ acre – 2 kgs; 1 acre – 4 kgs)



Wash your hands with soap after treating the field with aflasafe KE01.

### After application of aflasafe KE01



After treating the maize, guard the plot for the first 14 days, against poultry and birds, as they are likely to feed on the aflasafe grains.



Observe the colour of the aflasafe - sorghum grain in the field for 5 – 10 days after application. A greenish growth on all or some of the sorghum grains will indicate there is adequate moisture.

Follow good pre-harvest and post-harvest practices of the crop, in order to optimize on the benefits of using aflasafe KE01.

### NOTES

- Do not worry if ants carry off the sorghum grains into their nest as they will bring them back to the soil surface 1- 3 days after. This will not affect the performance of aflasafe KE01.
- aflasafe KE01 does not affect chicken, guinea fowl, birds, wildlife and other domestic animals that may pick up some of the grains.

- If irrigating, ensure soil is not waterlogged.
- Adequate moisture in the soil allows the aflasafe KE01 to work well.
- It is recommended that weeding is done before application of aflasafe KE01, if it has to be done after application, it must be after 14 days from application date (do not bury the aflasafe KE01 grains).
- Apply fertilizers, insecticides or fungicides at the appropriate time.
- Do not mix aflasafe KE01 with fertilizers, insecticides or fungicides when applying.
- Store aflasafe KE01 in a dry place. Avoid exposure to relative humidity greater than 80% .
- Avoid reuse or refilling of the container or bag. Offer the bags for recycling.

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