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Improving food safety on the farm

Experimental evidence from Kenya on agricultural incentives and subsidies as public health investments

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ABSTRACT

Evidence continues to mount that foodborne illness imposes a staggering health burden in developing countries. However, standard approaches used by developed country governments to ensure food safety are not appropriate in settings where regulatory enforcement capacity is weak and most firms are small and informal. Thus, interventions to improve food safety in developing countries must take into account the constraints and incentives faced by producers in these countries. In this paper, we test the impact of two such interventions: subsidies for technologies that improve food safety and price premiums for safer produce. We examine the case of on-farm control of aflatoxin, a carcinogenic toxin linked to child stunting that is produced by a fungus commonly found on maize and groundnut. We show that compared to Kenyan farmers who produce maize only for their family's own consumption, Kenyan farmers who produce maize for sale are less likely to undertake post-harvest practices that increase the unobservable quality of aflatoxin safety. Employing randomized discount vouchers, we find that willingness to pay for a new post-harvest technology to prevent aflatoxin contamination is significantly lower among market producers than subsistence farmers. However, we find that take-up of the technology among market producers increases when they have the opportunity to sell aflatoxin-safe maize at a premium a few months after harvest. Using take-up rates from the experiment, we model the impacts of public subsidies and market incentives for aflatoxin control. We find that subsidization of aflatoxin control technologies is a cost-effective strategy for reducing liver cancer and possibly also for reducing stunting in children. The most cost-effective technologies considered are widely adopted by both subsistence and market producers, implying little additional impact of a price premium on food safety.

Keywords: Food safety, aflatoxin, cost-effectiveness, technology adoption

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1. Introduction

Foodborne illnesses impose a global disease burden comparable to that of tuberculosis and more than double that of maternal health disorders and deaths (WHO, 2015; Global Burden of Disease Collaborative Network, 2017). Most foodborne illnesses can be prevented through the use of safe food production and handling practices. As a result, the vast majority of the health burden from unsafe food is located in developing countries, where regulatory enforcement capacity is weak.

In poor countries, many food safety hazards, including pathogens and fungal toxins, originate on the farm during production or post-harvest handling of crops. However, addressing food safety at this stage of the value chain is challenging because farms in developing countries are typically very small and traceability systems are limited to high-value crops destined for export. Thus, public investment may be required to promote improved production practices that protect public health. To make such investments effectively, policymakers require a greater understanding of how farmers and other stakeholders involved in food markets respond to the costs of and incentives for safe food production.

In this study, we focus on a specific food safety issue that constitutes a major public health concern in Africa. Aflatoxin is a toxin produced by the Aspergillus fungus. The fungus affects a number of food crops, with maize and groundnuts being particularly susceptible. While contamination can begin while crops are still in the field, the fungus tends to increase most rapidly after harvest. Contamination is increased by post-harvest contact with soil (which contains a reservoir of the fungus), inadequate drying, and poor storage conditions. Effective technologies exist to prevent contamination but are not commonly used because aflatoxin contamination is effectively unobservable. Large millers may test for aflatoxin, but such testing is prohibitively costly for individual small-scale farmers or traders. In addition, most small-scale farmers either consume their own maize or sell it in local markets, so existing regulations regarding aflatoxin contamination limits are unenforceable. Producers thus have no incentive to invest in aflatoxin prevention.

The resulting high rate of chronic aflatoxin exposure in the developing world poses is a serious public health concern with links to liver cancer and child stunting. In addition, consumption of foods highly contaminated with aflatoxin can lead to acute illness and death (Strosnider et al., 2006; Gong et al., 2004; Turner et al., 2007). In Kenya, various studies have shown that between 15 and 65 percent of maize, a key staple food, contains aflatoxin levels above the regulatory limit, with high levels of both spatial and temporal variation (Daniel et al., 2011; Mutiga et al., 2014, 2015). The eastern part of the country is considered a global aflatoxin hotspot and periodically experiences outbreaks of acute aflatoxin poisoning, resulting in fatalities. Contamination above regulatory limits has been found in both informally marketed maize and commercially branded maize (Lewis et al., 2005; Hoffmann and Moser, 2017). Not surprisingly, Kenyan consumers have a strong preference for own-produced maize rather than purchased maize (Hoffmann and Gatobu, 2014).

We hypothesize that encouraging farmers to adopt aflatoxin prevention technologies could be an effective public health intervention. Potential approaches to encourage the use of these technologies could include (i) training farmers on the use of existing prevention technologies, (ii) subsidizing the cost of existing technologies, (iii) making new technologies more readily available, potentially at subsidized costs, and (iv) increasing observability of aflatoxin in local markets, thereby generating a price premium for aflatoxin-safe maize and increasing the market return to investing in aflatoxin prevention. In order to estimate the potential public health return of any of these strategies, we first require evidence regarding farmers' expected response to technology promotion under different combinations of cost subsidies and price premiums. In order to generate this evidence, we conducted a cluster-randomized controlled trial to test the impact of various strategies for the promotion of aflatoxin-prevention technologies in Eastern Kenya.

Our study examines farmers' responses to training on aflatoxin prevention coupled with free provision of a simple, low-cost, widely available technology: plastic sheeting for use as a barrier between maize and the soil during sun-drying of the crop. We additionally observe adoption of a new, higher-cost, more advanced technology: a mobile flatbed dryer to ensure that maize grain is fully dry before storage. This new technology is promoted under three different cost schemes. For both of these technologies, we report adoption both with and without a simulated price premium for selling aflatoxin-safe maize after three months of storage.

Findings from the trial indicate that Kenyan farmers who produce maize for the market are less likely to adopt aflatoxin-prevention technologies relative to farmers who produce only for home consumption. Given recent rapid urbanization and an increased share of food sold through markets, this has significant implications for public health. We additionally find that subsidies greatly increase adoption of aflatoxin reduction technologies by both subsistence and market producers and that incentives close the adoption gap between these two types of farmers.

We calculate the private and public costs of these technologies under various combinations of subsidy and incentive; we also combine original consumption data and published research findings to simulate the reduction in aflatoxin-related diseases associated with the levels of technology adoption observed under each of these scenarios. We compare the cost per disability-adjusted life year saved for these technology promotion schemes to benchmark costs within the public health literature. We find that all of the technology promotion schemes studied here would be considered cost effective as public health interventions, with some costing far below the international benchmark. Finally, we discuss the implications of these findings for policies regarding consumer welfare and health inequality.

2. Study Design

2.1 Aflatoxin Prevention

There are a number of low-cost post-harvest actions that farmers can take to reduce the probability of aflatoxin contamination and more generally to increase the quality of their maize.

Adequately drying harvested maize before storage is the front-line defense against fungal growth and thus aflatoxin contamination. While maize may be exposed to fungi during cultivation and harvesting, fungi will only continue to multiply and produce aflatoxin if the maize is inadequately dried and/or stored. Maize is considered adequately dry for long-term storage once it has attained a moisture content of 13.5 percent or lower. Farmers in Kenya typically dry their maize in two steps. First, they lay the cobs on the bare ground for a few days to be sun-dried. The kernels are then removed from the cobs (shelled). Some farmers further dry the maize after shelling, typically by laying it back on the bare ground or on a sheet made of used woven storage bags. The final moisture content achieved through this process depends on the weather. Rains and high relative humidity during the post-harvest period are common in the study area, so sun-drying alone is often not sufficient to attain the recommended moisture content.

The Aspergillus fungus lives in the soil and often infects maize during the post-harvest drying stage. Exposure to the fungus can be significantly reduced by using an impermeable barrier between maize and the ground to ensure that the grain does not come into contact with soil during drying. Use of such a barrier also prevents transmission of humidity from the soil and facilitates collection of grain at night and in case of unexpected rain. While the majority of farmers in the study area do dry their maize on some kind of barrier, the commonly used woven plastic bags are both difficult to clean and permeable. Thus, fungal spores that remain on these bags from the previous storage season or that are present in the soil may still reach the drying crop. Impermeable plastic sheeting is available in the study area but is rarely used for drying maize.

Sorting out damaged or rotten maize prior to storage also reduces aflatoxin contamination by pre- venting fungi from these infected or susceptible grains from spreading. However, sorting maize can be quite labor intensive and can result in significant reduction of the volume available for sale. Treating the maize with chemical pesticides before storage can also reduce aflatoxin contamination. Pest infestation, which can spread fungal spores, damage grains, and make the crop more vulnerable to fungal infection, can be reduced through treatment with insecticide; preservatives and fungicides can be used to control mold growth directly (Noomhorm and Cardona, 1991). However, in the study area, chemical treatment is widely through to lower the desirability of maize due to health concerns.

2.2 Sample and Baseline

The study sample consists of maize farmers in 30 randomly selected maize-growing villages in Meru and Tharaka-Nithi counties in Eastern Kenya, a region where acute aflatoxin poisoning leads to frequent and sometimes fatal outbreaks of aflatoxicosis (see Appendix Table A3 and Daniel et al., 2011). Each of the 30 study villages was visited in June 2013 for baseline data collection. In each village, an average of 23 households containing either a pregnant woman or a child under 24 months of age were enrolled. At least one farmer from each of the study villages was then selected in consultation with community leaders to be trained regarding the causes and consequences of aflatoxin contamination in maize and on recommended practices for aflatoxin prevention. Trained farmers were given printed training materials and asked to share this information with others in their communities.[1]

Fifteen of the study villages were then randomly assigned to a technology treatment group. Maize farming households in technology treatment villages received access to a package of post-harvest technologies described below. Farmers in the remaining 15 villages constituted the control group.

Of the 540 households reached for a follow-up survey in June 2015, the primary sample for this study includes the 534 households that cultivated maize in the Oct 2014 - Feb 2015 season.[2] Among these farmers, the median annual harvest size at baseline was 320 kg, with a mean of 594 kg. At baseline, 44 percent of these farmers had sold any maize in the past 12 months. Among market producers, the median amount sold in a year was 100 kg, with a mean of 490 kg.

The primary determinant to producing maize for the market is the amount of maize harvested. The median subsistence farmer produces 158 kg of maize per year, while the median market producer harvests nearly four times that amount (585 kg).[3] The harvest distribution for each group is shown in Figure 1.

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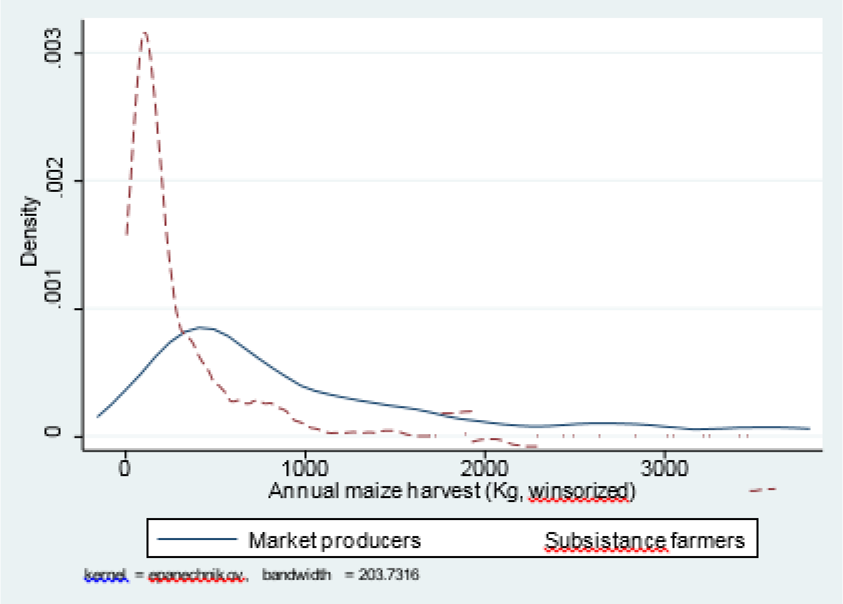
[1] This type of training is the standard of care for aflatoxin prevention in the study region and was implemented based on ethical considerations.

[2] While 20 percent of the original sample were lost to follow-up over the two-year study, analysis indicates that there are no significant demographic differences between those followed up with and those lost. Further, differences in determinants of attrition between treatment and control groups do not suggest any discernible pattern. In the treatment group, attritors have smaller households and lower food consumption per adult equivalent. In the control group, attritors have higher head education but lower wife education and smaller harvests.

[3] It is possible that some of these “subsistence farmers” sold other crops and were subsistence farmers only in regard to maize production.

Figure 1. Harvest size by producer type



Note: Harvest sizes are winsorized at the top and bottom 1%

In addition to maize harvest sizes, these groups also differ in a number of other ways. Table 1 displays the means of key demographic and economic characteristics for market and subsistence producers, as well as p-values for the tests of equality of means. Market producers are more educated, have more assets, and have higher values of food consumption. Non-food expenditures of market producers are over one-third greater than those of subsistence households, and the area of land owned by market producers is 62 percent higher. To assess the relative importance of these differences, we estimate a probit model of market producer status as a function of these characteristics. Significant correlates of market producer status include landholdings, non-food expenditures, and education of household head; household size is also slightly higher among subsistence producers.

Table 1. Farmer characteristics by producer type

	Subsistence Farmers (1)	***Market Producers*** (2)	***Difference*** (3)	***p-value*** (4)	***Probit*** (5)
Household size (adult equivalent)	3.67	3.48	-0.19	0.12	-0.13*
	(0.08)	(0.11)			(0.07)
HH head has any secondary schooling	0.14	0.26	0.12	0.00	0.30**
	(0.02)	(0.04)			(0.12)
Wife has any secondary schooling	0.15	0.26	0.11	0.01	0.20
	(0.03)	(0.05)			(0.15)
Asset index	-0.37	0.49	0.86	0.00	0.00
	(0.12)	(0.14)			(0.00)
Food consumption/AE/week (KSh)	2266.97	2572.83	305.86	0.00	-0.00
	(129.97)	(117.53)			(0.00)
Non-food expenditures/HH/week (Ksh)	1083.46	1458.94	375.48	0.00	0.15**
	(127.53)	(106.67)			(0.06)
Land owned (acres)	1.39	2.25	0.86	0.00	0.20***
	(0.16)	(0.18)			(0.07)
N	299	235			534

Note: Sample includes 534 farmers who harvested maize in the season of interest and were followed up at endline. Columns 1 and 2 present the mean values by producer group. Column 4 presents the p-value of the test of equality of means. Column 5 presents the results of a probit estimation of market producer status on the same characteristics. Bootstrapped standard errors in parentheses, corrected for village clustering. For column 5: * p<.10; ** p<.05; *** p<.01.

In the following sections, we examine how market producer status impacts a farmer's probability of adopting technologies to improve food safety, as well as his or her response to market incentives. However, differences in asset base and standard of living may also contribute to differences in decision-making. Therefore, we construct a propensity-to-sell score based on the estimated probit and include specifications controlling for this variable to ensure that differences are driven by market orientation rather than other underlying characteristics.

2.3 Intervention and Follow-up

The intervention was designed to increase farmers' knowledge about aflatoxin control and access to post-harvest technologies to reduce aflatoxin contamination in maize. The intervention included information regarding routes of aflatoxin contamination and training on good post-harvest practices for prevention, such as sufficient drying, sorting, and safe storage. It also included free provision of plastic sheeting to be used as a barrier during sun-drying. The intervention additionally provided access to a mobile maize dryer, which circulated heated air around the shelled maize to dry it until the desired moisture content was reached. Access to the dryer was provided at three different price points.

The intervention proceeded as follows. In technology treatment villages, members of each participating household were visited at their homes and invited to attend a meeting in the village in a few days' time. At that meeting, information was to be presented regarding aflatoxin prevention and the maize dryer, including how participants could access the dryer. Upon invitation, participants were informed that at the meeting, they would be able to enter a lottery through which they could win a partial discount on use or even free use of the dryer. They were also told that plastic sheeting on which to dry maize would be given to all attendees for free.[4] Information regarding participants' anticipated quantity of harvest was collected prior to the village meeting, either during the invitation visit or as participants were gathering for the meeting.

During the village meetings, the mobile maize dryer was described and photographs of the dryer were shown. Meeting attendees who had previously stated that they expected to harvest at least 45 kg of maize (77 percent of attendees) were invited to participate in a public lottery, through which the price they would be charged for use of the dryer was determined.[5] There were three possible prices: (i) a full "commercial" price of 350 Kenyan shillings (KSh) per 90 kg bag, which covered both operating expenses and the capital cost of the dryer, including a profit margin set in consultation with an NGO working on dryer commercialization; (ii) a partially subsidized "NGO" price of 150 KSh per bag, reflecting the price required to cover only the operating expenses of the dryer; and (iii) a full subsidy (zero price) offer, reflecting a public service provision model in which the government or a non-profit entity would provide the drying service free of charge. Farmers were given vouchers indicating the price they had drawn.[6] This design allowed us to observe the proportion of

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[4] We note that encouragement of assigned study participants to attend the meetings was significant in achieving sufficient statistical power for the study. Gathering a significant number of farmers for a meeting is generally not difficult in the study area, particularly if an item of value is given to attendees, but ensuring that the attendance of specific study participants is more challenging. For the purposes of the study, fliers containing information about the meeting's purpose and the scheduled time and location were left with all invitees. Three separate attempts were made to find each invited household, and meeting information fliers were also left with village officials to pass on to those who were not found by the third attempt. Phone calls to all invitees were made the day prior to each meeting, reminding them of the time and location.

[5] Farmers with harvests lower than 45kg were not eligible to use the dryer due to the minimum operating requirement.

[6] Hermetic storage bags were offered at the full market price of 220 KSh each to those using the dryer under the full price treatment and discounted by roughly the same proportion as the dryer for those using the dryer in the partial

farmers willing to use the mobile drying service at three potential price points.

At baseline, fewer than 15 percent of the sample had harvested less than 45kg in the main growing season. The second key aspect of the design is the random assignment of a market incentive for producing aflatoxin-safe maize. Within each village in which the package of post-harvest practices was offered, 50 percent of farmers were assigned to the market incentive sub-treatment. These farmers were told that two to three months after harvest, they would have an opportunity to sell up to 45 kg of maize at the prevailing market price plus 15 KSh per kg (a price premium of approximately 50 percent), but only if the maize tested below the regulatory standard for aflatoxin contamination.[7]

In order to minimize both confusion and potential experimental effects arising from interpersonal comparisons, separate meetings were held in each village for farmers assigned to the market incentive treatment and for those not offered the incentive payment. The meetings were identical in content except for the explanation of the market incentive. Information regarding whether participants intended to use the dryer, the approximate date at which they anticipated harvesting, and the quantity of maize they expected to dry were elicited immediately after the lottery for subsidies. At the end of the meeting, attendees were given a booklet describing recommended post-harvest practices for aflatoxin control, information on how to access the dryer, and a reminder of the market incentive, if relevant. This booklet was written in Kiswahili and made extensive use of simple graphics.

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subsidy group. Those in the free group were given a free hermetic bag for the first 90 kg dried and one more bag for every two bags dried thereafter. Due to complications with implementation, we do not study take-up of the hermetic bags here. However, we note that the offer of discounted bags may have acted to increase take-up of the dryer. Nonetheless, any inflation in take-up will not affect the estimates of cost-effectiveness in Section 4.2.5, as the cost of subsidizing the dryer is entirely variable based on demand. While fixed costs for a given dryer exists, we assume the production of dryers would respond to dryer demand, thus also making capital costs variable.

[7] Sales were capped at 45 kg due to logistical and budget constraints; the premium of 15 KSh / kg was set to achieve a total premium payment that would be comparable to a lower per-kg premium and a larger amount sold.

Appointments for use of the drying service were later finalized by phone. On each day when appointments were scheduled within a certain village, one of the study dryers was transported to a central location within that village. The drying service included transportation of farmers and their maize from their homestead to the dryer location, measurement of initial grain moisture content, use of the flatbed dryer, and post-drying moisture testing. Several measures were taken to prevent participants from using the drying service for less than their randomly assigned price. First, farmers were allowed to dry only as much maize as they had previously reported that they expected to harvest. Second, farmers were asked to show the voucher indicating the price at which they were entitled to use the dryer. Finally, farmers were asked to verify their identity, either by showing their national ID or by placing a call to a member of the research team using a phone number associated with the household in the study data. Participants whose maize tested at or below 13.5 percent moisture prior to drying were refunded the fee, and their maize was not dried.

Researchers visited households approximately three months after harvest to sample stored maize and to make purchases from those in the market incentive treatment. Samples of maize grown and stored by the household were collected from all households with such maize in store. Survey data were subsequently collected on maize drying and storage practices.

2.4 Treatment Assignment

As shown in Table 2, the 534 maize-cultivating households that were followed up with in June 2015 were evenly distributed across treatment and control groups. Treatment assignment was not stratified on market producer status; however, it is fairly balanced within producer groups, with 45 percent of market producers and 53 percent of subsistence farmers assigned to the technology treatment. Within the treatment group, both market and subsistence maize producers are allocated across subsidy treatments (full/partial/none) roughly according to the 50/25/25 design. Reported reasons for non-participation are comparable across producer groups. We test for differences across treatment and control groups in all of the demographic characteristics and post-harvest practices discussed in Section 2 and find that treatment is balanced for each of these factors.[8]

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[8] Results available upon request.

Table 2. Random assignment of farmers to treatment groups

	Subsistence Farmers	Market Producers	Total	% of Tx group	% of participants
Total	299	235	534		
Control	140	129	269		
Treatment	159	106	265		
% Treated	53%	45%	50%		
Lottery participants	***127***	***86***	***213***	***80%***	
No subsidy	29	18	47	18%	22%
Partial subsidy	29	26	55	21%	26%
Full subsidy	69	42	111	42%	52%
No incentive	64	48	112	42%	53%
Sales incentive	63	38	101	38%	47%
Non-participants	***32***	***20***	***52***	***20%***	
Insufficient harvest expected	19	12	31	12%	
Declined	6	6	12	5%	
Did not attend meeting	7	2	9	3%	

Note: Sample is as in Table 1. The mobile maize dryer requires a minimum of 45kg of maize to operate. Farmers expecting a maize harvest of less than 45kg were expected to be ineligible to use the dryer and therefore did not participate in the lottery.

As shown in Table 3, not all of the farmers with whom we followed up at endline were eligible for questions regarding drying and storage, as some had not cultivated maize in the most recent agricultural season or had not stored maize due to a small harvest. A total of 468 farmers harvested maize for storage during the study; these form the sample of focus for analyses of post-harvest practices. For analyses of mobile dryer adoption, we additionally consider whether a farmer was eligible to use the dryer. We lose one-third of the treated sample due to non-participation in the lottery; this loss is mostly due to farmers with an expected harvest below the 45 kg minimum operating requirement for the dryer. A few more farmers who participated in the lottery were ultimately ineligible for dryer use due harvesting less than 45 kg, despite having stated that they expected to harvest more than this.

Table 3. Sample sizes for analysis

Category		***Treatment***	***Control***	***Total***
Total followed up		268	272	540
Of which,	Cultivated this season	265	269	534
	Self-dried this season	235	233	468
Participated in lottery		236	..	236
Of which,				
Eligible for dryer use (sufficient harvest)		180	..	180

Note: Some farmers with very small harvests consume maize fresh and harvest as needed, with no intention to dry and store the maize. Some farmers who expected a harvest of at least 45kg participated in the lottery but later realized a harvest of less than 45kg and were thus ineligible to use the drying service.

3. Results

3.1 Baseline Post-harvest Practices for Food Safety

At baseline, prior to any intervention, we measured maize farmers' post-harvest investments in maize quality, as presented in Table 4. Nearly 63 percent of farmers reported drying maize both before and after shelling; this increases the probability of achieving the required dryness compared to storing directly after shelling. Of farmers who sun-dry maize at all, 60 percent used a barrier while drying maize on the ground. However, only 3 percent of farmers who sun-dry maize report using a barrier made of plastic. As discussed previously, plastic is significantly more effective than traditional materials at preventing aflatoxin infection from the soil while drying. Further, only 37 percent of farmers sorted out bad kernels before storing — an effective, if tedious, practice for preventing the proliferation of fungus in stored grains. Finally, 65 percent of farmers reported treating maize with chemicals before storing, a practice that can reduce fungus but can also potentially pose other health risks.

Table 4. Baseline practices by producer type

	Full sample	*Subsistence Farmers*	*Market Producers*	*p-value for difference*
Dried maize again after shelling	0.629	0.613	0.65	0.32
	0.021	0.029	0.031	
Used any barrier while ground drying	0.594	0.682	0.491	0.00
	0.022	0.029	0.033	
Used plastic barrier while ground drying	0.031	0.027	0.036	0.56
	0.008	0.01	0.012	
Sorted	0.365	0.38	0.346	0.35
	0.021	0.028	0.031	
Used chemicals	0.649	0.565	0.753	0.00
	0.021	0.029	0.028	
N obs.	540	301	239	

Note: Means from 2013. Standard errors in parentheses. Final columns shows p-values for test of difference in means between subsistence and market producers.

We note that market producers are more likely than subsistence farmers to report post-harvest practices that may have negative implications for public health. While market producers report similar rates of extended drying and sorting, they are significantly less likely to use a barrier while ground-drying and more likely to use chemicals.

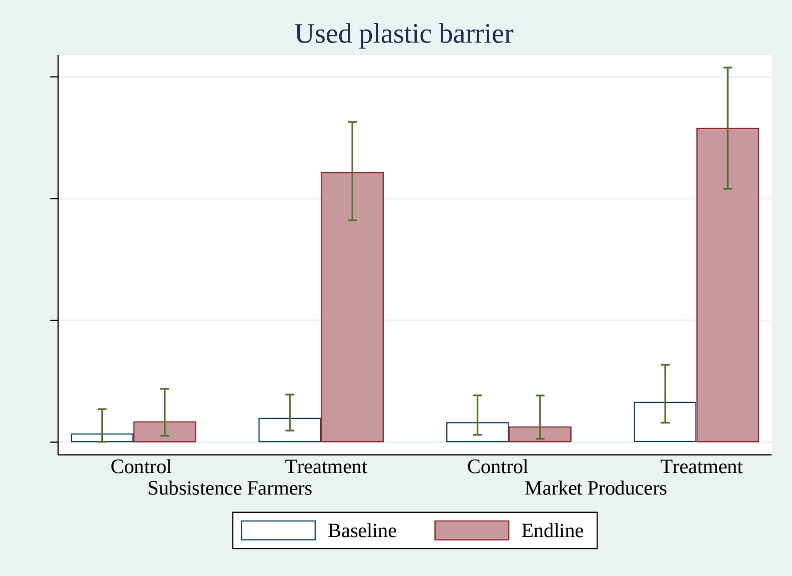
3.2 Adoption of Post-harvest Technologies for Food Safety

All of the study farmers in treatment villages were offered the training and a plastic barrier for free. Ninety-three percent of invited farmers attended the training, and nearly all of these received a plastic barrier as well.

3.2.1 Plastic Barrier Adoption

We first examine changes in plastic barrier use as a result of the free provision of plastic sheeting. Figure 2 shows reports of plastic barrier use during drying at baseline in 2013 and at endline in 2015, separated by treatment and control groups and by subsistence and market producers. At baseline, the use of plastic was extremely low and remained so among farmers in the control group. Among farmers assigned to the treatment group, plastic usage increased from 3-5 percent to 45-55 percent. The increase was slightly higher for market producers, although we cannot statistically reject that the increases are the same.

Figure 2. Take-up of plastic barriers by producer type and treatment



We examine changes in plastic use in a regression framework. Among the 468 farmers who harvested and sun-dried maize in the season of interest, we estimate

$$B_i = \alpha + \delta_1 Free_i + (\delta_2 Free_i \times Incentive_i) + (\delta_2 MP_i + \delta_3 Free_i \times MP_i + \delta_4 \gamma_i) + \varepsilon_i \tag{1}$$

where B_i indicates that farmer i ever used a plastic barrier while sun-drying maize, $Free_i$ indicates assignment to the treatment group and thus the opportunity to receive free plastic sheeting, $Incentive_i$ indicates sub-assignment to the sales incentive group, MP_i indicates market producer status, γ_i is farmer i's propensity to be a market producer based on other observable characteristics, and ε_i is a normally distributed error term.[9] Standard errors are bootstrapped to correct for clustering at the village level for all estimations. Table 5 presents the estimations of equation 1 with and without the terms shown in parentheses. We see that plastic barrier usage among subsistence farmers in the control group was exactly the same at endline as it was at baseline (3 percent, as shown in Table 4, column 6, bottom row). However, among those who received the fully subsidized plastic sheeting, usage increased to 47 percent. Assignment to the incentive treatment

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[9] Note that *Incentivei* alone is not included, as the incentive was offered only to a sub-set of the group to which free plastic sheeting was provided.

did not significantly affect use of plastic sheeting among those who received it (column 2). Similarly, the effect of free provision is not significantly different between market and subsistence producers (column 3).

Table 5: Plastic barrier use is increased by free provision

	(1)	*(3)*	*(2)*
Free provision	0.442***	0.412***	0.411***
	(0.060)	(0.051)	(0.065)
Free x Sales Incentive		0.063	
		(0.069)	
Market Producers			-0.010
			(0.031)
Treatment x Market Producers			0.080
			(0.066)
Propensity to sell			0.019
			(0.082)
Excluded Group Mean	0.030	0.030	0.034
Observations	468	468	468
Free+(Free x Market) p-val			0.490*** 0.000
Market+(Free x Market)			0.069
p-val			0.276

Note: In all columns, the dependent variable is a binary indicator of using a barrier while drying. Sample is conditional on doing any self-drying in the relevant season. Columns 3 and 4 include only those assigned to treatment. Bootstrapped standard errors in parentheses, corrected for village clustering. * p<.10; ** p<.05; *** p<.01.

3.2.2 Dryer Adoption

We define take-up of the dryer as bringing maize to the dryer, along with a sufficient amount of money to dry this maize at the assigned price. A simple examination of take-up rates for the drying service among eligible producers reveals some interesting patterns, shown in Figure 3.[10] When the mobile drying service is offered

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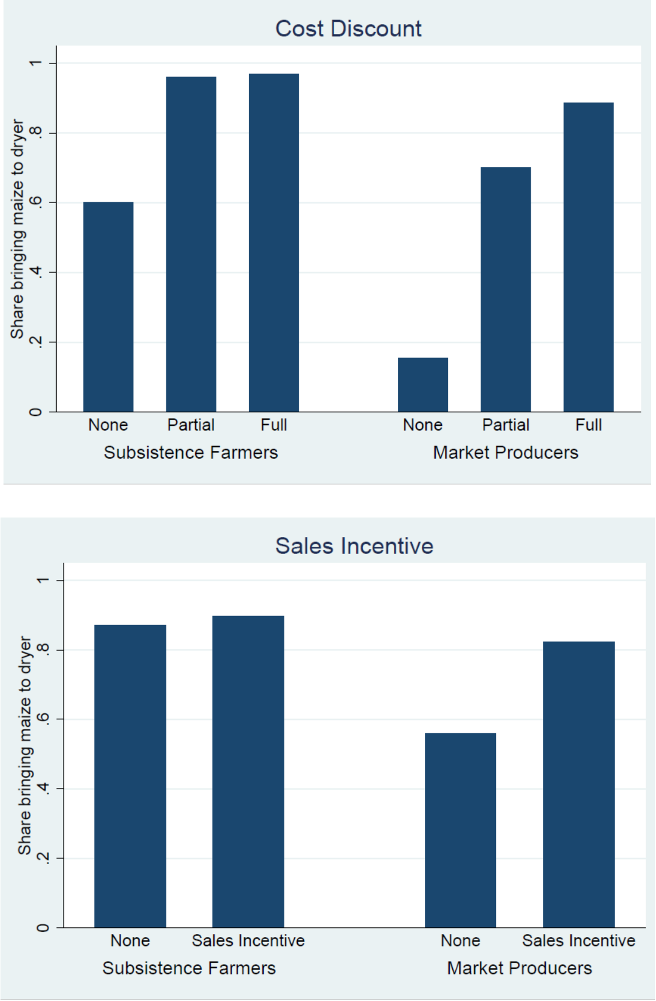
[10] See Table 3 and its associated text for sample size and explanation of eligibility.

free of charge, take-up is comparable between eligible subsistence producers (97 percent) and market producers (89 percent). When offered at the maximum anticipated price of 350 KSh per bag, on the other hand, take-up by commercial farmers falls dramatically to just 15 percent; however, 60 percent of subsistence farmers still bring maize for drying at this price point. This finding is striking given the fact that the socioeconomic status, particularly the consumption level, of market producers is higher, which would suggest a greater ability to pay for technology. Yet it seems that subsistence farmers have a greater willingness to pay. Among eligible market producers, the sales price incentive increases take-up by 26 percentage points (pp) (46 percent), bringing it almost to the level of take-up by subsistence farmers. Among eligible subsistence farmers, the sales price incentive has little discernible impact (3 pp), which is expected as these farmers do not sell their maize.

Figure 3. Take-up of drying service by producer type and treatment



Note: Samples include those who were eligible to use the dryer, which required a minimum of 45kg of maize to operate.

We additionally examine these differences in a regression framework. For this analysis, we note that whether or not an individual who participated in the lottery was ultimately eligible for dyer use could potentially be endogenous, as the stated harvest amount could respond to the subsidy value drawn. Therefore, we use the larger sample of 236 farmers who participated in the lottery as our sample for analysis of dryer take-up. The take-up patterns among this group are similar to those of the sub-sample who are eligible for dryer use, although the take-up rates are of course lower when including those who were ultimately ineligible due to low harvest. For the sample of farmers who participated in the lottery, we estimate

$$Y_i = \alpha + \beta_1 MP_i + \beta_2 FullDisc_i + \beta_3 PartialDisc_i + \beta_4 Incentive_i +$$

$$\beta_5 MP_i \times FullDisc_i + \beta_6 MP_i \times PartialDisc_i + \beta_7 MP_i \times Incentive_i + (\beta_8 \gamma_i) + \varepsilon_i \quad (2)$$

where Y_i indicates that farmer *i* brought maize to the dryer for drying, $FullDisc_i$, $PartialDisc_i$, and $Incentive_i$ indicate assignment to each of the three treatments, and MP_i, γ_i , and ε_i are as described previously. Estimations of equation 2, both with and without the propensity-to-sell score, are presented in columns 1 and 2 of Table 6, respectively. As before, standard errors are bootstrapped to correct for potential correlation at the village level.

Table 6. Cost discounts and sales price incentives increase use of drying service, differentially for market and subsistence producers

		(1)	*(2)*
a b	Market Producers (MP) Full Discount	-0.395*** (0.118) 0.367*** (0.073)	-0.356*** (0.102) 0.362*** (0.074)
c	MP x Full Discount	0.137	0.152
		(0.108)	(0.110)
d	Partial Discount	0.251**	0.248**
		(0.125)	(0.123)
e	MP x Partial Discount	0.135	0.142
		(0.185)	(0.189)
h	Incentive	0.005	0.012
		(0.057)	(0.061)
i	MP x Incentive	0.154	0.157
		(0.107)	(0.114)
j	Propensity to sell		-0.290
			(0.209)
	Excluded Group Mean	0.316	0.316
	Observations	236	236
	Effect of full discount or incentive on MP:		
k	FullDisc+(Market x FullDisc)	0.504***	0.514***
	p-val	0.000	0.000
m	Incen+(Market x Incen)	0.159*	0.169**
	p-val	0.050	0.049
	Effect of being an MP in presence of full discount or incentive		
n	Market+(Market x FullDisc)	-0.258**	-0.205**
	p-val	0.037	0.046
o	Market+(Market x Incen)	-0.241	-0.200
	p-val	0.172	0.220

Note: Sample includes 236 farmers who participated in the lottery. In all columns, the dependent variable is a binary indicator of attempting to use the dryer. In all columns the excluded category is subsistence farmers offered the dryer without any subsidy or incentive. Bootstrapped standard errors in parentheses, corrected for village clustering. * p<.10; ** p<.05; *** p<.01.

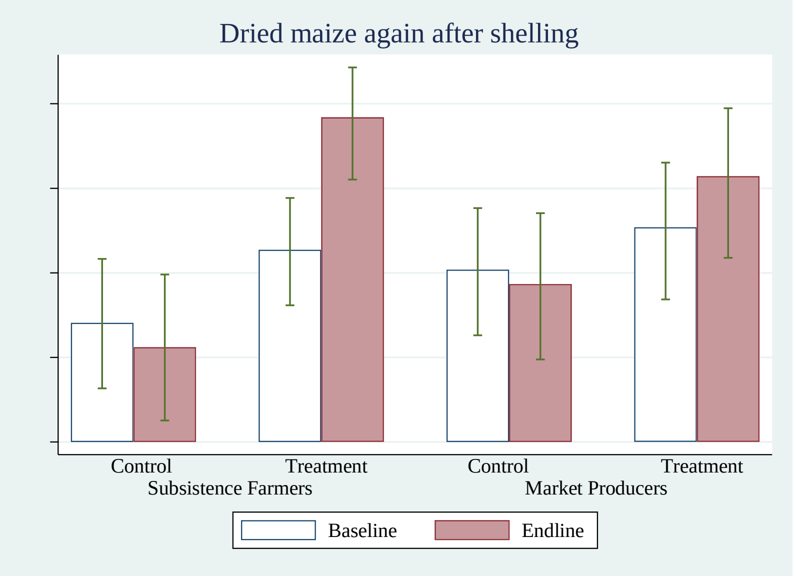
As initially indicated by Figure 3, market producers are significantly less likely than subsistence farmers to invest in drying technology. Without any subsidy, this difference is 36-40 pp (Table 6, row a). Fully subsidizing the technology increases adoption by 36-37 pp for subsistence producers (row b) and by 50-51 pp for market producers (row k) but does not close the gap between the producer types (row n). The partial subsidy is also somewhat effective, increasing adoption by 25 pp for subsistence farmers (row d) and 39 pp for market producers (row d+e).

While the price incentive has no impact on the behavior of subsistence maize producers (row h), it does appear to increase investment by market producers. Specifically, the incentive increases adoption of drying technology by market producers by 16 to 17 pp (row m). In the presence of the incentive, the difference in adoption between market and subsistence producers is reduced and is no longer significant (row o). The results do not change when we control for underlying socioeconomic differences between producer types using the propensity score (col 2).

3.2.3 Other Post-harvest Practices

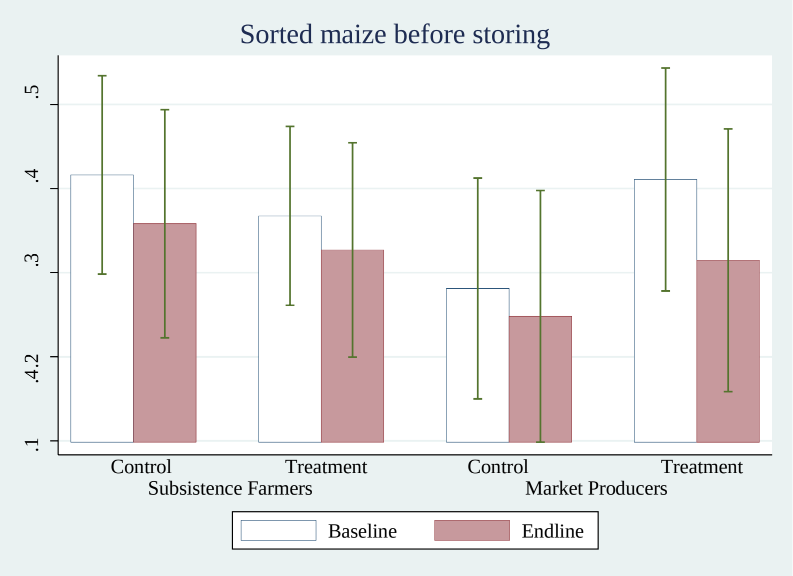
We additionally examine the impact of the training on other post-harvest practices. Figures 4 and 5 show the same information as Figure 2 for the post-harvest practices of drying shelled maize and sorting maize before storing it, respectively. Training had a large impact on drying practice. Fifty-five percent of farmers in control villages reported drying their maize after shelling and prior to storage; this number reached 76 percent for farmers in treatment villages. The rate of drying was 12 pp higher and statistically significant at p=0.025 even among those in treatment villages who reported not drying their maize on plastic sheeting. Interestingly, we see that sorting actually fell slightly across all groups, although we cannot reject that sorting is the same across all groups at all points in time.

Figure 4. Change in drying maize again after shelling, by producer type



Note: Bars indicate the proportion of the sample who report the practice. Lines indicate the Agresti-Coull approximation of the binomial confidence interval (Agresti and Coull, 1998).

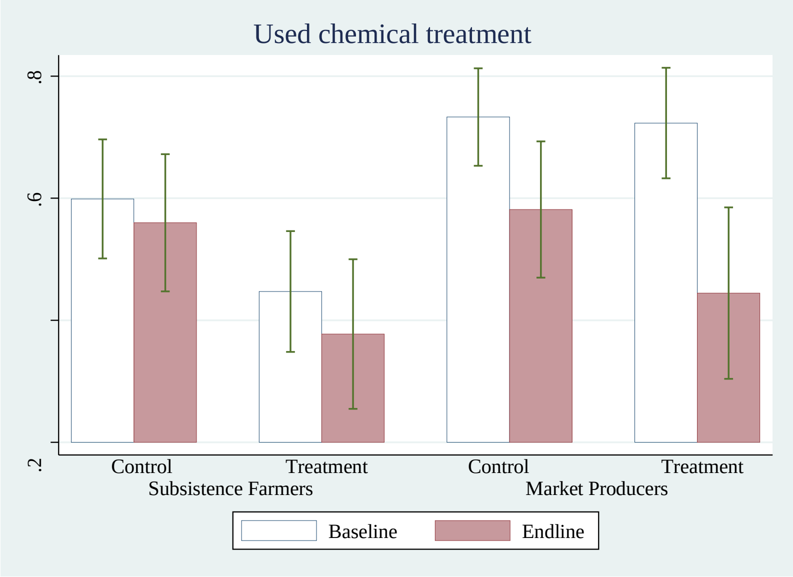
Figure 5. Change in maize sorting by producer type



Note: Bars indicate the proportion of the sample who report the practice. Lines indicate the Agresti-Coull approximation of the binomial confidence interval (Agresti and Coull, 1998).

Figure 6 examines the application of chemical dusts to maize before storage. We note that use of chemicals was much higher among market producers than subsistence farmers at baseline. Both treatment and control market producers reduced their chemical use substantially at endline, although the decrease is significant only for market producers in the treatment group. Subsistence producers also reduced their chemical use slightly more in the treatment than control group, but the differences are not statistically significant. The observed reductions in chemical use and sorting may reflect a substitution effect between these practices and improved drying.

Figure 6. Change in chemical use by producer type



Note: Bars indicate the proportion of the sample who report the practice. Lines indicate the Agresti-Coull approximation of the binomial confidence interval (Agresti and Coull, 1998).

These results indicate that training affected practices beyond the use of the technologies made available through the intervention. Results reported by Pretari et al (2018) also suggest that training alone reduced aflatoxin contamination, independent of the use of any technology. In addition to increasing the proportion of farmers who dried their maize after shelling, the provision of information regarding routes of contamination and methods of prevention may have increased farmers' precautions against contact with soil during and after harvest, their vigilance regarding rainfall during sun drying, or other such mechanisms.

3.3 Discussion of Results

We glean several takeaway messages from these results. First, in the part of Kenya under study, smallholders' post-harvest aflatoxin management practices are poor in the absence of any intervention. More than one-third of farmers do not dry their maize after shelling. Of those who do dry their maize, one-third do not use any barrier, and almost no one uses an impermeable plastic barrier. Only one-third of farmers sort their grain before storage, and more than two-thirds use potentially harmful chemicals.

Second, we see that some practices are significantly worse among market producers. This is not surprising, given aflatoxin's unobservability in local markets and the resulting lack of a price premium for aflatoxin-safe maize. This concept is formalized by Fafchamps et al. (2008), who demonstrate that when an attribute is costly (or impossible) to verify, the associated premium for that attribute falls (or disappears). In such cases, there will be under-provision of that attribute.[11] This suggests that improving the observability of aflatoxin in local markets could generate price premiums. We find that for costly technologies such as the dryer, the existence of a price premium significantly increases the likelihood that market producers invest in aflatoxin-prevention—by nearly 50 percent.

Third, we find that all farmers significantly increase their efforts to prevent aflatoxin when technologies are subsidized. A full subsidy increases the use of a plastic barrier from 3 percent to 47 percent and more than doubles dryer adoption. Even a partial subsidy of the dryer has a nearly equal impact on adoption, generating take-up rates of 56 percent by subsistence farmers and 35 percent by market producers. For subsistence farmers, investing in aflatoxin prevention is purely for the benefit of their own health and that of their family. Similarly, farmers who sell a portion of their maize may be motivated by health concerns to invest in the safety of the maize they retain for household consumption. The strong negative response of take-up to price is

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[11] Existing research on quality in agricultural markets is consistent with the prediction that only qualities that are observable, or that have reliable observable proxies, are rewarded in the market. For example, Kadjo et al. (2016) find that a 10-percent increase in visible pest damage results in a price reduction of 3-9 percent for maize in Benin. Similarly, the market price of rice is affected by product origin and variety, which proxy for unobservable nutritional content and cooking times (Sakurai et al., 2015). In contrast, aspects of food quality and safety that are invisible and idiosyncratic, with no available proxy, such as pathogenic contamination of perishable foods or fungal contamination of stored grain, do not face a price penalty (Hoffmann et al., 2013). Detecting these characteristics requires laboratory tests, making them fully unobservable to the average consumer in an informal market.

consistent with many other studies examining take-up of preventive health technologies for household use (Hoffmann et al., 2009; Ashraf et al., 2010; Cohen and Dupas, 2010; Dupas, 2011).

In the following section, we consider the feasibility of scaling up the promotion strategies tested in this study. We first consider the cost of the subsidies we offered. We then examine whether the market could support a price premium that would generate an incentive comparable to the one we offered. In Section 4.2, we simulate the potential human health effects of the various combinations of these two approaches to promotion of on-farm aflatoxin management. We calculate the cost-effectiveness of each scheme and compare this to international cost-effectiveness benchmarks for public health interventions.

4. Policy Simulations

4.1 Scaling Up Methods for Aflatoxin Prevention

4.1.1. Subsidy costs

In the previous sections, we have shown that both cost subsidies and sales price incentives are effective methods for increasing the adoption of aflatoxin prevention technologies. In this section, we consider the cost and feasibility of these approaches for both the mobile drying technology and the provision of plastic sheets.

We assume that promotion of both the drying service and the plastic sheeting would require village- level meetings with farmers. Based on study costs, we estimate that two meetings attended by 25 farmers each can be held each day, at a cost of $85 US ($60 for vehicle rental and $25 for wages) per day. We assume that these promotions occur once every two years and include distribution of plastic sheets.[12] We then multiply the cost of training by 1.18, which is the marginal cost of public funds in Kenya as estimated by Auriol and Warlters (2012), and apply the five-year average of the one-year Kenya bond rate (0.047) as the social discount rate to account for the fact that benefits of this investment accrue over two years (Warusawitharana, 2014). Finally, we multiply the per-farmer, per-year cost of promotion and distribution ($1.10 US) by the total number of

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[12] Plastic sheets are assumed to develop tears, rendering them less effective after two years of use. Refresher trainings may also be required to remind farmers of good practices after this interval; a similar study testing the impact of village-level training and tarp provision on aflatoxin in Ghana found impacts two years post-intervention(Hoffmann et al., 2017b).

farmers in Eastern Kenya (697,657).[13] We reach a total training cost of $767,687 US for the region.

The costs for subsidizing the provision of plastic sheeting and drying services are presented in Table A5. The cost of providing fully subsidized plastic sheeting is based on the current cost of 750-gauge plastic in Meru town. We assume that the 14.6-square-meter pieces of sheeting provided through the study are sufficient to dry 600 kg over the course of the year (less each season) and will last for two years (four agricultural seasons). Many farmers produce less than 600 kg of maize; we estimate the mean kg dried per sheet annually to be 377 kg, using the baseline harvest distribution in the study sample. By multiplying the 416 KSh material cost of sheeting per farmer by the marginal cost of public funds and social discount rate as above and then dividing by the amount of maize dried over the two-year lifespan of the sheets, we find a cost of 0.71 KSh per kg, equivalent to approximately $0.007 US. We then multiply this cost by regional maize production and the proportion of study farmers who attended training sessions, resulting in a total public cost of $2,519,359 US.

The equipment and operating costs of the mobile dryer are taken from ACDI-VOCA's Aflastop project, which designed the dryer and tested its commercial viability (personal communication, Marius Rossouw, April 7, 2016). We assume that the useful life of the dryer is five years, and that the dryer is used for 30 days per year (15 days for each season). We apply the Kenya bond rate as the social discount rate, compounded over the five-year dryer lifespan, and the (one-time) marginal cost of public funds to calculate the full cost of the capital investment in the dryer. This full capital cost is then converted to a daily cost by dividing by the number of days on which the dryer is used over five years. Annual maintenance costs are assumed to be 15 percent of the dryer cost, before accounting for the cost of capital, and are divided by the number of operational days per year to arrive at a daily maintenance cost. We model both a partial dryer subsidy, in which the capital cost of the dryer is covered by public funds and operating expenses are covered by user fees, and a full subsidy. Under full subsidization, the marginal cost of public funds is also applied to the variable cost of drying maize. Finally, we assume that management of subsidies entails personnel costs of 2,500 KSh

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[13] This is estimated by dividing the region's total average annual maize production by of 383,356 metric tonnes (of Agriculture. Central Planning and Unit, 2015) mean per-farmer production in our sample (549 kg).

per day for a team to manage either the operating cost of 10 fully subsidized mobile dryers or the disbursement of three capital subsidies per month. Assuming that an average of 1,250 kg (2.5 batches of 500 kg) of maize is dried per day, we arrive at a cost of 2.93 KSh per kg to fully subsidize the mobile dryer and 0.73 per kg to partially subsidize the dryer (covering the capital cost). Assumptions for these calculations are presented in Appendix Table A1.

While the full subsidy increases dryer adoption significantly, it also represents a very large public cost relative to other options. Given that a partial dryer subsidy increases dryer adoption nearly as much as the full subsidy, it seems unlikely that fully subsidization is the best policy choice. We return to this in greater detail in Section 4.2.5.

4.1.2 Feasibility of price premiums

We also consider the impact of developing markets to support a price premium for aflatoxin safety. A *de facto* premium for aflatoxin safety already exists in Kenya's branded maize flour market. Increasingly, processors test maize for aflatoxin contamination and other quality attributes in company laboratories prior to purchase. At the time of writing, however, none of the large-scale millers in the study area of Meru and Tharaka-Nithi Counties tested for aflatoxin. Transporting maize to the Nairobi market, where several millers do test for aflatoxin, is prohibitively costly due to the long distance and the excess fees charged by several county borders crossed along the way. However, local millers could be encouraged to invest in aflatoxin testing through a combination of capacity building and increased regulatory enforcement.

Based on the price premium currently offered by millers that test for aflatoxin, we estimate that a realistic wholesale premium for aflatoxin-safe maize that could be passed on to farmers would be about 2 KSh per kg. Would this be sufficient to induce adoption of improved technologies? At the full operating cost for a private business, including the opportunity cost of private capital invested in the dryer and the cost of a plastic drying sheet, the full technology package (plastic sheets plus mobile drying service) offered in our study costs an estimated 2.9 KSh per kg.[14] Thus, under a pure private model of provision, this premium would not have any

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[14] We use the weighted average lending interest rate of commercial banks in Kenya, minus inflation rate over the following 12 months, for the five-year period up to Feb 2017, to estimate the cost of private capital at 10.2 percent.

impact. At the partially subsidized drying cost (including free plastic sheets), we estimate that the cost to the farmer is 1.7 KSh per kg dried. A market producer's return on investment in drying would thus be 0.3 KSh per kg under a 2 KSh per kg price premium. To determine whether this would be sufficient to trigger widespread adoption, we consider the level of production at which technology use would generate an incentive comparable to those offered through the experiment.

In our experiment, the maximum amount of maize that a farmer could sell at the premium price was capped at (the very low level of) 45 kg, and the premium was set at (the very high level of) 15 KSh per kg. Therefore, we consider here the total return to the adoption of drying, rather than the return per kg. Farmers who dried and sold 45 kg of maize through the study could earn a total incentive payment of 675 KSh. At the intermediate price point of 1.67 KShp er kg charged in the experiment (75 KSh to dry 45 kg), this yields a total return of 600 KSh on the decision to adopt drying. In the experiment, the adoption rate among market producers charged this price was 60 percent. In reality, however, the total return to adoption will depend on the amount of maize dried and sold by a farmer. In order for a 2 KSh per kg premium to yield a return of 600 KSh, a farmer paying the partially subsidized rate of 1.7 KSh per kg for dryer use would need to dry and sell at least 2,000 kg of maize. This is a very large quantity; only 3.7 percent of the farmers in our sample had sold at least this amount in the 12 months preceding the baseline survey. However, while a realistic price premium would induce adoption for only a small share of farmers, it could have a significant impact on aflatoxin contamination in markets: that 3.7 percent of farmers accounted for 42.4 percent of all maize sold in our sample.

4.2 Using Agricultural Technology to Improve Human Health

Given the well-documented links between aflatoxin and human health, in this section, we consider how investment in and adoption of aflatoxin prevention technologies could impact health outcomes. We estimate the potential impacts of improved drying technologies on health outcomes, as well as the cost- effectiveness of these technologies as health interventions. In order to do this, we need to answer several key questions:

This rate is compounded over the five-year investment in the dryer.

1. How much does the technology reduce contamination in maize to which it is applied?
2. What is the expected level of technology adoption at various price levels, with and without price incentives?
3. What are the expected changes in dietary aflatoxin exposure from the adoption-adjusted reductions in contamination?
4. What is the relationship between dietary aflatoxin exposure and health outcomes?
5. What is the cost of subsidizing the technology, and how does this compare to other interventions with comparable health impacts?

The calculations employed to answer these questions are detailed in Table 7. We consider six policy scenarios involving three levels of subsidization. In the first two scenarios (columns A and B of Table 7), training and plastic sheets are provided for free. In scenarios C and D, the subsidy additionally covers the capital costs of the mobile maize dryer; users pay a per-kg fee that covers the variable costs of the dryer's operation and maintenance. Scenarios F and G include the full subsidization of training, plastic sheeting, and drying service. At each level of subsidization, we present a simulation with and without the assumption of a market price premium for aflatoxin-safe maize.

Table 7. Policy simulations for training and plastic tarp & dryer subsidy and incentive schemes

			Training + Free Plastic +					
			No Dryer		***Discounted Dryer***		***Free Dryer***	
Q	**R**		***No Prem. (A)***	***Premium (B)***	***No Prem. (C)***	***Premium (D)***	***No Prem. (E)***	***Premium (F)***
1	1	Efficacy: Training + Plastic + Dryer			0.759	0.759	0.759	0.759
	2	Efficacy: Training + Plastic	0.701	0.701	0.701	0.701	0.701	0.701
	3	Efficacy: Training	0.409	0.409	0.409	0.409	0.409	0.409
2		***Subsistence Maize***						
	4	Share maize affected by training at all	0.932	0.932	0.932	0.932	0.932	0.932
	5	Share maize affected by training only	0.488	0.488	0.167	0.167	0.014	0.014
	6	Share maize affected by training + plastic only	0.444	0.444	0.059	0.059	0.096	0.096
	7	Share subsistence farmers using full package*			0.706	0.706	0.822	0.822
	8	Proportion of maize dried, conditional on dryer use			0.540	0.540	0.721	0.721
	9	Share maize affected by full package			0.381	0.381	0.592	0.592
		Marketed Maize						
	10	Share maize affected by training at all	0.931	0.931	0.931	0.931	0.931	0.931
	11	Share maize affected by training only	0.431	0.396	0.264	0.231	0.209	0.138
	12	Share maize affected by training + plastic only	0.500	0.535	0.222	0.100	0.111	0.103
	13	Share market producers using full package*			0.444	0.600	0.611	0.690
	14	Net incentive payment in experiment			0	600	0	675
	15	Drying cost per KG (KSh)			1.70	1.70	0	0
	16	KG sales to earn same incentive at 2 KSh/kg premium			n/a	2000	n/a	337.5
	17	Share of market producers selling at least this much			n/a	0.037	n/a	26.25
	18	Share of maize produced by these farmers (%)**			0	0.424	0	0.839
	19	Simulated share maize affected by full package			0	0.254	0	0.579
	20	Simulated share maize affected by training + plastic only			0.667	0.446	0.722	0.214
3	21	% reduction in contamination of subsistence maize	0.511	0.511	0.627	0.627	0.684	0.684
	22	% reduction in contamination of marketed maize	0.527	0.537	0.575	0.600	0.592	0.646
	23	AF exposure, stored maize (ng/day/kg bodyweight)	24.06	24.06	18.36	18.36	15.56	15.56
	24	AF exposure, purchased maize (ng/day/kg bodyweight)	9.22	9.02	8.27	7.79	7.95	6.90
	25	Total exposure through maize (ng/day/kg bodyweight)	33.3	33.1	26.6	26.2	23.5	22.5
	26	% Dietary reduction relative to status quo	0.515	0.518	0.612	0.619	0.657	0.673

Table 7. Continued

			No Dryer		Discounted Dryer		Free Dryer	
Q	**R**		***No Prem. (A)***	***Premium (B)***	***No Prem. (C)***	***Premium (D)***	***No Prem. (E)***	***Premium (F)***
4	27	Reduction in aflatoxicosis deaths/year in region	10.7	10.8	12.7	12.9	13.7	14.0
	28	Reduction in HCC cases per year in region	34.4	34.6	40.8	41.3	43.8	44.9
	29	Standardized mean difference, LAZ	0.159	0.160	0.188	0.191	0.202	0.207
5	30	Cost of training	$767,687	$767,687	$767,687	$767,687	$767,687	$767,687
	31	Cost of subsidizing plastic	$2,519,359	$2,519,359	$2,519,359	$2,519,359	$2,519,359	$2,519,359
	32	Cost of subsidizing dryer	$0	$0	$751,603	$952,109	$4,702,125	$6,539,904
	33	Total cost (USD)	$3,287,046	$3,287,046	$4,038,649	$4,239,156	$7,989,172	$9,826,950
	34	Public cost per life saved (USD)	$72,938	$72,530	$75,435	$78,293	$138,919	$166,969
	35	Public cost per DALY saved (USD)	$1,319	$1,312	$1,364	$1,416	$2,512	$3,019
	36	Public cost/child under 5 years	$3.72	$3.72	$4.57	$4.80	$9.05	$11.13
	37	Public cost per SMD	$23.46	$23.33	$24.26	$25.18	$44.68	$53.71

*We assume that farmers choosing to use the dryer would also use plastic. This may generate an overestimate of the effectiveness for these scenarios.

** We assume that in the absence of any incentive, no marketed maize will receive dryer treatment, even if it only costs time/effort.

4.2.1 How much does the technology reduce contamination in maize?

To assess the level of aflatoxin reduction stemming from the combined use of plastic drying sheets and the mobile maize dryer, we rely on published evidence. Kaaya and Kyamuhangire (2010) find that at three months of storage, maize that was dried using a biomass dryer similar to the one employed in this study saw 85 percent lower aflatoxin levels than maize dried on the bare ground. This is comparable to our experiment (the training and the use of both the plastic sheets and the mobile dryer) because the maize studied by Kaaya and Kyamuhangire was handled by skilled staff, placed directly in the dryer prior to shelling, and did not come into contact with the soil. Kaaya and Kyamuhangire (2010) also report month-specific levels of aflatoxin in their experiment, which we use to estimate the monthly level of contamination in both status quo maize and maize dried using the mobile dryer.[15] Averaging the month-specific reduction levels over Kaaya and Kyamuhangire's six month study yields an average reduction of 75.9 percent over the course of a full year with two harvest seasons (Table 7, row 1).

Unfortunately, Kaaya and Kyamuhangire (2010) do not disaggregate the effects of preventing contact with the soil and using the dryer. To estimate the efficacy of training and the use of plastic drying sheets without the dryer, we rely on evidence from Pretari et al. (2018), who use data from the same experiment described earlier in this paper.[16] Their findings suggest that maize grown by farmers who attended the training and used plastic sheeting for drying (but did not use the dryer) had 78 percent lower aflatoxin contamination three months after harvest than farmers assigned to the control group; this difference is significant at the 1% level. Relying on the relative month-specific reductions reported by Kaaya and Kyamuhangire (2010), this extrapolates to an average reduction of 70 percent over the course of a year (row 2).

The results reported by Pretari et al. (2018) also suggest that a significant part of the estimated impact stems from the training itself, as those attending the training (and not using the plastic or the dryer) had

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[15] See Appendix Table A2.

[16] When possible, we use results from Kaaya and Kyamuhangire (2010) rather than Pretari et al. (2018) because the former are experimental, whereas the latter are based on farmers' decisions to use the technologies offered, which could potentially introduce bias. However, because Pretari et al. provide the only direct evidence of the relative contributions of drying on plastic sheets and use of the mobile dryer, we use their results to estimate the impact of drying on sheets without use of the mobile dryer.

contamination levels that were 41 percent lower than farmers in the control group (extrapolated average for one year; row 3). However, as few farmers in this category had maize available for testing three months after harvest, the difference is not statistically significant and we are hesitant to make any claims about the impact of the training alone.[17] We therefore do not simulate the impacts of providing training alone.

4.2.2 What is the expected level of technology adoption?

We model adoption of the training only, the training and use of plastic barriers, and the full package of training, plastic barrier, and dryer. We model these as the share of maize affected, separately for subsistence farmers and market producers.

Among subsistence farmers, 93.2 percent of those invited to a training session attended the session.[18] If a farmer attended the training or used a plastic barrier to dry maize, we assume that the benefits of this knowledge or practice applied to all of the maize that s/he produced, so that the share of maize affected is equal to the share of farmers taking up the intervention (rows 4-6).[19] For the use of the dryer, we multiply farmer-level take-up (row 8) by the average share of maize harvest brought to the dryer, conditional on bringing any maize (row 7) in order to calculate the share of maize affected by the full package (row 9). Given that subsistence farmers would be unaffected by market price premiums, take-up for these farmers does not vary between the premium and no-premium scenarios.

For marketed maize, we similarly apply the share of market producers who attended the training or used a plastic barrier as the share of marketed maize affected by these technologies (rows 10-12). In row 13, we present the share of market producers who used the dryer at all as the share of farmers using the full package. Note that we assume here that any farmer choosing to use the dryer would also use the plastic.[20] We note that this assumption mechanically increases the estimated effectiveness of subsidizing the dryer; a point to

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[17] See Pretari et al. (2018) for additional details regarding the sample and testing protocols.

[18] We note that this figure is constant across columns, as the content of the meeting (regarding discounts and incentives) was not disclosed to participants in advance and so could not have determined attendance.

[19] While the number of observations is small, there is no difference in contamination levels between maize stored for sale and that stored for home consumption by such farmers in the data analyzed by Pretari et al. (2018).

[20] This assumption is required because we have no information regarding the efficacy of the dryer in conditions in which the maize has been dried on bare ground. This category exists in Pretari et al. (2018), but the size of the group is far too small to give a reliable estimate of efficacy.

which we return in Section4.3.

Modeling the impact of the price premium on the share of marketed maize to which the dryer is applied is more complex. As described in Section 4.1.1, only relatively large-scale producers would stand to earn a profit equal to the incentive payment offered through the experiment. While smaller-scale farmers could earn a smaller profit through dryer use, we do not have information regarding adoption levels when the total payoff is below this value. We take a conservative approach, assuming that due to the fixed costs associated with arranging for dryer use, market producers who stand to earn a profit less than that offered through the experiment do not use the dryer. We calculate the proportion of farmers in our sample who sold enough maize to earn the experimental bonus (row 17) and the proportion of maize marketed by sample farmers that was sold by this subset (row 18). We then multiply this proportion by the observed adoption rate among market producers at the partially subsidized and zero price (row 13) in order to estimate the share of marketed maize affected by the full package of technologies (row 19). Under our conservative assumption that only relatively large farmers find it worthwhile to adopt the maize dryer under a per-kg premium, fewer farmers use the dryer than observed in the experiment. We assume that farmers who used the dryer in the experiment but whose production is too low to do so under a per-kg incentive make use of both the training and the plastic. Therefore, rather than employing the observed share shown in row 12, we add to this the difference between rows 19 and 13, yielding the simulated share (row 20).

For subsistence maize, we predict that under free provision (columns A & B), 44 percent of maize would be dried on a plastic barrier, and an additional 48 percent would be improved through the increased knowledge regarding aflatoxin prevention gained through the farmer training. This implies reduced contamination for 93 percent of maize produced. Under partial subsidization of drying services (columns C & D), 38 percent of subsistence maize would be dried on plastic and in the dryer, 6 percent would be dried on plastic (only), and 17 percent would be improved through the farmer training. A full subsidy of the dryer (columns E & F) improves this further, with 60 percent of maize being dried in the dryer, 10 percent being dried on plastic only, and <2 percent being improved through the training only.

For marketed maize, take-up is similar, but only in the presence of the market premium. While the existence of a market price premium yields only a slight improvement in plastic use, shifting 3.5 percent of marketed maize from the "training only" to the "dried on plastic" category (column B) has a strong impact on dryer take-up (columns D vs. C and F vs. E). In the absence of a market premium, market producers are unlikely to use the dryer, even when it is fully subsidized, due to the effort and time costs involved. In contrast, the training and use of plastic cost less and benefit farmers by making sun-drying easier and by potentially producing maize of better visible quality; this yields market returns even without a safety premium. The market premium increases dryer use for marketed maize from 0 to 30 percent under a partial dryer subsidy and to 58 percent under a full dryer subsidy.

4.2.3 What are the expected changes in dietary aflatoxin exposure?

In order to answer the second question, we first calculate the percent reduction in aflatoxin contamination in both stored and purchased maize that arises from the adoption modeled in Section 4.2.2. We multiply the efficacy rates in rows 1-3 of Table 7 by the share (or simulated share where applicable) of maize affected by each technology group and sum these products, separately for subsistence and marketed maize (rows 21 and 22).[21]

We next calculate the status quo aflatoxin exposure through maize in this region. This requires information regarding monthly consumption of maize from farmers' own stores and from the market, as the level of aflatoxin contamination varies over the course of the year and depends on mitigation practices used by subsistence and market producers. Appendix Table A2 provides details of these calculations.

Maize consumption is measured using data collected during three rounds of interviews, approximately four months apart, for a sample that includes both households involved in this study and households involved in a separate study for which recruitment criteria were similar, as well as monthly reports of maize purchases collected as part of the latter study.[22] This data is presented in rows A and B of Table A2. The average household consumes 23.7 kg of maize per month, and 71.4 percent of this maize comes from their own

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[21] Regarding purchased maize, we assume autarky in maize within the region. The high transport costs of maize from other maize-exporting regions make this assumption reasonable.

[22] Villages for the two studies were randomly drawn from maize-growing villages in Meru and Tharaka-Nithi counties. Households were eligible to participate in the present study if they contained at least one child under the age of two, while those eligible for the other study had to include a woman who was in the third trimester of pregnancy at the time of enrollment. The protocol for the other study is described in Hoffmann et al. (2015).

production and storage. To estimate status quo aflatoxin exposure from maize consumption, we use the mean level of aflatoxin detected in maize stored by control group house- holds three months after harvest (18.5 ppb) and extrapolate contamination in other months using the findings of Kaaya and Kyamuhangire (2010) regarding the monthly change in aflatoxin contamination in ground-dried maize (row D). Month-specific estimates of aflatoxin levels in the study region under status quo post- harvest practices are shown in row J. We apply these month-specific contamination rates to total monthly maize consumption and assume an average body weight of 70 kg per adult equivalent in order to calculate status quo exposure from stored maize (49.2 ng/kg/day, row L) and purchased maize (19.5 ng/kg/day, row M).[23] Multiplying the reductions from rows 21 and 22 in Table 7 by the status quo consumption levels, we present the aflatoxin exposure from stored and purchased maize in rows 23 and 24, respectively. The total reduction in dietary aflatoxin exposure from maize is shown in row 26.

As expected, increasing the intensity of the intervention (via premium or subsidy) increases the effectiveness in terms of percent reductions in dietary aflatoxin exposure from maize. The percentage reduction in exposure ranges from 52 percent to 67 percent.

4.2.4 What is the relationship between dietary aflatoxin exposure and health outcomes?

Acute consumption of extremely high levels of aflatoxin can cause acute aflatoxicosis. There is no reliable treatment for this condition, which can be fatal (Strosnider et al., 2006). Close to 300 deaths from aflatoxicosis were recorded in Eastern Kenya from 2001-2014, a rate of 20.8 deaths per year (see Table 8). Assuming that the number of fatalities is proportional to exposure through maize,[24] the reductions in exposure considered here could prevent an average of between 10.7 and 14 deaths from aflatoxicosis annually (Table 7, row 27).

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[23] Here we assume that the maize stored by households and maize purchased in the market is equally contaminated. Data collected by the authors for a companion study in the same region supports this assumption (Hoffmann et al., 2015).

[24] All aflatoxicosis outbreaks have been linked to consumption of contaminated maize; aside from sorghum (to which the technologies discussed here would also apply), other foods consumed in the region that are prone to aflatoxin contamination are either consumed in quantities too small to result in aflatoxicosis (groundnuts) and or do not reach high enough levels of contamination h to result in acute illness (milk).

Table 8. Health burden calculations

8.A

Disease status	***Proportion of population in Eastern Kenya (from Table 8.B, below)***	***Aflatoxin cancer potency (IPCS and WHO, 1998)***	***Estimated annual HCC cases, Eastern Kenya***
HBV-, HIV-	0.946	0.01	40.6
HBV+, HIV-	0.017	0.30	21.7
HBV-, HIV+	0.035	0.01	1.5
HBV+, HIV+	0.002	0.30	2.9
Total	1.0	n/a	66.7

8.B

Disease	***Prevalence***	***Population***	***Data source***
Hepatitis B virus	0.018	HIV- adults, Eastern Kenya	National AIDS and STI Control Programme, 2013
Hepatitis B virus	0.060	HIV patients, Nairobi	Muriuki et al., 2013
HIV	0.037	15-64 adults, Eastern Kenya	Ly et al., 2016

Note: For each row in Table 8.A, we multiply the total estimated population of Eastern Kenya in 2018 (6.255 million, according to Unicef projections - see https://data.humdata.org/dataset/kenya-population-projection-by-county-2009-2018-and-subcounty-2015) by the proportion of the population in that category, the estimated average daily aflatoxin exposure per KG body weight based on study data, and the cancer potency factors (cases per 100,000 per ng/KG exposure), to estimate the number of HCC cases due to aflatoxin in the absence of any intervention. Regionally representative statistics on HBV prevalence are only available for the HIV negative population in Eastern Kenya. We use HBV prevalence reported for a group of HIV positive patients recruited from Nairobi health centers for the HIV positive share of the population, as this is the location closest to the study area for which an HBV prevalence rate among HIV-positive individuals is available

While chronic dietary exposure to lower levels of aflatoxin is associated with a number of negative health impacts, the most well-established of these association is that with hepatocellular carcinoma (HCC), a type of liver cancer. We combine cancer potency estimates for aflatoxin (WHO, 1998) and the status quo exposure levels reported in Appendix Table A2 to estimate the annual incidence of HCC in Eastern Kenya (see Table 8). The contribution of aflatoxin exposure to the risk of developing HCC is 30 times greater for individuals infected with Hepatitis B virus than for others (*ibid*). As previous studies report estimates of Hepatitis B prevalence in Eastern Kenya separately for HIV-positive and HIV-negative individuals (Ly et al., 2016; Muriuki et al., 2013), we also employ estimates of HIV prevalence in Eastern Kenya (Ministry of Health, Kenya, 2013) to calculate the overall Hepatitis B rate. Multiplying UNICEF's 2018 population estimate for Eastern Kenya[25] by the calculated HCC incidence, we estimate that dietary aflatoxin exposure through maize causes 66.7 HCC cases in the region each year. Based on the estimated reductions in exposure, we find that between 34 and 45 of these cases could be prevented annually through aflatoxin mitigation (Table 7, row 28).

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[25] https://data.humdata.org/dataset/kenya-population-projection-by-county-2009-2018-and-subcounty-2015

A more speculative analysis can be conducted based on emerging evidence that aflatoxin contributes to stunting in young children. A recent cluster-randomized controlled trial conducted in the same study area finds that reducing aflatoxin exposure by 44 percent (based on administrative data and estimates of exposure through various sources) led to a standardized mean difference (SMD) in length for age Z-score (LAZ) of 0.136 at 13 to 14 months of age (Hoffmann et al., 2017a). We adjust the impact on child growth based on the estimated reduction in total dietary exposure achieved in each scenario modeled in Table 7. We find that promotion of post-harvest technologies could yield a standardized mean difference (SMD) in child linear growth of between 0.16 and 0.21 (row 29).

4.2.5 How does cost-effectiveness compare to other interventions?

Simulated costs

The public costs of subsidizing the training, plastic sheeting, and drying technology, as discussed in Section 4.1.1, are shown in USD in rows 30, 31, and 32, of Table 7 respectively.[26] To calculate these costs, we employ the per-kg costs of plastic sheets and mobile dryers, presented in Table A5, and multiply these unit costs by the estimated volume of maize to which the technology is applied. We estimate volume by multiplying the shares of subsistence and marketed maize dried (rows 9 and 19 of Table 7) by their respective diet shares and then by multiplying this by total regional production.

We do not include an additional public cost for the market premium, but rather assume that price premiums are paid by the consumers who choose to purchase safer brands. The increase in public cost when premiums are assumed arises from the higher level of adoption of the subsidized technology.

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[26] We use the March 14, 2018 exchange rate from www.xe.com, which is 101.30 KSh per USD.

Cost effectiveness

We use these costs and the health benefits calculated in rows 27 and 28 of Table 7 to estimate costs per life saved and per disability-adjusted life year saved. We also estimate the cost per child for improving growth and the cost per SMD of LAZ for comparability with other interventions.

We first consider the cost per life saved by preventing deaths from aflatoxicosis and HCC (row 34). This ranges from $72,938 US in scenario B to $$166,969 in scenario F. In order to compare these costs to standard benchmarks for cost-effective health interventions, we calculate the cost per disability-adjusted life year (DALY) saved. Appendix Table A4 presents the calculations for converting deaths averted into DALYs saved, based on the most recent DALY calculation method published by the World Health Organization (WHO, 2017). The benchmark of one to two times the gross national income per capita for each DALY saved (Shillcutt et al., 2009) implies a reasonable cost per DALY saved of $3,130-$6,260 US in Kenya in 2018. Aflatoxin prevention technologies cost between $1,312 and $3,019 US per DALY saved (row 35 of Table 7). Even by the lower benchmark of one times the GNI, all scenarios would be considered cost-effective.

We also consider the cost-effectiveness of aflatoxin control for improving child growth. Dividing the total cost of the subsidy by the number of children under the age of five years in Eastern Kenya, we find that the public cost of deploying these technologies ranges from $3.72 to $11.13 US per child (row 36). This translates into a cost per standardized mean difference achieved in length-for-age z-score of $23.33 to $53.71/SMD/child (row 37). We find that all scenarios except the fully subsidized dryer are more cost-effective than nutrition education, a common intervention for improving child growth, which was recently calculated to cost $30.31/SMD/child (Bhutta et al., 2013).[27]

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[27] Bhutta et al. (2013) estimated a cost of 5.22 Special Drawing Rights (SDR) per child for an intervention that increased LAZ by 0.25 SMD; this converts to $7.59 US at the March 14, 2018 exchange rate.

4.3 Discussion of Policy Simulations

In sum, all policies considered are deemed to be cost-effective interventions for reducing death from aflatoxicosis and HCC. This is consistent with previous research evaluating the cost-effectiveness of aflatoxin control measures in terms of HCC prevention (Wu and Khlangwiset, 2010). In addition, emerging evidence regarding the role of aflatoxin in child stunting suggests that lower-cost measures to limit exposure to the toxin could be a cost-effective strategy for improving child linear growth in the study region.

We note that the most cost-effective of the simulated policies are scenarios A-D, with similar costs of $1,319 to $1,416 US per DALY saved. However, as discussed previously, due to limitations in knowledge regarding the efficacy of the dryer after maize has been dried on the bare ground, these simulations make the optimistic assumption that all dryer users also use plastic barriers. This mechanically increases the effectiveness of the dryer in our simulations. We therefore conclude that the most cost-effective approaches are scenarios A and B.

We further note that while scenario B offers a slight improvement over scenario A, this improvement is unlikely to be worth the effort required to ensure that the existing price premium for safer grain is passed on to producers; it is also unlikely to be worth the potential unintended consequences. Creating a farmer- level premium would require diffusion of low-cost, simple-to-use rapid testing, as well as awareness campaigns to create consumer demand. Such testing raises questions about how to deal with contaminated maize. In all likelihood, maize above the regulatory limit would not be destroyed as prescribed but would instead be sold at lower prices to households unable to afford the premium for safer grain. The distributional implications of this approach are non-trivial. As such, we find that encouraging adoption of aflatoxin mitigation technology through subsidies is preferable (and far more effective) than intervening in the market to expand and promote the transmission of a price premium for aflatoxin-safe maize.

The advantage of subsidies over a price premium in this context stems from the nature of the most cost-effective technology made available to farmers. Drying maize on plastic sheets requires no more effort than drying the grain on the used woven bags typically employed by farmers for this purpose; drying on plastic sheets also likely reduces effort compared to drying maize on the bare ground by making it easier to gather the maize after drying. Thus, this technology will see a high rate of adoption for both marketed and home-consumed maize. We further note that the food safety premium actually reduces cost-effectiveness when both plastic sheets and the partially or fully subsidized dryer are offered. Dryer adoption by market producers entails significant public cost, while the additional reduction in aflatoxin arising from dryer use is marginal relative to that achieved through the use of plastic sheeting and other practices promoted through training.

4.3.1 Other technologies

The methodology presented in this study to model the health impact and cost-effectiveness of post- harvest technologies could be applied to other aflatoxin control technologies. For example, a new biocontrol product, Aflasafe® KE01, was recently approved for use on maize in Kenya.[28] This product, which consists of spores of non-toxigenic strains of the same fungal species that produces aflatoxin, is applied to maize in the field and has been shown in field trials to consistently reduce aflatoxin contamination by over 80 percent under a range of agroecological conditions (Bandyopadhyay et al., 2016). However, the translation of efficacy to effectiveness is unclear in this case, as the timing and density of application are both critical to efficacy. Achieving 80 percent effectiveness may require significant investment in training to teach farmers how to use the product correctly.

In addition, little is known about the expected adoption rate for Aflasafe. The cost of Aflasafe for farmers is comparable to the other technologies considered in this study.[29] However, there are reasons to expect that adoption of Aflasafe would be considerably lower. First, there are no benefits of Aflasafe beyond aflatoxin control. For example, improved drying also prevents infestation with other molds, which may reduce post-harvest losses and improve other qualities that are important to consumers. In contrast, Aflasafe does not prevent contamination by other molds; in fact, it works by introducing a competitive fungus. Second, drying maize on sheets makes it easier to gather the grain at night or in case of rain, while rapid drying saves

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[28] Neither the authors, nor any funder of this study, has any personal, professional or financial interest in the promotion or usage of plastic sheeting, drying services, or Aflasafe, in Kenya or elsewhere.

[29] The current retail price of Aflasafe in Kenya is 1,600 KSh per hectare. As Aflasafe is applied to the field rather than to harvested grain, its cost per unit of maize harvested depends on yield. The mean cost of treating maize with Aflasafe per kg of maize for the subsistence farmers in the study sample is 1.90 KSh. Since farmers who produce maize for sale have higher average yields, their cost of Aflasafe treatment is correspondingly lower at 1.22 KSh/kg.

the labor involved in laying out and guarding maize to dry in the sun. Aflasafe does not address either of these concerns. Third, under rain-fed conditions, maize yields are uncertain and total harvest failure remains a possibility. As such, a pre-harvest investment in Aflasafe is much riskier than a post-harvest investment in drying technology. Finally, post-harvest drying technologies are variations on the familiar practice of drying maize before storage, whereas farmers' lack of familiarity with biocontrols may dampen adoption of Aflasafe. These hypotheses are borne out by early results from an ongoing study in which only one-third of farmers purchase Aflasafe when the product is offered at a price of 800 KSh / hectare (a 50-percent discount on the current price).

Because Aflasafe was not yet approved for use in Kenya at the time this study was conducted, we were unable to experimentally test adoption rates. Nonetheless, the foregoing discussion suggests that adoption rates at this time may be too low to consider subsidization of Aflasafe as a viable public health intervention. However, if prices fall and farmers' familiarity with the product increase over time, this may change adoption rates; thus we leave an evaluation of the benefits of Aflasafe for public health for future work.

5. Conclusions

Produce markets that lack effective regulation or quality certification systems are susceptible to market failures, whereby market producers under-invest in unobservable qualities. We document evidence that investment in low-cost post-harvest practices to improve food safety are generally lacking in Kenya and that this underinvestment is worst among market producers. This can have significant implications for human health through the contamination of food with biological and chemical hazards.

The potential costs of this market failure likely justify government intervention to improve public health. While increased testing for unobservable attributes would be expected to increase returns to quality, we caution that such an approach is likely to generate (or exacerbate) inequality in food safety, as the poorest households typically consume the least expensive foods (Hoffmann and Moser, 2017). Any increase in either regulatory enforcement or voluntary testing must therefore be accompanied by affordable technologies to increase quality across the price spectrum.

This study assesses the cost-effectiveness of alternative approaches to this issue. We find that simply increasing farmers' knowledge of aflatoxin contamination and prevention does change post-harvest practices. However, insufficient data exists with which to evaluate the effectiveness of training alone. In contrast, we find that fully subsidizing a new, relatively expensive drying technology results in high rates of take-up and very high rates of aflatoxin reduction. However, the significant public costs of this scheme render it a poor choice relative to other options. Partially subsidizing the same drying technology yields similar rates of take-up and reductions in aflatoxin at a much lower cost.

We find that combining farmer training with the provision of a very simple, low-cost drying technology (plastic barriers for ground drying) is likely the most cost-effective option for aflatoxin control in Eastern Kenya. Under this policy scenario, we estimate that improved post-harvest practices would be applied to 93 percent of the maize produced in this region and that nearly 50 percent of this maize would be dried on a plastic barrier. This results in a predicted 52-percent reduction in dietary aflatoxin exposure in Eastern Kenya, leading to 45 averted deaths annually at a cost of $1,319 US per DALY saved. This is well below the lower bound of cost-effectiveness in Kenya, based on the benchmark of GNI per capita ($3,130).

While we also explored the potential benefits of passing a portion of the observed market price premium for aflatoxin-safe maize on to farmers (e.g. through efforts to increase consumer awareness in high-aflatoxin regions and by making testing more accessible), our simulations indicate that such a premium would not significantly affect the effectiveness of our recommended policy. This result arises due to the fact that attending training and using free plastic barriers are extremely low-cost investments that are also likely to have benefits beyond aflatoxin control. Further, because of the zero or negative marginal cost of using free plastic sheets for sun-drying, farmers are unlikely to apply this technology to only a portion of their harvest. Given that nearly all market producers also grow maize for home consumption, adoption of low to negative marginal cost technologies is high even in the absence of a market premium. In contrast, usage of the dryer has a positive marginal cost (even when subsidized), and its use is typically limited to a subset of the total maize produced. As such, market premiums do make some difference in the effectiveness of dryer-focused interventions.

Our findings suggest that even if it were possible to successfully pass the market premium for aflatoxin-safe maize on to farmers, this alone would be unlikely to make a significant difference in contamination of the food supply. An additional challenge associated with relying on a market premium to motivate technology adoption is that aflatoxin, like most food safety hazards, can be reduced but not eliminated. Further, aflatoxin levels vary widely from farm to farm and year to year based on weather conditions during cultivation and ecological factors outside of farmers' control. Together, these factors imply that investing in aflatoxin control with the expectation of a market reward can be risky, especially when the efficacy of the control technology is limited. Over time, farmers supplying premium markets would learn about this efficacy risk, which could negatively affect adoption in the long run. The idiosyncratic portion of efficacy risk is greatly reduced by aggregating maize across farmers prior to testing; this is also necessary to make testing affordable. However, the covariate portion of this risk is significant and may require other instruments for effective management, such as aflatoxin insurance for farmers or a regulatory framework that responds to the level of contamination.[30][31]

In sum, our analysis indicates that encouraging aflatoxin reduction in marketed maize in Kenya through a food safety premium has little impact on food safety and would require overcoming a number of challenges. In comparison, increasing the use of aflatoxin control technologies by both subsistence and market producers in high-risk areas is a far simpler task. Based on the reduced cancer and aflatoxicosis burdens alone, subsidies for aflatoxin control meet standard benchmarks of cost-effectiveness for public health interventions. Taking into account emerging but still speculative evidence regarding the impact of aflatoxin exposure on child growth, such subsidies could also be an important and cost-effective intervention against child stunting.

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[30] This is the approach taken by the United States, where the Food and Drug Administration may relax a general prohibition on adding grain above the regulatory limit to grain below the limit in years when aflatoxin levels are especially high.

[31] Data collected by the authors for two related studies indicate that in 2013 and 2015, aflatoxin levels were low enough in the study region that under universal adoption of drying sheets alone, aggregated maize would have passed Kenya's regulatory limit of 10 ppb (Pretari et al., 2018; Hoffmann et al., 2015). However, mean aflatoxin levels in 2014 were almost an order of magnitude higher, and even use of better technologies would likely not have resulted in compliance with the 10 ppb regulatory standard. Data from additional years would be required to properly assess the expected profitability risk and efficacy risk of the various technologies assessed.

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Appendix

Table A1: Assumptions for tarp and dryer subsidy costing

General assumptions	
KES to USD exchange rate, March 14	101.2
Marginal cost of public funds	0.18
Rate of return on private capital	0.102
Discount rate for public resources	0.047
Mean maize harvest, subsistence producers	281
Mean maize harvest, market producers	908
Mean maize harvest, all producers	549
Mean maize yield per ha, subsistence producers	846
Mean maize yield per ha, market producers	1306
Mean maize yield per ha, all producers	1054

Technology assumptions	**Mobile Dryer**	**Plastic Sheet**
	A	**B**
Operating days / year	30	n/a
Useful life (years)	5	2
KG dried / day or drying sheet	1250	300
Operating hours / day	7	n/a
Capital costs		
Cost of equipment	75,000	416
Total cost of capital (@ private lending rate)	121,975	416
Total cost of equipment (incl. MCPF + SDR)	111,570	539
Daily operating costs		
Daily private cost of capital	813	n/a
Daily public cost of capital	743.80	n/a
Daily maintenance & repairs	375	n/a
Labor costs (daily)	1,000	n/a
Fuel cost / operating day @ 50 KSh / hour	350	n/a
Transport cost / operating day	400	n/a

Subsidy management costs	
Capital subsidies disbursed per team per month	3
Operating subsidies managed per team	10
Daily cost of management team	2500
Capital subsidies management cost per KG	0.133
Operating subsidies management cost per KG	0.200

Table A2. Aflatoxin Exposure Calculations

		Feb **(1)**	Mar **(2)**	Apr **(3)**	May **(4)**	Jun **(5)**	Jul **(6)**	Aug **(7)**	Sep **(8)**	Oct **(9)**	Nov **(10)**	Dec **(11)**	Jan **(12)**	Mean **(13)**	Per day **(14)**
Household maize consumption															
Own produced (kg)	**A**	20.3	26.7	25.9	25.1	17.6	18.8	19.2	11.5	11.9	9.4	6.9	10.2		0.557
Purchased maize (kg)	**B**	4.8	4.0	4.8	2.6	7.1	5.9	5.5	7.8	7.4	9.9	12.5	9.1		0.223
Maize contamination over time															
Months since harvest	**C**	0	1	2	3	4	5	6	0	1	2	3	4		
AF: bare ground drying (PPB)[i]	**D**	1.67	2.27	5.0	9.0	17.5	25.7	32.5	1.67	2.27	5.0	9.0	17.47		
Relative to 3mo post-harvest	**E**	19%	25%	56%	100%	194%	285%	361%	19%	25%	56%	100%	194%		
AF: dried in dryer (PPB)[i]	**F**	0.50	0.83	0.87	1.33	2.23	7.67	11.83	0.50	0.83	0.87	1.33	2.23		
Reduction: train. + barrier + dryer	**G**	70%	63%	83%	85%	87%	70%	64%	70%	63%	83%	85%	87%	**75.9%**	
Relative to 3mo post-harvest	**H**	82%	74%	97%	100%	102%	82%	75%	82%	74%	97%	100%	102%		
Reduction: training	**I**	38%	34%	44%	**46%**	47%	38%	34%	38%	34%	44%	46%	47%	**40.9%**	
Reduction: training + barrier	**J**	65%	59%	76%	**79%**	81%	65%	59%	65%	59%	76%	79%	81%	**70.1%**	
Status quo exposure															
Status quo PPB[ii]	**K**	3.4	4.7	10.3	**18.5**	35.9	52.8	66.8	3.4	4.7	10.3	18.5	35.9		
Subsistence consumption (ng/kg) [iii]	**L**	277	495	1059	1848	2507	3938	5098	157	222	384	504	1457		**49.2**
Market consumption (ng/kg)[iv]	**M**	65	75	197	190	1017	1241	1459	106	137	405	916	1300		**19.5**
Total consumption (ng/kg)	**N**	342	570	1256	2038	3525	5179	6557	264	358	789	1421	2757		**68.6**

Notes: (i) Kaaya and Kyamuhangire (2010); (ii) extrapolated based on months since harvest using [E x J4]; J4 was measured in our data; (iii) [A x J x 1000 / (kg/HH)]; (iv) [B x J x 1000 / (kg/HH)]; (v) [K x G]; (vi) [L x G]; (vii) [K x H]; (viii) [L x H]

Table A3. Aflatoxicosis Outbreaks

Year	Location	Deaths		Source
1981	Machakos	12		Ngindu et al. (1982)
1987	Meru North	3		Wangia (2017)
2001	Meru	16		Wangia (2017)
2003	Eastern	68		Muthomi (2014)
2004	Thika/Makueni/Kitui	125		Lewis et al. (2005)
2005	Makueni/Kitui	35		Githanga and Awuor (2016)
2006	Makueni/Kitui	21		Githanga and Awuor (2016)
2007	Makueni/Kitui	21		Muthomi (2014)
2008	Eastern	2		Muthomi (2014)
2010	Makueni/Kitui	3		Muthomi (2014)
2014	Kajiado (not eastern)	10		Githanga and Awuor (2016)
1981-2014	**Total**	**316**	**9.3**	per year
2001-2014	**Total**	**301**	**21.5**	per year
2001-2014	**Eastern Total**	**291**	**20.8**	per year

Table A4. Converting lives saved to disability adjusted life years (DALYs) saved

Aflatoxicosis		***Notes***
Mean age of diagnosis of aflatoxicosis in Kenya	22.5	(Azziz-Baumgartner et al., 2005)
Median years from diagnosis to death in Kenya	0.185	18 of 40 cases died within 2 months of diagnosis (Azziz-Baumgartner et al., 2005)
DALY weight of living with aflatoxicosis	0.540	disability weight for terminal stage liver disease (Salomon et al., 2015)
YLL, based on WHO life expectancy	69.57	employs standard loss function [WHO, 2017, table 2.1]
YLL, based on Kenya life expectancy	39.44	employs Kenyan life expectancy (62.13, World Bank, 2017)
YLD	0.10	0.185*0.540 (WHO, 2017)
DALY cost per aflatoxicosis death	69.67	YLL+YLD (WHO, 2017)
Hepatocellular Carcinoma		
Mean age of HCC diagnosis in Kenya	40	(Mwangi and Gatei, 1993)
Median years from HCC diagnosis to death in Kenya	2.941	Imputed, based on assumption of linearity over time (Ministry of Health, 2013)
DALY weight of living with HCC	0.372	(.288*.333) + (.540*.667) (Salomon et al., 2015)
YLL, based on WHO life expectancy	49.73	employs standard loss function [WHO, 2017, table 2.1]
YLL, based on Kenya life expectancy	19.19	employs Kenyan life expectancy (62.13, World Bank, 2017)
YLD	1.09	2.941*0.372 (WHO, 2017)
DALY cost per HCC death	50.82	YLL+YLD (WHO, 2017)

Table A5: Costs for sheeting and dryer subsidies

	Plastic sheets			Mobile Dryer			Plastic sheets + Mobile Dryer		
	KG	90-KG bag	MT	KG	90-KG bag	MT	KG	90-KG bag	MT
Cost to farmer									
Private provision model	0.69	62	693	2.05	184	2,048	2.74	247	2,742
Partial subsidy	n/a	n/a	n/a	1.63	146	1,625	1.63	146	1,625
Subsidy cost									
Partial subsidy	n/a	n/a	n/a	0.35	31	350	1.25	112	1,247
Total subsidy	0.90	81	898	2.27	204	2,267	3.16	285	3,165

Note: The partial subsidy for the combined package assumes that the plastic sheet is fully subsidized and the dryer is partially subsidized. Costs given in USD per unit, where the unit is the column header.

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