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Improved drying and storage practices that reduce aflatoxins in stored maize: Experimental evidence from smallholders in Senegal

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Abstract

Consuming food contaminated with aflatoxins has large negative consequences on the health and economic productivity of millions of people in developing countries. We conducted a randomized control trial with nearly 2,000 small-scale maize-producing households in Senegal during the 2016/17 harvest and post-harvest season. Our goal was to test which constraint(s), i) low awareness of aflatoxins, ii) lack of effective drying technologies and/or iii) lack of effective storage technology were the greatest barrier to storing safe maize. A novel feature of our intervention is that we offered both drying and storage technologies to farmers and evaluate their combined impact. We varied four inputs provided to each household: 1) training on recommended post-harvest practices; 2) low-cost moisture meters to detect if maize is dried to a safe level before storage; 3) tarps to reduce ground drying; and 4) hermetic (airtight) bags to store maize after it has been dried. Only hermetic bags caused a statistically significant reduction in total aflatoxin levels after 3-4 months of storage. The reduction was relatively meaningful (8.4 ppb, or 34% of the control group average). All maize stored by households that received the bags, even that stored in other containers, showed lower total aflatoxin levels, suggesting that effective storage technologies were the main binding constraint. Our results provide practical guidance on ways to lower aflatoxins for populations that mainly grow maize for home consumption and suggest that strategies to reduce aflatoxins should address issues from harvest to storage in a comprehensive manner.

Keywords
Post-harvest practices
Grain drying
Cost-effectiveness
Improved storage technology
Hermetic bag
Randomized control trial (RCT)

Introduction

As many smallholder farmers in the developing world consume much of what they produce, deficient on-farm food safety practices are likely to be a major contributor to the poor health of millions of people. One critical food safety problem is exposure to aflatoxins, toxic compounds produced by certain fungal species of the *Aspergillus* family that are frequent contaminants of maize, groundnuts, and other agricultural products. Aflatoxins are invisible, odorless, and tasteless, making them particularly difficult to control (1-3). This is a major health challenge, as an estimated 4.5 billion people in the developing world are chronically exposed to aflatoxins Williams*, et al.* (4).

This article reports findings from a randomized control trial (RCT) that addressed several constraints facing smallholder farm households in improving the safety of their own food production. We provided households in southern Senegal with training and with three inputs aimed to improve drying and storage of maize, the main food crop. Drying quickly and thoroughly is a key step in controlling aflatoxins in stored crops (5). The training corrects for smallholders' lack of knowledge of aflatoxins and other food safety hazards (6). The inputs – moisture meter, tarp, and hermetic (airtight) grain storage bag – are simple technological innovations with the potential to improve the safety of stored maize, but that have yet to be tested for prevention of aflatoxins in staple foods on a large scale. The impact of each input indicates which constraint(s) drive(s) smallholder farm households' decision-making: lack of knowledge of food safety hazards, insufficient ways to thoroughly and cleanly dry staple grains, and/or lack of appropriate storage solutions that maintain foods safe during storage.

Examining constraints to safe grain drying and storage is important, as people in developing countries are "nearly ubiquitously exposed to moderate to high levels of aflatoxins"

(7). In a study of 31 foodborne diseases, the burden from aflatoxins was ranked second only to tapeworm in disability adjusted life years per case (8), although the burden per case may be lower when considering a broader range of aflatoxins' health impacts. The World Health Organization estimates that 20,000 deaths occurred from aflatoxins in 2010, with over 600,000 years of life lost (8). Both one-time and chronic exposure to aflatoxins have important negative impacts on health, including liver cancer (9, 10). An estimated 28 percent of liver cancers worldwide, and up to 40 percent in Africa, are attributable to exposure to aflatoxins (7). In turn, poor health reduces economic growth in developing countries (11-13).

To determine which constraints are binding in drying and storing safe grain, we randomly assigned 209 villages to one of five groups, and we analyzed outcomes for 1,981 households. Households living in villages assigned to the control group (Group 1) received no input for the duration of the study. Households in the training-only group (Group 2) were trained by local extension agents on the risks from aflatoxins and improved drying and storage practices but receive no inputs. Households in the hygrometer group (Group 3) were trained and received a low-cost moisture detection device to determine when maize is dry enough for safe storage. Households in the tarp group (Group 4) were trained, received a hygrometer, and received a 5x2m ($10m^2$) tarp as an alternative to drying maize on the bare ground. Finally, households in Group 5 received training, a hygrometer, a tarp, and one 50-kg Purdue Improved Crop Storage (PICS) hermetic grain storage bag. PICS bags are designed for optimal chemical-free storage of crops, but also control aflatoxins in two ways that we describe below.

The existing evidence on the effectiveness of interventions to reduce aflatoxins in staple crops in developing countries is very limited. To our knowledge, the only experimental study that tested the effectiveness of interventions to reduce aflatoxins is a recent study by Hoffmann, Magnan, Garrido, Kanyam and Opoku (14). The authors conducted an RCT to estimate the effect of providing Ghanaian smallholders with a plastic tarp for drying groundnuts and find that it leads to a 31 percent reduction in total aflatoxin levels.[1]

An earlier study by Turner*, et al.* (15) also tested the impact of a package of improved post-harvest technologies for groundnuts (training and inputs: mats, natural-fiber bags, wooden pallets, and insecticide) on the level of blood aflatoxin-albumin concentration among adults in Guinea. Authors find that five months after harvest the mean aflatoxin-albumin concentration in the 10 treatment villages was 50% of that in the 10 control villages, but it is not clear whether treatment villages were selected randomly, limiting the ability to draw causal conclusions from the evidence. Hoffmann and Jones (16) study post-harvest practices for maize in Kenya, but focus on the *adoption* of new technologies (plastic tarps and a mobile flatbed dryer) and do not measure aflatoxin levels.

Studies in laboratory settings have shown that key inputs could contribute to reducing aflatoxins. Hermetic storage bags have been shown in a lab-in-the-field study of 33 smallholder farmers in Kenya to prevent accumulation of aflatoxins in maize that is properly dried before being sealed in the bag (17). In addition, hygrometers, which differ from traditional moisture meters in that they measure air moisture rather than grain moisture directly, have never been tested for adoption by farmers to encourage adequate grain drying but have been shown under laboratory conditions to be reliable moisture detection devices following a simple protocol described below (18).

The present article adds to the sparse literature on interventions to reduce aflatoxins in developing countries, and is the first RCT-based large-scale study focusing on a staple crop,

[1] Total aflatoxin refers to the sum of the four principle types of aflatoxins (B_1, B_2, G_1 and G_2).

maize primarily used for home consumption, rather than a cash crop like groundnuts as in the Hoffmann, Magnan, Garrido, Kanyam and Opoku (14) and Turner*, et al.* (15) studies. A novel feature of our study is that we evaluate the impact of both drying and storage technologies on reducing aflatoxins, and we partially tease out the effect of individual technologies. In addition, we are the first to identify and offer a low-cost moisture detection device to farmers, and to evaluate its effectiveness in reducing aflatoxins. Our results provide practical guidance for policy makers, donors, and practitioners on ways to lower aflatoxins for populations that mainly grow maize for home consumption.

We found that the provision of a hermetic storage bag caused a relatively meaningful reduction in total aflatoxin levels in stored maize. Households who received hermetic storage bags had 34-percent lower total aflatoxin levels (eight ppb) than households in the control group, on average. We found suggestive evidence that the training lowered total aflatoxin levels (by six to eight ppb on average), but regression coefficients were only marginally significant. Tarp provision reduced the number of households drying maize directly on the bare soil but had no statistically significant effect on total aflatoxin levels. Similarly, providing hygrometers had no impact on total aflatoxin levels, possibly because weather conditions in our field site helped dry maize promptly after harvest.

The positive impact of hermetic bags is particularly significant from a policy perspective. These bags yield other benefits for stored crops beyond aflatoxin reduction, such as reducing quantity and value losses due to insects, rats and other pests that attack during storage, increasing their value to smallholders.

Background

Maize is a main staple crop and the most widely consumed cereal crop produced in sub-Saharan Africa (SSA), making up the majority of calories consumed by millions of low-income smallholder farm households (19). As such, the occurrence of acute aflatoxicosis, a lethal disease caused by consumption of food contaminated with high levels of aflatoxins, has only been reported from maize consumption, which may reflect higher daily intakes of maize as compared to groundnuts (9). *Aspergillus flavus*, the fungus primarily responsible for producing aflatoxins, infects maize ears in the field pre-harvest when farmers do not use products intended to control aflatoxins (e.g., Aflasafe®), and/or post-harvest because of poor grain harvest and handling practices (e.g., piling fresh maize on the ground after harvest). In-field contamination from aflatoxins frequently occurs when the plants are stressed by hot and dry conditions. Fungi of the *Aspergillus* genus appear as an olive-green mold on highly-infected maize kernels (20), but maize kernels with no visible mold can also contain total aflatoxin levels above those recommended for human consumption.

In the post-harvest period, *A. flavus* comes in contact with maize via contaminated surfaces, such as the soil when maize is dried directly on the ground. Once maize is infected by *A. flavus*, the spread of the fungus and aflatoxins can be stopped by drying maize to lower than 13.5 percent moisture content and storing it in airtight containers. Contrary to in-field contamination, spread of *A. flavus* during storage is more likely when maize moisture content is higher than 13.5 percent and conditions are warm and humid (21). Controlling for moisture is not sufficient as insects spread fungi during movement, feeding, defecation, and by boring into kernels (22, 23). Hermetic storage bags are a key tool to limiting insect infestation in stored grain. By sealing their content, hermetic storage bags limit oxygen and increase carbon dioxide, and kill any insects on the grain at the time of storage (24). In turn, they prevent insects from spreading the fungi responsible for aflatoxins. Maize stored in polypropylene or jute bags has been found to have five to eight times higher total aflatoxin levels after 35 weeks than hermetically stored maize (17). The authors conclude that "profuse insect activity probably explain[s] the increase in [aflatoxins] on maize stored in polypropylene and jute bags even when moisture content was within the limit for safe storage" (17).

The United States and European Union have strict and enforced regulatory limits on aflatoxins based on the product and its intended use. In the US, the most stringent limit is 20 ppb for maize intended for human consumption and certain types of animal feed (25). The limit in the EU is 10 ppb for maize "to be subjected to sorting or other physical treatment before human consumption" (26).[2] At the time of this study (2016), Senegal had no regulatory limit on total aflatoxin levels in food or animal feed. The Ministry of Agriculture and Rural Development has since committed funding for the development and implementation of a National Aflatoxin Control Plan, focusing on maize and groundnut (27). In countries such as Senegal, with no enforced limit on aflatoxins, households are unlikely to be aware of the hazards posed by aflatoxins (28, 29). Previous studies that examine total aflatoxin concentrations in Senegal find their levels dependent on agro-ecological zone, variety, shelling practice, and storage location (30). In the area of Southern Senegal where we implement the study described in this paper, a recent study found that 26 of 88 maize samples (30 percent) taken randomly from post-harvest cobs or shelled corn contained aflatoxins, suggesting high baseline levels (31).

[2] COMMISSION REGULATION (EC) No 1881/2006 sets the limit for maize destined for human consumption to 5 ppb (5 μg/kg) for aflatoxin B_1, and to 10 ppb for the sum of aflatoxins B_1, B_2, G_1 and G_2. COMMISSION REGULATION (EU) No 165/2010 later reduced the limit to 2 ppb (B_1) and 4 ppb (total) for all cereals except maize. The Afla-V AQUA Strip Tests used in this study detect and measure total aflatoxin levels, so we use the 10 ppb limit.

Intervention

An assessment of post-harvest challenges for maize growers in southern Senegal conducted in 2015, the year prior to our intervention, suggested that maize drying practices of many households in southern Senegal increased the risk of contamination from aflatoxins (31). The authors observed many farmers drying cobs (without husks) on the bare ground, and many postharvest samples were dirty, with abrasion-wounds on the kernels.

Based on this assessment and known ways in which maize gets contaminated with aflatoxins, described above, we focused our intervention on four possible sources of contamination and accumulation of aflatoxins: (1) low awareness of aflatoxins, their negative health consequences, and how to prevent contamination; (2) absence of tools to sufficiently dry of maize before storage, causing the crop to be stored wet and allowing aflatoxins to accumulate over time; (3) lack of tools to avoid maize kernels coming into contact with the bare soil by drying on the ground, which may cause initial contamination from aflatoxins; and (4) absence of storage solution that avoids insect infestation during storage, which allows insects to damage maize kernels and move aflatoxins around in the stored product. We provided treated households with four inputs that have the potential to reduce each of these sources of aflatoxins (training, a hygrometer, a tarp, and a hermetic storage bag), which we discuss in detail.

Training

We provided training on improved post-harvest practices to all treated groups (Groups 2, 3, 4 and 5; 1,599 households). Both male and female adults from households selected for the baseline survey were personally invited to the training, but the session was open to everyone in the village. In total, about 3,800 men, women, and youth (estimated to be younger than 15 years) attended. Local extension agents from the Agence Nationale de Conseil Agricole et Rural (ANCAR), Senegal's national agricultural extension agency, conducted the training in their assigned areas. This ensured that the people conducting the training understood local challenges, knew the population, and were well respected by village leaders. In the study area, maize is generally harvested by cutting the stalks, and is then left in the field to begin drying (while other crops are harvested). A primary focus of the training was to describe the existence, sources, evidence, and effects of aflatoxins. To help smallholder address the risk, the training instructed households not to pile maize, but to stook the stalks after harvest, even with the husks still covering the ears. Doing so can reduce fungal contamination by preventing kernels from touching the soil and helps avoid ears near the bottom of a pile getting too wet. Finally, the training emphasized the needs to dry maize quickly and off the ground, and to put maize in storage off the bare ground after harvest to stop the accumulation of any aflatoxins in it from the field.

Hygrometers

We provided hygrometers to Groups 3, 4 and 5 (1,209 households) as a low-cost grain moisture verification tool. Hygrometers were the smallest and cheapest item we provided; thus, we chose it as the physical input provided to the largest number of treatment groups. In developed countries, farmers and traders use moisture meters to measure grain moisture, but their US $100+ price is prohibitive for smallholder farmers in developing countries. Considering this cost barrier, no one in our sample owned or used a moisture meter of any kind prior to our intervention. The hygrometers we distributed were purchased in bulk at a unitary cost of about $1.13 (imported into the US from China). As a point of comparison, at baseline 87 percent of study participants stated that they were willing to pay $1.79 for a hygrometer that could measure maize moisture content. Hygrometers measure relative humidity and not grain moisture content. However, when grain is placed in a sealed container (such as a small Ziploc bag; see Appendix A) with the hygrometer, the grain's moisture comes into equilibrium with the air in the bag. After 15 minutes, the bag reaches an equilibrium relative humidity, which is read by the hygrometer. Equilibrium relative humidity and temperature (also indicated by the hygrometers we distributed) can be used to calculate the moisture content of the grain in the bag. For ambient temperatures of 21 degrees Celsius and higher, an equilibrium relative humidity of 65 percent or below corresponds to a grain moisture content of 13.5 percent or below, which is acceptable for storage (18). Hence, households can simply and reliably know that their grain is dry enough for storage by whether the hygrometer's relative humidity reading is below 65 percent.

Tarps

Groups 4 and 5 (812 households) received a 10m^2 tarp as an alternative to drying their maize directly on the bare ground. These tarps can sun dry about 200 kg of maize to below 13.5 percent moisture content over two to three days. At baseline, households harvested 675 kg of maize on average, thus most households would dry their entire maize harvest in three to four stages. About 25 percent of households dried some or all their maize directly on the soil at baseline. All other households dried their maize off the ground, for example in the field (with the husks still on the cobs to prevent contact with the bare soil) or on a wooden or cement platform. The tarps, purchased locally in bulk, cost $3.27 per 10m^2 tarp. This cost compares favorably with most households' stated willingness to pay: at baseline, 90 percent of all households stated that they were willing to pay $5.36 for a 10m^2 tarp to dry their maize.

Hermetic storage bags

We provided one 50-kg PICS bag to each household in Group 5 (404 households) as a hermetic storage bag. Although the PICS bags were less expensive than the tarps, tarps could be purchased locally and were less bulky, thus we provided the PICS bags to the fewest number of treated households. PICS bags hermetically seal grains stored in them, and control aflatoxins in two ways. First, they kill any insects on the grain at the time of storage by limiting the amount of oxygen in the bags (32). Lack of oxygen causes insects to go dormant and suffocate, eliminating their movement and ability to spread the fungi that produce aflatoxins. Second, properly-closed PICS bags keep grain moisture constant over time, so that any fungi present are less likely to accumulate on grain that is properly dried before being sealed in the bag (21). Hermetic storage bags also eliminate the need for storage pesticides, thus mitigating any health concerns about consuming insecticide-treated maize. A supplier in Dakar stocked PICS bags imported from Nigeria. When purchased in bulk, the 50-kg bags cost $2.22 each. At the time of intervention, PICS bags were not available locally in Southern Senegal, and no one in our sample was using them prior to the intervention.

Sample and data

Households included in the study live in the department of Vélingara, region of Kolda, in southern Senegal. The area provides only one maize growing season (May-June to October-November). A census list of villages was provided by our local implementing partner, the Institut

Sénégalais de Recherches Agricoles (ISRA). We eliminated areas that were too urban to have a satisfactory number of maize producers or that were too unsafe for field teams to operate. We then randomly selected 200 of the remaining 307 villages to constitute the sample. Power calculations indicated that a sample of 2,000 households in 200 villages, with randomization at the village level, allowed us to detect a 10 ppb (0.2 standard deviations) average drop in total aflatoxin levels, which is considered a small effect size (33).[3]

We conducted a rapid census of these 200 villages, and randomly selected 10 households within each village to be included in the study. If a village had fewer than 10 households, enumerators randomly selected additional households from the nearest village that had not already been selected to take part in our baseline survey (hence the total number of 209 villages in the analysis sample). In all, 1,981 households were included in a baseline survey, conducted in May 2016 (Table 1). We collected data from one male respondent and one female respondent within each household. The baseline survey did not include the collection of maize sample and measures of aflatoxins level before the intervention, so baseline data were not used in the analyses of impact.

[3] Power calculations used the mean, standard deviation, and intra-cluster correlation coefficient values from maize samples tested for total aflatoxin levels in the same area where this project was implemented as part of a previous research project 31. Ileleji K, Woloshuk CP, Sarr I, & Olasubulumi J (2015) Post-harvest operations survey: Senegal. (Purdue University, West Lafayette, IN). Calculations were based on one post-intervention measurement (we only measured total aflatoxin levels once) and a cluster size of 10 households per village.

Table 1. Sample size.

	Group					
	1	2	3	4	5	All
Households surveyed at baseline (May 2016)	382	390	397	408	404	1,981
Households who harvested maize in 2016 (October/November 2016)	255	292	295	343	310	1,495
Households surveyed in the first post-intervention survey (January/February 2017)	382	390	397	408	404	1,981
Households surveyed in the second post-intervention survey (May 2017)	382	390	397	408	404	1,531
Households with stored maize available for testing (May 2017)	143	176	174	201	202	896
Number of samples taken for testing of aflatoxins (May 2017)	241	303	293	370	373	1,580

Group 1 is the control group. Group 2 received training only. Group 3 received training and a hygrometer. Group 4 received training, a hygrometer, and a $10m^2$ tarp. Group 5 received training, a hygrometer, a $10m^2$ tarp, and a hermetic grain storage bag. The first post-intervention survey was conducted after the training and soon after harvest. For testing of aflatoxins, during the second post-intervention survey we took two maize samples per household from 684 households that still had maize in May 2017 from the 2016 harvest; 212 other households had a small amount of maize still in storage, from whom we took only one sample.

After concluding the baseline survey, we randomly assigned villages to treatment groups, stratifying by the extension agents that would conduct the trainings to avoid trainer-specific effects that could influence results through the effectiveness of the training. To test the balance of randomization we ran a multinomial logit model including the baseline variables shown in Table 2. Coefficients are shown in Appendix B and show that the village-level randomization was overall successful in creating groups of similar households.[4] At baseline, households in groups 2 and 4 were more likely than households in the control group (Group 1) to have maize in storage from the 2015 harvest ($p<0.05$). Households in group 5 may have also been more likely

[4] The randomization assigned *villages* to control and treatment groups, which may allow for some differences in *household* characteristics across the groups.

than control households to have maize in storage at baseline (May 2016) from the 2015 harvest, and households in group 4 may have been less likely to dry maize on the ground, but these coefficients are only statistically significant at the 10 percent level. As a result, we present all regression results with and without controlling for these two variables (having maize in storage in May 2016 and drying any maize on the ground); our treatment effects estimates are robust across specifications.

The intervention was implemented in early October 2016, just prior to the 2016 maize harvest. It was followed by two post-intervention surveys. The first post-intervention survey took place in January/February 2017, and reached all households surveyed in the baseline (Table 1). This survey focuses on (1) determining who implemented recommended practices from the training, and (2) measuring the moisture content of participants' stored maize. Because rains stopped too early to allow full maize maturity in 2016, only 1,495 households harvested maize. The second post-intervention survey was conducted in May 2017 to measure total aflatoxin levels in maize after three to four months of storage.[5] We were able to re-survey all the original households. However, only 896 households still had maize in storage in May 2017 (from the 2016 harvest), from whom we took 1,580 maize samples (Table 1). We discuss how we dealt with the analytical challenge arising from the non-random loss of observations due to households not having grain in storage for testing of aflatoxins in the following sections.

We instructed enumerators to take two handfuls of maize per household and note how the household dried and stored the maize in each sample. Most samples were dried only one way, and stored in only one type of container; only eight percent of maize samples were dried using more than one method (up to three, for example on a raised platform, in the field, or on the side

[5] The maize harvest takes place in October/November of each year. Maize is left to dry for two to three months after that, while the household deals with other crops, and put into storage around February.

of road), while only two percent of samples had been stored in multiple containers since harvest (for example, in a traditional granary, in a metallic silo, on the ground in the house). If the household stored maize in more than one type of container, enumerators were instructed to collect samples that used different drying and storage methods within a household.[6] If the household received a hermetic bag, one of the samples was to be taken in that bag and one from another vessel. Although we intended to take two samples per household from the 896 households that still had maize in the second post-intervention survey, for households with only a very small amount of maize still in storage, enumerators took only one sample (212 households). Maize samples were ground by hand and tested using VICAM Afla-V AQUA kits and a VICAM Vertu™ lateral flow reader.

Table 2 describes our sample at baseline, in aggregate and by treatment group. Households were large, with 13 members on average.[7] Household heads were men (only 0.5 percent of households in our sample were headed by a woman) in their late forties, about one third of whom had any formal education (excluding Koranic school). The average distance from the village center to a paved road is 14 km. Household heads had, on average, 20 years of maize farming experience. In this region of Senegal, crops are harvested in October-November of each year. As a result, questions in the baseline survey in May 2016 about maize harvested pertained to the 2015 harvest. On average, households planted 4.4 hectares of all crops in the 2015 season, 1.7 of which were planted with maize. The average maize harvest that year was 675 kg. Maize

[6] If the household only had maize in one vessel, the instructions were to take one sample close to the top of the vessel, and the other sample as close to the bottom of the vessel as possible. The instructions to sample maize from different areas stems from the fact that aflatoxin contamination can be local, particularly when low levels of aflatoxins are present. In our data, the correlation between two samples taken from the same household (all groups) was 0.478, so taking two samples with this procedure increased the reliability of our aflatoxin measurement.
[7] The variable measuring household size is winsorized at the 95th percentile (28 members); in the raw data, 3 percent of households reported having more than 30 members, up to a maximum of 102 members. Even though some households practice polygamy, the raw figures are unlikely to be accurate.

was overwhelmingly a self-consumed crop (only seven percent of households sold any portion of their harvest; not shown in Table 2). Yet most households were not maize self-sufficient: from the time of storage,[8] they estimated their stored maize would last only 14 weeks on average before running out. Sixty-four percent of households still had maize in storage in May 2016 from the 2015 harvest.

[8] Households likely consider the "time of storage" as January/ February, although they harvest in October/ November. They frequently leave the maize to field dry for 2-3 months while harvesting other crops, before bringing it to the household compound for longer-term storage.

Table 2. Descriptive statistics at baseline.

	Mean in group					Overall mean	Overall standard deviation
	1	2	3	4	5		
Panel A. Household characteristics							
Household size	12.2	12.6	12.5	11.8	12.3	12.3	6.7
Age of household head (years)	46	47	47	48	48	47	12
Household head had any formal education (%)	35	35	32	30	30	32	47
Woman respondent reports that any woman in the household had access to a mobile phone (%)	67	71	70	70	69	69	46
Distance from village center to nearest paved road (km)	12	15	13	15	13	14	16
Panel B. Crop production and storage							
Maize farming experience of household head (years)	19	20	20	20	21	20	12
Area cultivated in 2015 (ha)	4.1	4.2	5.3	4.3	4.2	4.4	12.8
Area of maize cultivated in 2015 (ha)	1.8	1.5	1.4	2.2	1.7	1.7	6.0
2015 maize harvest (kg shelled)	643	732	615	723	660	675	904
Weeks that 2015 maize stored for consumption lasted	13	13	13	15	14	14	13
Had 2015 maize harvest still in storage in May 2016 (%)	57	65	64	68	67	64	48
2015 harvest duration (days)	9.6	9.1	9.5	10.1	10.2	9.7	9.9
Respondent knew that aflatoxins are toxic (%)	25	28	30	31	28	28	45
Dried some maize directly on the ground (%)	25	29	29	19	24	25	43
Stored some maize in a single layer plastic bag (%)	44	40	45	41	46	43	50

N=1,981 households. Group 1 is the control group, which received no input. Group 2 received training only. Group 3 received training and a hygrometer. Group 4 received training, a hygrometer, and a plastic tarp. Group 5 received training, a hygrometer, a plastic tarp, and a hermetic storage bag. Appendix B shows the results of statistical tests of randomization balance across all five groups from a multinomial logistic regression. Questions in the baseline survey (May 2016) about maize harvested pertained to the previous harvest (October/November 2015). One household did not report how it dried maize in the baseline, so the number of observations for the variable indicating drying directly on the ground is 1,980.

Knowledge of aflatoxins and post-harvest practices that reduce the risk of contamination was low. At baseline, only 28 percent of households knew that aflatoxins are toxic. In addition, about 25 percent of households dried their maize directly on the ground, a key practice that can lead to contamination from aflatoxins. Forty-three percent of households stored maize in a single layer plastic bag at baseline, which increases the risk of contamination from aflatoxins by insects and by allowing grain moisture to increase over time.

Empirical model

Our empirical analysis estimates the intent-to-treat effect of being assigned to receive each input (training, hygrometer, tarp, and hermetic storage bag) on the average level of aflatoxins in stored maize for household i in village j. We model the impact of each input on total aflatoxin levels with the following cross-sectional regression modeling aflatoxin levels in the second post-intervention survey as a function of which input each household was assigned to receive and baseline characteristics of households:

$$A_{ij} = \beta_1 + \beta_2 Train_{ij} + \beta_3 Hygro_{ij} + \beta_4 Tarp_{ij} + \beta_5 PICS_{ij} + \delta X_{ij} + \lambda E_j + \varepsilon_{ij}, \qquad (1)$$

where A is the total aflatoxin level in stored maize, ranging from zero to 100 ppb. The variables *Train, Hygro, Tarp,* and *PICS* are binary variables equal to one if the household received the training, a hygrometer, a tarp, or a hermetic storage bag, and zero otherwise. Note that *Train, Hygro, Tarp,* and *PICS* do not indicate treatment groups but inputs. Thus, $\hat{\beta}_2$, $\hat{\beta}_3$, $\hat{\beta}_4$, and $\hat{\beta}_5$ estimate the marginal effect of receiving training, a hygrometer, a tarp, or a bag, respectively, in addition to any other inputs received on the household's total aflatoxin level in stored maize. It is important to note that because the inputs are cumulative, the comparisons made from $\hat{\beta}_2$ - $\hat{\beta}_5$

are the marginal effects of each added input, conditional on having received the other input(s). The results are not necessarily robust to re-ordering of the inputs.

The vector of the two covariates that were not balanced at baseline is denoted by X_{ij}; we present all results excluding and including the variables in this vector. E_j is a vector of six binary variables controlling for the seven extension agents who conducted the training and distributed inputs in village j. It is included because, as noted above, the randomization was stratified by extension agent. The error term is denoted by ε_{ij}. Standard errors are clustered by village, reflecting the level of randomization (34).

The analysis needs to consider two important features of the setting and data. First, our measurement of total aflatoxin is censored at 100 ppb. The machine we used to measure total aflatoxin levels requires a second reading on a different setting to read exact levels over 100 ppb. We opted not to undertake any second reading because (a) we did not know when planning the study what level of aflatoxins to expect and how many readings would be above 100 ppb, (b) 100 ppb is well above the recommended safe level of 10 to 20 ppb so the loss of precision was *a priori* acceptable, and (c) we wanted to contain the cost of aflatoxin testing ($6 per test strip, plus labor and transport costs; a second strip would have been needed for each second reading). As a result, our data cannot differentiate between total aflatoxin levels of 100 ppb and higher levels.[9] Of the 1,580 samples we tested, 134 (eight percent) returned an "above range" reading (Table 4). Consequently, we use ordinary least squares (OLS) and interval regressions to confirm that our results are robust to the upper-level censoring at 100 ppb. Modeling the censored nature of the data with interval regressions is preferable to using tobit regressions in this setting because the

[9] Our protocol for testing and analyzing aflatoxins was set up under the supervision of a mycologist who is an expert on aflatoxins. He suggested that limiting the threshold at 100 ppb was sufficient from a scientific perspective.

aflatoxin level is limited at a known value, 100 ppb (35). For robustness we include estimates from tobit models in appendix C. The tobit results are similar to our main results.

The second feature of our setting is that we can only measure and analyze total aflatoxin in maize samples from households who had maize in storage in May 2017, six to seven months after harvest and three to four months after being placed into storage. Only 896 of the 1,981 households included at baseline still had maize in storage in May 2017 (1,495 harvested any maize in 2016). This feature affects our estimates if the treatment assignment affects the probability that households still had maize in storage in May 2017. The dependent variable therefore exhibits the properties of incidental truncation (36), analogous to Heckman's missing wages for people who do not participate in the labor force (37). To alleviate these concerns, we regress a binary variable indicating whether the household has any maize in storage in May 2017 on the treatment indicators, without and with a set of control variables. Table 3 reports these results and suggests that none of the coefficients on the indicators of treatment were statistically significant at the ten percent level ($0.125 \leq p \leq 0.976$; Table 3). This suggests that our treatments did not induce selection in the form of people having more maize in storage in May 2017.

Table 3. Determinants of probability of still having maize in storage in the second post-intervention survey.

	(1)	(2)	(3)	(4)
Dependent variable:	1 if household still has maize in storage in second post-intervention survey; 0 otherwise			
Model:	OLS	OLS	Probit	Probit
Household received training	0.0817	0.0593	0.0819	0.0613
	(0.0532)	(0.0489)	(0.0535)	(0.0486)
Household received a hygrometer	-0.0156	-0.00150	-0.0158	-0.00429
	(0.0526)	(0.0489)	(0.0524)	(0.0488)
Household received a tarp	0.0488	0.0356	0.0485	0.0350
	(0.0537)	(0.0496)	(0.0533)	(0.0493)
Household received a PICS hermetic storage bag	0.00923	0.0102	0.00944	0.00875
	(0.0524)	(0.0494)	(0.0517)	(0.0484)
Household size		0.00273		0.00243
		(0.00191)		(0.00192)
Age of household head (years)		0.000230		0.000222
		(0.00125)		(0.00123)
Household head had any formal education		0.0158		0.0130
		(0.0249)		(0.0247)
Distance from village center to paved road (km)		0.00167		0.00168
		(0.00206)		(0.00200)
Maize farming experience of household head (years)		-0.000334		-0.000392
		(0.00125)		(0.00125)
Weeks that 2015 maize stored for consumption lasted		0.00147		0.00129
		(0.00100)		(0.00100)
Household consumes moldy maize		-0.0384		-0.0396
		(0.0290)		(0.0287)
2015 maize harvest put into storage (kg shelled)		7.1e-05***		8.8e-05***
		(1.98e-05)		(2.84e-05)
2015 maize harvest still in storage in May 2016		0.148***		0.141***
		(0.0254)		(0.0246)
2015 harvest duration (days)		0.00404***		0.00398***
		(0.00109)		(0.00120)
Respondent knew that aflatoxins are toxic		-0.0900***		-0.0892***
		(0.0271)		(0.0264)
Dried 2015 maize directly on the ground		0.0119		0.0140
		(0.0266)		(0.0267)
Stored 2015 maize in a single layer plastic bag		-0.0332		-0.0344
		(0.0261)		(0.0256)
Stored 2015 maize on the cob		0.0319		0.0296
		(0.0275)		(0.0271)
Constant	0.335***	0.137*		
	(0.0602)	(0.0827)		
Observations	1,981	1,980	1,981	1,980
R-squared	0.029	0.098		
Trainer fixed effects included	Yes	Yes	Yes	Yes

Standard errors clustered by village in parentheses. *** p<0.01, ** p<0.05, * p<0.1. OLS: Ordinary Least Squares regressions (models are linear probability models) Coefficients in columns 3 and 4 are marginal effects. One household did not report how it dried maize in the baseline survey, so the number of observations in columns 2 and 4 is 1,980

Results

We structure the results section into two sub-sections, focusing on the main results and on pathways to impact. In addition, we show in Appendix E that our main findings are robust to a different definition of the dependent variable.

Main results

Table 4 shows average total aflatoxin levels in maize samples taken from households in each of the five groups in May 2017, three to four months after harvest. It shows three main results. First, average aflatoxin levels were highest in the control group, at 24 ppb. Second, levels were lower in Groups 2-4 than in the control group (17-19 ppb on average) but were similar to each other. Last, households in Group 5, who received all inputs, had the lowest average levels (11.5 ppb).

We found similar trends in the percentage of samples that lie below the 10 ppb threshold applied in the European Union for maize to be safe for human consumption, and the 20 ppb threshold applied in the United States. Roughly three quarters of all samples revealed total aflatoxin levels below both thresholds, but the percentages of samples below both thresholds was lower in Groups 2-4 than in Group 1, and lowest in Group 5. These results provided some *prima facie* evidence of two salient issues for our study: (1) aflatoxins were a significant problem for stored maize in our sample, and (2) our inputs were successful at lowering their levels.

Table 4. Average total aflatoxin levels by treatment group.

	Group					
	1	2	3	4	5	All
Mean total aflatoxin level (ppb)	24.4	16.7	16.9	19.3	11.5	17.3
Samples > 10 ppb (%)	33	26	27	29	20	27
Samples > 20 ppb (%)	29	21	24	25	16	22
Samples ≥ 100 ppb (%)	15	8	8	10	4	8
Number of samples analyzed	241	303	293	370	373	1,580

Group 1 is the control group. Group 2 received training only. Group 3 received training and a hygrometer. Group 4 received training, a hygrometer, and a $10m^2$ tarp. Group 5 received training, a hygrometer, a $10m^2$ tarp, and a hermetic grain storage bag. For 134 samples registering total aflatoxin levels higher than 100 ppb, we calculate the mean using the value of 100 ppb. The European Union permits a maximum concentration of aflatoxins in maize destined for human consumption of 10 ppb; in the United States the equivalent limit is 20 ppb. We analyze two samples per household from 684 households that still had maize in May 2017 from the 2016 harvest; 212 other households had a small amount of maize still in storage, from whom we took only one sample.

Next, we turn to regression analyses to evaluate the statistical significance of the differences in total aflatoxin levels by input received. Regression estimates (Table 5) generally concur with the three main results reported above in Table 4, but show that only receiving a hermetic bag caused a statistically significant marginal reduction in mean total aflatoxin levels in stored maize. Recall that $\hat{\beta}_2$, $\hat{\beta}_3$, $\hat{\beta}_4$, and $\hat{\beta}_5$ estimate the marginal effect of being assigned to receive each input separately rather than the impact of being assigned to one of the five groups. Columns 1 and 2 show the results estimated via OLS, while columns 3 and 4 show the results estimated by interval regressions to explicitly model that eight percent of samples had total aflatoxin levels above 100 ppb.

Table 5. Impacts of inputs on total aflatoxin levels.

	(1)	(2)	(3)	(4)
Dependent variable:	Total aflatoxin level in stored maize (ppb)			
Model:	OLS	OLS	Interval	Interval
Household received training ($\hat{\beta}_2$)	-6.667	-6.642	-7.566	-7.543
	(4.183)	(4.180)	(4.643)	(4.639)
Household received a hygrometer ($\hat{\beta}_3$)	1.186	1.208	1.321	1.337
	(3.316)	(3.304)	(3.608)	(3.594)
Household received a tarp ($\hat{\beta}_4$)	1.669	1.666	1.893	1.887
	(3.555)	(3.592)	(3.860)	(3.899)
Household received a PICS hermetic storage bag ($\hat{\beta}_5$)	-7.711**	-7.705**	-8.415**	-8.405**
	(3.122)	(3.144)	(3.389)	(3.413)
2015 maize harvest still in storage in May 2016		-0.551		-0.469
		(2.108)		(2.285)
Dried some 2015 maize directly on the ground		-0.132		-0.151
		(2.030)		(2.198)
Constant	22.81***	23.25***	24.29***	24.67***
	(4.202)	(4.444)	(4.664)	(4.904)
Observations	1,580	1,580	1,580	1,580
R-squared	0.035	0.036		
Trainer fixed effects included	Yes	Yes	Yes	Yes

Standard errors clustered by village in parentheses. Interval regression models account for the upper-level censoring of the total aflatoxin level at 100 ppb. *** p<0.01, ** p<0.05, * p<0.1. Each observation is one maize sample; samples were taken from households who had maize in storage 3-4 months after harvest (i.e. not every household).

Receiving a hermetic storage bag lowered total aflatoxin levels in stored maize by about eight ppb more than the combination of training, a hygrometer, and a tarp, on average ($0.013 \leq p \leq 0.015$). This impact is meaningful, representing a third of the average total aflatoxin level in the control group. Coefficient estimates from the interval regressions in columns 3 and 4 were slightly higher than the OLS estimates in columns 1 and 2, by about 0.7 ppb on average. Overall the consistency of impact estimates between the two estimators lends credibility to the robustness of our results.

Consistent with the lower average total aflatoxin levels in Groups 2-5 compared to the control group (Group 1), the regression estimates of the impact of the training were negative and relatively meaningful, but they were not statistically significant (p-values in columns 1-4 of Table 5 range from 0.103 to 0.114). Table 5 also indicates that the hygrometer and the tarp did not cause any reduction in aflatoxin levels beyond that caused by the training (which all households who received a hygrometer and a tarp also received), as coefficients $\hat{\beta}_3$ and $\hat{\beta}_4$ were small and not statistically significant ($0.624 \leq p \leq 0.721$). As mentioned earlier, it is important to keep in mind that since these inputs are cumulative, the results indicate the marginal impact of each input, conditional on having received other inputs, and are not robust to re-ordering of inputs.

The impacts of the four inputs on total aflatoxin levels in stored maize are not heterogeneous. Figure 1 shows the cumulative distribution function of total aflatoxin levels in the maize samples in the control and treatment groups. It suggests that the aflatoxin-reducing impacts of our intervention were distributed throughout the sample rather than stemming from a large impact on a few households, for example those with very high total aflatoxin levels.

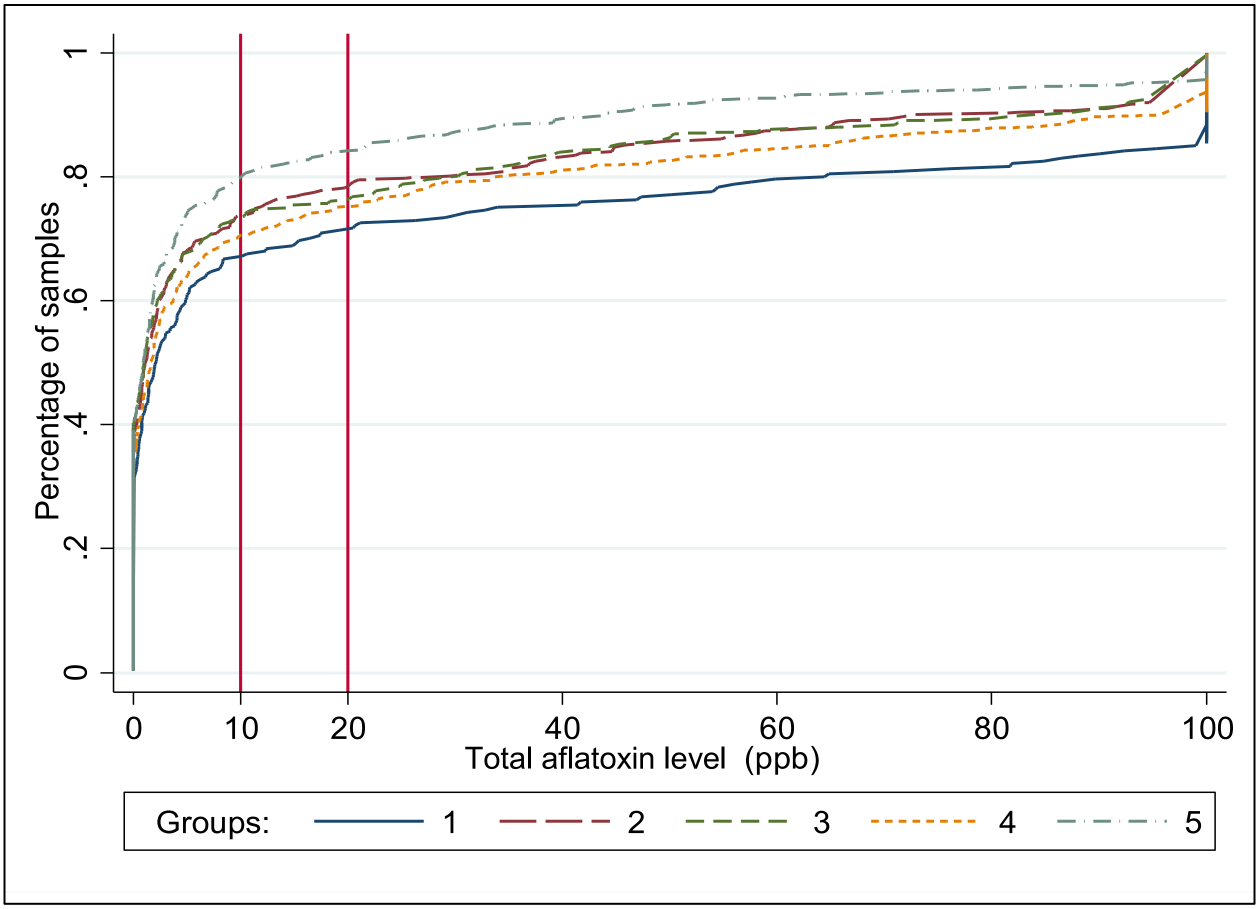

Figure 1. Cumulative distribution functions of total aflatoxin levels by treatment group

Group 1 is the control group. Group 2 received training only. Group 3 received training and a hygrometer. Group 4 received training, a hygrometer, and a 10m^2 tarp. Group 5 received training, a hygrometer, a 10m^2 tarp, and a hermetic grain storage bag. Total aflatoxin levels are censored at 100 ppb.

We further examine the distributions in Figure 1 for first-order stochastic dominance, using the empirical likelihood ratio test described in Davidson and Duclos (38). The test examines whether the cumulative density function of the aflatoxin levels distribution caused by one package of inputs strictly dominates the cumulative density function of another distribution caused by another package, at every point. Because higher aflatoxin levels are bad, in our setting a dominated distribution is preferred over another (unlike in the setting of a lottery, where stochastic dominance tests are often applied and where dominant distributions are preferred by expected utility maximizers). Results indicate that Group 1's distribution first-order dominates those of Groups 2 and 5, which means that the training, and the combination of training, hygrometer, tarp, and hermetic bag always yield lower total aflatoxin levels than no input(s) (Table 6). In addition, Group 4's distribution first-order dominates Group 5's distribution: the combination of inputs received by Group 5 (training, hygrometer, tarp, and hermetic bag) always lowers total aflatoxin levels compared to the inputs received by Group 4 (training, hygrometer, and tarp). These results confirm the beneficial impact of the hermetic storage bag, and indicate that the training itself (received in Group 2) also yielded lower total aflatoxin levels (compared to the control group, Group 1).

Table 6. First-order Stochastic Dominance

		Group			
		1	2	3	4
Group	2	1.352***			
		(0.007)			
	3	1.225*	0.000		
		(0.051)	(1.000)		
	4	0.091	0.029	0.046	
		(1.000)	(1.000)	(1.000)	
	5	2.830***	0.115	0.000	1.215**
		(<0.001)	(1.000)	(1.000)	(0.030)

Empirical likelihood ratio statistic is F-distributed. P-values are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Pathways to impacts

In this section we present evidence to understand why each input does or does not lead to changes in total aflatoxin levels. First, the training increased household awareness of aflatoxins and knowledge of their toxicity.[10] The baseline and first post-intervention surveys included

[10] Increased awareness of aflatoxins' harmfulness could have led farmers to sort their maize based on estimated level of contamination, and possibly give the worst-looking grains to animals. Further, farmers could have sorted differently based on the other inputs that they received. This behavior would have taken out of the universe of possible maize samples the most contaminated kernels, and imply that the impacts that we measured are lower-bounds of the potential real impacts.

questions on the specific topics covered in the trainings. The percentage of farmers who were aware of aflatoxins and their toxicity increased by 38-49 percentage points between the baseline and first post-intervention surveys in the groups that received the training (Groups 2-5), but decreased by seven percentage points in the control group (p-value from a t-test that the average change in knowledge of aflatoxins' harmfulness differed between Group 1 and Groups 2-5 households < 0.001).[11] The training's success in transferring information was likely due in part to households having been trained by local extension agents, well known to and trusted by village chiefs and households, and with a medium- to long-term presence in the villages (39). Despite the knowledge transfer, however, we only found suggestive evidence that training alone reduced total aflatoxin levels. Only a few regression coefficients in some analyses were statistically significant (e.g., Appendix Table E.2).

Second, the lack of effect of providing a hygrometer on total aflatoxin levels could have reflected the fact that farmers already knew how to take advantage of natural local conditions to dry grains. For example, in January 2017 we tested the moisture content of maize to assess how dry maize is when it goes into storage.[12] At that time, we found that moisture content of maize going into storage was not a concern, with 96 percent of all samples' having a moisture content of 13.5 percent or below, the threshold under which fungi are unlikely to grow. Thus, it is unlikely that receiving a hygrometer could have made a meaningful marginal contribution to lowering total aflatoxin levels through proper grain drying.

[11] This result also indicates that there was no spillover of information on aflatoxins from treated households to households assigned to the control group, increasing our confidence in the high degree of internal validity of the study.

[12] We used one John Deere Moisture Check PLUS SW08120 and several Dickey John M-3G Portable Grain Moisture Testers brought to Senegal from the United States for the survey.

Third, the lack of impact of receiving a tarp on total aflatoxin levels runs counter to existing evidence that providing a tarp lowers total aflatoxin levels in stored groundnuts in Ghana (14). Our data showed that households reported using the tarps yet receiving a tarp failed to lower total aflatoxin levels on average (Appendix F). These results suggest that households that received a tarp used it, or at least *reported* using it, but using a tarp did not lower total aflatoxin levels. It is possible that the change in drying method was not widespread enough to generate an impact on average total aflatoxin levels; the nine percentage point decrease in the likelihood to dry on the ground created by the provision of tarps represents a decrease in the practice by about a third from baseline level (25 percent dried on the ground at baseline). It is also possible that the total aflatoxin levels we measured in the second post-intervention survey contaminated maize in the field, or at least did so that year, so that local drying practices did not influence total aflatoxin levels.

Finally, hermetic storage bags limit the spread of aflatoxins when grains are properly dried before being inserted in a bag, and when the bags are properly closed (17). We can think of two possible reasons why the hermetic bags had the largest marginal impact on aflatoxin reduction of any of the interventions offered to participants in our intervention. First, as mentioned earlier, the physical properties of bags – they stop airflow and suffocate insects – have been shown under laboratory conditions to stop the spread of aflatoxins in stored grains (19, 30). This also seems to hold true in our smallholder farm household setting in southern Senegal, as maize was stored in the hermetic bags for 3-4 months before we took aflatoxin samples. As such, the hermetic bag's ability to control aflatoxins' spread over this relatively long time period was a key technological improvement over the status quo, which is storing in one-layer woven bags that let air and moisture into the bags and allow insects to thrive and spread aflatoxins.

Second, there could have been a behavior response by smallholders to receiving the hermetic bags, as they were a completely new technology to all of the farmers in our sample. During the training, participants where shown the benefits of the hermetic bags and their proper use that yields those benefits. Good harvesting and post-harvest practices are not effective over the long term without good storage practices and technologies. It may have been that the hermetic bags were viewed by participants as the key input or technology, which was novel enough and effective enough to motivate them to reduce aflatoxin contamination at the harvesting and drying stages more than farmers in other treatment groups.[13]

Conclusion

The present article discusses results from an RCT-based study of an intervention aiming to improve post-harvest practices and reduce aflatoxins in maize produced and stored by smallholder farmers in Senegal. To test which constraints are binding to prevent safe maize drying and storage, we provided training (on the dangers of aflatoxins and best practices to prevent them), hygrometers (to reduce maize moisture content levels, thus minimizing accumulation of aflatoxins in stored maize), tarps (to reduce contact with possibly contaminated soil that may have contained aflatoxins), and hermetic storage bags (to kill insects which spread aflatoxins in stored maize, and to maintain moisture content). We found that, while households did attend trainings and use the hygrometers and tarps, only receipt of a hermetic storage bag caused a statistically significant reduction in average total aflatoxin levels. The impact of receiving a hermetic bag was meaningful at 8.4 ppb in an interval regression model, representing

[13] This argument would not apply to hygrometers and tarps, for which substitute "technologies" exist. For example, people can use touch or biting kernels to (imperfectly) test dryness instead of a hygrometer, and they can use roofs, roadsides, or mats other than tarps to dry maize off the ground.

34 percent of the average total aflatoxin levels in the control group. Thus, the lack of a safe storage structure for grains was the primary constraint preventing farmers from lowering total aflatoxin levels in their stored maize.

One caveat to the interpretation of our results is that since the inputs were cumulative by treatment groups, the results are not robust to re-ordering inputs. We found that training, hygrometers and tarps had no statistically significant effect on aflatoxin levels without the hermetic storage bags, but our data cannot tell whether the hermetic bags would have had a significant impact without the other inputs. In particular, the hermetic storage bags require a training about their proper use to be effective. Our evidence of their impact must therefore be understood in the context of our intervention, which provided inputs cumulatively. Testing different combinations of inputs, with an eye toward cost-effectiveness, is an important topic for future research.

Our finding that providing plastic tarps to dry maize has no significant effect on total aflatoxin levels differs from that of Hoffmann, Magnan, Garrido, Kanyam and Opoku (14), the only other study to separately test the impact of tarp provision on aflatoxins. An important difference is that the Hoffmann, Magnan, Garrido, Kanyam and Opoku (14) tested the effectiveness of tarp use on reducing total aflatoxin levels in groundnuts; further study is needed to establish more precisely the conditions under which tarps are effective at reducing total aflatoxin levels across a variety of crops.

Finally, the finding that hermetic storage bags caused significant marginal decreases in total aflatoxin levels, including for maize stored in other vessels, raises interesting questions about behavioral responses to the intervention. The result suggests that harvesting, drying, and storage practices may go together in the mind of smallholder farm households. Additional evidence is required to understand the direct (e.g.: less air flow, lower moisture content, and fewer insects) and indirect (e.g.: better post-storage care of grains) impacts of hermetic grain storage (40). Our results suggest that, from a policy and development implementation perspective, post-harvest interventions should consider harvest, post-harvest, and storage issues together rather than separately when engaging with smallholders.

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Appendix A. Picture of the hygrometer and maize moisture content reading.

The large number (23 in the picture) is the relative humidity percentage. The small number (24.5 in the picture) is the temperature in degrees Celsius.

Appendix B. Multinomial logit model to test randomization balance.

	(1)	(2)	(3)	(4)
	Household assigned to treatment group			
Dependent variable:	2	3	4	5
Household size	0.0042	0.0051	-0.0214	-0.0064
	(0.0157)	(0.0157)	(0.0148)	(0.0142)
Age of hh head (years)	-0.0045	-0.0048	0.0026	0.0042
	(0.0092)	(0.0086)	(0.0097)	(0.0087)
Household head has any formal education (%)	-0.0428	-0.1449	-0.2447	-0.1846
	(0.1896)	(0.1835)	(0.1855)	(0.1737)
Any woman in hh has access to a mobile phone (%)	0.1863	0.2401	0.0731	0.1055
	(0.1765)	(0.1978)	(0.1703)	(0.2009)
Distance from village center to nearest paved road (km)	0.0300	0.0117	0.0351	0.0172
	(0.0233)	(0.0255)	(0.0219)	(0.0211)
Maize farming experience of household head (years)	0.0106	0.0110	0.0100	0.0133
	(0.0106)	(0.0106)	(0.0111)	(0.0106)
Area of crop cultivation in 2015 (ha)	-0.0003	0.0064	0.0008	0.0007
	(0.0128)	(0.0047)	(0.0052)	(0.0054)
Area of maize cultivation in 2015 (ha)	-0.0051	-0.0148	0.0094	-0.0019
	(0.0148)	(0.0178)	(0.0136)	(0.0131)
2015 maize harvest (kg shelled)	0.0001	-0.0001	0.0001	-0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Duration 2015 maize stored for consumption lasted (weeks)	-0.0088	-0.0033	0.0037	0.0050
	(0.0080)	(0.0085)	(0.0077)	(0.0080)
2015 maize harvest still in storage in May 2016 (%)	0.4387**	0.2894	0.4495**	0.4155*
	(0.2120)	(0.2271)	(0.2225)	(0.2176)
2015 harvest duration (days)	-0.0089	-0.0022	-0.0018	-0.0003
	(0.0101)	(0.0097)	(0.0095)	(0.0092)
Respondent knows that aflatoxins are toxic (%)	0.0018	0.1201	0.2065	-0.0129
	(0.2031)	(0.2088)	(0.1998)	(0.1983)
Dried some 2015 maize directly on the ground (%)	0.2275	0.2084	-0.4346*	-0.0544
	(0.1981)	(0.2189)	(0.2234)	(0.2069)
Store some maize in a single layer plastic bag (%)	-0.2277	0.0703	-0.1609	0.1099
	(0.2719)	(0.2784)	(0.2748)	(0.2543)
Constant	0.0042	0.0051	-0.0214	-0.0064
	(0.0157)	(0.0157)	(0.0148)	(0.0142)
Observations	1,980			
Trainer fixed effects included	Yes			
Chi2 test that all regressors are jointly = 0	Chi2 = 120.04; p = 0.006			

Standard errors clustered by village in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Household size is winsorized at the 95th percentile (28 members). Whether any woman in the household had access to a mobile phone is reported by a woman respondent. One household did not report how it dried maize in the baseline survey.

Appendix C. Impacts of inputs on aflatoxin levels, Tobit estimates to account for censoring at 100 ppb.

	(1)	(2)	(3)	(4)
Dependent variable:	Total aflatoxin level in stored maize (ppb)			
Model:	Tobit - Gaussian		Tobit - Logistic	
Household received training ($\hat{\beta}_2$)	-7.566	-7.543	-3.921	-3.875
	(4.643)	(4.639)	(2.931)	(2.921)
Household received a hygrometer ($\hat{\beta}_3$)	1.321	1.337	1.060	1.113
	(3.608)	(3.594)	(2.237)	(2.221)
Household received a tarp ($\hat{\beta}_4$)	1.893	1.887	0.925	0.928
	(3.859)	(3.899)	(2.513)	(2.539)
Household received a PICS hermetic storage bag ($\hat{\beta}_5$)	-8.415**	-8.405**	-4.440**	-4.427**
	(3.389)	(3.413)	(2.220)	(2.237)
2015 maize harvest still in storage in May 2016		-0.469		-0.987
		(2.285)		(1.405)
Dried some 2015 maize directly on the ground		-0.151		-0.078
		(2.198)		(1.264)
Constant	24.29***	24.67***	13.053***	13.762***
	(4.664)	(4.904)	(3.133)	(3.263)
Observations	1,580	1,580	1,580	1,580
Trainer fixed effects included	Yes	Yes	Yes	Yes

Standard errors clustered by village are shown in parentheses in columns 1-4. *** p<0.01, ** p<0.05, * p<0.1. Each observation is one maize sample; samples were taken from households who had maize in storage 3-4 months after harvest (i.e. not every household).

Appendix E. Tests of the robustness of our main findings.

We verify that our main findings are robust to different definitions of the dependent variable. First, we estimate the probability that total aflatoxin levels are above the European Union (EU) and United States (US) standards of 10 ppb and 20 ppb, respectively. Table E.1 shows the results from linear probability models in which we replace the dependent variable in Equation 1 by a binary variable taking the value one if the total aflatoxin level in a sample was higher than 10 and 20 ppb, and zero otherwise. In addition to testing the robustness of the main result, this analysis provides insight into the impact of our interventions on compliance with EU and US standards for total aflatoxin levels in maize intended for human consumption. Results in Table E.1 are consistent with our main results in Table 5. Receiving a hermetic storage bag decreased the probability of being above both the EU and US standards by nine percentage points ($0.035 \leq p \leq 0.050$). Similar to our main analysis, the training, hygrometer, and tarp did not have a statistically significant impact aflatoxin levels ($0.217 \leq p \leq 0.964$).

Table E.1. Impact of inputs on probability of total aflatoxin levels in stored maize being above the European Union and United States standards.

	(1)	(2)	(3)	(4)
Dependent variable:	1 if total aflatoxin level > 10 ppb; 0 if ≤ 10 ppb		1 if total aflatoxin level > 20 ppb; 0 if ≤ 20 ppb	
Standard applicable in:	European Union		United States	
Model:	LPM	LPM	LPM	LPM
Household received training	-0.0515	-0.0513	-0.0612	-0.0601
	(0.0480)	(0.0478)	(0.0494)	(0.0492)
Household received a hygrometer	0.0125	0.0138	0.0333	0.0338
	(0.0499)	(0.0499)	(0.0481)	(0.0477)
Household received a tarp	0.0185	0.0197	0.00299	0.00236
	(0.0535)	(0.0540)	(0.0511)	(0.0515)
Household received a PICS hermetic storage bag	-0.0897*	-0.0911**	-0.0896**	-0.0887**
	(0.0456)	(0.0456)	(0.0423)	(0.0425)
2015 maize harvest still in storage in May 2016		-0.0154		-0.0197
		(0.0297)		(0.0275)
Dried some 2015 maize directly on the ground		0.00890		-0.0101
		(0.0272)		(0.0273)
Constant	0.301***	0.310***	0.267***	0.284***
	(0.0535)	(0.0594)	(0.0517)	(0.0558)
Observations	1,580	1,580	1,580	1,580
R-squared	0.026	0.026	0.021	0.022
Trainer fixed effects included	Yes	Yes	Yes	Yes

Standard errors clustered by village in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions are linear probability models (LPM). Each observation is one maize sample; samples were taken from households who had maize in storage 3-4 months after harvest (i.e. not every household). At the time of the study, Senegal did not have an official maximum amount of aflatoxins allowed in foods.

Second, we show in Table E.2 that the main result holds when using the inverse hyperbolic sine of the aflatoxin level measurement. Inverse hyperbolic sine transformations of dependent variables yield regression coefficients that are interpreted like natural logarithm transformations, but have the benefit of being defined for zero values of the original variable (41). Coefficients were adjusted for the input indicators being binary variables (42, 43).

Appendix Table E2 confirms the main finding about the hermetic bags, and provides limited evidence that the training may have had an impact on lowering aflatoxin levels.

Coefficients $\hat{\beta}_5$ indicate that providing a hermetic storage bag reduced total aflatoxin levels by 36 to 40 percent, on average (0.005≤p≤0.010). Our main estimates placed the impact at 34 percent of the control group average. In terms of the impact of the training, the interval regressions indicate a statistically significant reduction in total aflatoxin levels by 34 percent (p=0.040 and p=0.042), but the coefficients in the OLS regression are smaller in magnitude and only statistically significant at the 10 percent level (p=0.067 and p=0.070).

Appendix Table E2. Impacts of inputs on inverse hyperbolic sine of total aflatoxin levels.

	(1)	(2)	(3)	(4)
Dependent variable:	Total aflatoxin level in stored maize (ppb)			
Model:	OLS	OLS	Interval	Interval
Household received training ($\hat{\beta}_2$)	-0.288*	-0.286*	-0.340**	-0.337**
	(0.158)	(0.158)	(0.166)	(0.166)
Household received a hygrometer ($\hat{\beta}_3$)	0.0246	0.0342	0.0324	0.0418
	(0.236)	(0.236)	(0.255)	(0.255)
Household received a tarp ($\hat{\beta}_4$)	0.110	0.116	0.123	0.130
	(0.278)	(0.282)	(0.303)	(0.307)
Household received a PICS hermetic storage bag ($\hat{\beta}_5$)	-0.360**	-0.365***	-0.396***	-0.400***
	(0.140)	(0.140)	(0.142)	(0.141)
2015 maize harvest still in storage in May 2016		-0.134		-0.132
		(0.109)		(0.119)
Dried some 2015 maize directly on the ground		0.0310		0.0292
		(0.125)		(0.134)
Constant	1.897***	1.983***	2.005***	2.088***
	(0.251)	(0.267)	(0.277)	(0.294)
Observations	1,580	1,580	1,580	1,580
R-squared	0.038	0.039		
Trainer fixed effects included	Yes	Yes	Yes	Yes

Standard errors clustered by village in parentheses. Interval regression models account for the upper-level censoring of the total aflatoxin level at 100 ppb. *** p<0.01, ** p<0.05, * p<0.1. Each observation is one maize sample; samples were taken from households who had maize in storage 3-4 months after harvest (i.e. not every household).

Appendix F. Determinants of probability of drying maize directly on the ground.

	(1)	(2)	(3)	(4)
Dependent variable:	1 if household reported drying maize directly on the ground in 2016; 0 if not		1 if household reported drying maize on a sheet or mat in 2016; 0 if not	
Household received training	-0.0504	-0.0520	0.0557	0.0487
	(0.0406)	(0.0398)	(0.0364)	(0.0371)
Household received a hygrometer	0.000794	0.00312	-0.0626*	-0.0583*
	(0.0350)	(0.0338)	(0.0337)	(0.0344)
Household received a tarp	-0.0938***	-0.0912***	0.309***	0.309***
	(0.0269)	(0.0264)	(0.0351)	(0.0343)
Household received PICS hermetic storage bag	-0.00487	-0.00836	0.0308	0.0316
	(0.0203)	(0.0198)	(0.0497)	(0.0485)
Household size		-0.000159		-0.00109
		(0.00140)		(0.00175)
Age of household head (years)		-0.000464		-0.00280**
		(0.000961)		(0.00117)
Household head has any formal education (%)		0.0453**		0.0194
		(0.0197)		(0.0240)
Maize farming experience – household head (years)		0.00177*		0.00324**
		(0.000943)		(0.00132)
Household consumes moldy maize		-0.0195		-0.0122
		(0.0213)		(0.0295)
2015 maize harvest put into storage (kg shelled)		1.22e-05		6.51e-06
		(1.22e-05)		(1.55e-05)
2015 maize harvest still in storage in May 2016		-0.00821		0.0143
		(0.0201)		(0.0247)
Weeks that 2015 maize stored for consumption lasted		-0.00115*		-9.63e-05
		(0.000672)		(0.00106)
2015 harvest duration (days)		-0.000170		-0.000716
		(0.000972)		(0.00121)
Dry maize directly on the ground		-0.00786		-0.0178
		(0.0226)		(0.0260)
Store maize on the cob		-0.00431		-0.0250
		(0.0184)		(0.0225)
Store maize in a single layer plastic bag		-0.00256		-0.0393
		(0.0203)		(0.0243)
Constant	0.192***	0.190***	0.126***	0.235***
	(0.0369)	(0.0611)	(0.0390)	(0.0674)
Observations	1,498	1,497	1,498	1,497
R-squared	0.037	0.047	0.125	0.134
Trainer fixed effects included	Yes	Yes	Yes	Yes
Mean of dependent variable at baseline:	0.252		0.032	

Standard errors clustered by village in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Regressions are linear probability models. One household did not report how it dried maize in the baseline survey, so the number of observations in columns 2 and 4 is 1,497.