How do improved drying and storage practices influence aflatoxin spread? Evidence from smallholder households in Senegal

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Maize is the most widely consumed cereal crop produced in Sub-Saharan Africa (SSA), and makes up the majority of calories consumed by millions of low income smallholder farm households (APHLIS 2015). While an expansive literature documents the challenges associated with boosting maize yields in SSA, much less research has been conducted on farmers' incentives and constraints to safe drying and storage of maize after it is harvested. For example, poor storage conditions increase the risk of spoilage by fungi. Several *Aspergillus* fungal species (primarily *A. flavus*) produce aflatoxins, which are potent liver toxins associated with increased cancer risk as well as negative effects on nutrition and immune systems in humans and animals. An estimated 4.5 billion people in developing countries are chronically exposed to aflatoxin (Williams, et al. 2004).

A. flavus can contaminate maize while it is in the field (before harvest), or through poor post-harvest practices. Maize in-field contamination with *A. flavus* is more likely under hot, dry conditions when the plant is already stressed. Post-harvest, *A. flavus* contaminates maize via contaminated surfaces, such as drying maize directly on the dirt or transporting/ storing it in unclean containers. Once maize is contaminated with *A. flavus*, its impact can be minimized by preventing further growth during storage. Like any fungus, *A. flavus* likes hot, humid conditions; optimal growth occurs when maize is stored at > 14 percent moisture content (MC). Additionally, controlling for MC is not sufficient, as insects spread fungi during movement, feeding, and defecation (Magan and Aldred 2007; Williams, Baributsa and Woloshuk 2014; Ng'ang'a, et al. 2016).

The multiple facets of safe maize storage, and that only 7 percent of households in our study area sell their maize production, motivate this study's main research question:

What is the most cost-effective way to prevent aflatoxin contamination and spread in rural SSA for autarkic households? In countries such as Senegal where there is no enforced regulatory limit on aflatoxin, households may not be aware of aflatoxin or have the means to prevent it (Hell, et al. 2000; James, et al. 2007). While some studies have examined the role of low-cost technologies to prevent aflatoxin spread in SSA, they focused on crops that were sold by most households, thus inviting a larger role for market-based interventions (Gajate-Garrido, et al. 2016). Numerous authors have shown that, under laboratory or strictly controlled field conditions, limiting these factors reduces aflatoxin contamination (Williams, Baributsa and Woloshuk 2014; Ng'ang'a, et al. 2016).

The Senegalese Context

Purdue's Food Processing Laboratory (FPL) conducted two background studies in Vélingara, in Senegal's Kolda region, during 2015 to inform this and accompanying studies. The background studies suggest that households' current maize drying practices increase aflatoxin risk. Ileleji, et al. (2015) find that 26 of 88 maize samples (30%) taken randomly from post-harvest cobs or shelled corn contained aflatoxin. The study's authors observed that many farmers dry cobs (without husks) on the bare ground. Many postharvest samples are dirty, with abrasion-wounds on the kernels. The quality of stored maize is important, as 91% of families consume maize during the lean season and households are, on average, food insecure for 4.5 months/ year (McCoy, et al. 2016).

The background studies also reveal that households in Vélingara dry maize in stages. After cutting the maize stalks, they are either piled or stooked (heaped into a rounded, tepee-like arrangement) in the field. As Vélingara only has one growing season to produce maize, sorghum, groundnut and cotton, farmers leave stooked maize in the field until the cash crop (groundnut or cotton) harvest is complete. Households then bring the harvested maize to their homes, to further dry on the cob or after shelling.

To encourage households to take aflatoxin preventive measures, it is important to address the four root causes of aflatoxin contamination and spread: 1) Poor knowledge; 2) Initial field contamination; 3) High MC; and 4) Insect activity. Aflatoxin prevention will require additional time from household members or hired labor, and may require the household to acquire additional materials. With an unlimited budget, these four causes are easier to address: 1) Train farmers, 2) Provide farmers with clean surfaces on which to dry their maize, 3) Provide farmers with grain moisture verification tools, and 4) Provide farmers with storage containers or chemicals to prevent insect contamination. However, development practitioners, public or private, do not have unlimited budgets.

We determine the most cost-effective way to prevent aflatoxin contamination and spread in rural SSA by changing farmer knowledge, and available drying and storage technologies, via a randomized control trial (RCT). To our knowledge, no study has 1) disseminated low-cost grain moisture verification tools or 2) clean drying surfaces to autarkic smallholder farmers and tested their effectiveness in reducing the 3) MC and 4) aflatoxin levels of stored maize.

This will allow us to test three null hypotheses. H_1 will discern which treatment was most effective at encouraging farmers to dry maize on clean surfaces, while H_2 will estimate which was most effective at encouraging better storage practices to prevent insect contamination. Most importantly, H_3 allows us to test which implemented practices result in aflatoxin reduction.

H_1: Provision of improved technology does not influence households' decision to implement improved drying practices.

H_2: Provision of improved technology does not influence households' decision to implement improved storage practices.

H_3: The implementation of recommended drying and storage practices does not influence the aflatoxin content of households' maize after three months of storage.

RCT Design

We use an RCT to examine which combinations of training and technologies lower aflatoxin levels. We randomly assign households to one of five groups, four treatment groups and a control group. The assignment is at the village level, so that all households in one village are part of the same group (Table 1).

[Insert Table 1 here]

To our knowledge, the items we give to farmers are the most cost-effective way to prevent aflatoxin contamination and spread; we estimate the total investment cost of our interventions, before labor costs, to be $6.62 – $9.37. We provide hygrometers to three treatment groups (1,217 households) as a low-cost grain moisture verification tool; to our knowledge hygrometers have never been provided on a large scale as a grain moisture measurement tool. In developed countries, farmers and traders use moisture meters to measure grain moisture, but their $150+ price is cost prohibitive in a developing country context. The hygrometers used in this study measure relative humidity and temperature, and not grain MC. However, when grain is placed in a sealed container (such as a small Ziploc bag), the grain's moisture will come into equilibrium with the air in the bag. After 15-30 minutes, the bag reaches an equilibrium relative humidity (ERH), which can be read by a hygrometer. One can then use the ERH and temperature to calculate the MC of the grain in the bag. For this study, we assume an ambient temperature range and tell farmers that an ERH value of 65 or below is acceptable, but an ERH above 65 means they need to further dry the maize before storing. The hygrometers purchased in bulk from China for this study were $1.13/ each. Eighty-seven percent of study participants indicated they were willing to pay $1.79 for a hygrometer that could measure maize MC.

Two treatment groups (819 households) received a $10m^2$ plastic sheet as an alternative to drying their maize directly on the dirt. These sheets can sun dry ~200 kg maize over a given time (likely 2-3 days). On average, study households harvested 400 kg maize in 2015 (median was 675 kg), thus most households will need to dry their entire maize harvest in 2-3 stages. In the treatment groups that receive plastic sheets, 24 percent (205 households) dried their maize directly on the ground in 2015 or on a road-side pavement. All other household dried their maize off the ground, or in the field, presumably with the husks still on the cobs that would prevent contact with the bare soil. The plastic sheets, purchased locally in bulk, cost $3.27/ $10m^2$. Ninety percent of study participants indicated they were willing to pay $5.36 for a $10m^2$ plastic sheet.

We provide Purdue Improved Crop Storage (PICS) containers to households in the fifth treatment group (409 households) as a means of preventing insect contamination.

PICS containers hermetically seal maize, limiting oxygen and increasing carbon-dioxide, which kills any insects on the grain at the time of storage. The containers do not require chemical protectants, thus mitigating any concerns about consuming chemically treated maize. A supplier in Dakar stocks PICS containers imported from Nigeria. When purchased in bulk, the containers cost $2.22 each.

This complementary approach to input provision, rather than providing each treatment group a different input which implies substitutability, recognizes the complementarity of the technologies. For example, we address lack of farmer knowledge of the problem with training; lack of moisture detection devices with hygrometers; the contact of maize with contaminated surfaces post-harvest with a tarp; and the contribution of insects to aflatoxin spread with hermetic storage (PICS containers).

A baseline survey was conducted with ~10 households in all 210 villages (1,996 households) in May 2016. In October 2016, all villages in treatment groups 2) – 5) received training on improved drying and storage methods. After the training, the same households that were surveyed in May 2016 may have also received a hygrometer/ plastic sheet/ PICS container, depending on their treatment group. All households were surveyed again January 26 – February 24, 2017 when most households will put their maize into storage, to determine which households implemented recommended practices and the MC of their dried maize. A final survey was conducted May 2 – 22, 2017 to measure aflatoxin levels of stored maize.

Empirical model

Our data consists 1,993 household-level observations collected in January 2017. Of those, 382 households make up the control group. The regression model to test hypotheses 1 and 2, which have binary dependent variables, is

$$\Pr(Implement_{ij} = 1|\cdot) = \Phi(\beta_0 + \beta_1 T_i + \beta_2 T_i \cdot H_i + \beta_3 T_i \cdot H_i * P_i + \beta_4 T_i \cdot H_i \cdot P_i \cdot C_i + \delta X_i + \varepsilon_i) \quad (1)$$

where the dependent variable is a binary variable {0,1} if household *i* implements the improved practices $j \in$ {drying, storage}. T_i is a binary variable {0,1} if we assigned the household's village to receive training (Groups 2-5). H_i is a binary variable {0,1} if we assigned the households in the village to receive a hygrometer (Groups 3-5). P_i is a binary variable {0,1} if we assigned the households in the village to receive a plastic sheet (Groups 4-5). C_i is a binary variable {0,1} if we assigned the households in the village to receive one PICS bag (Groups 5).

X_i is a vector of household-level covariates that may explain the implementation decision. Although randomly divided villages into treatment groups, the relevant chi-squared and ANOVA tests found that some covariates are not independent across treatment groups. These include households that dry maize on the ground; only field dry their maize; and households that store their maize simply hanging in the open air. Other covariates whose independence will be tested before the final evaluation are how long the household intends to store their maize, their intended maize use (sales, storage, or seed), the quantity harvested and stored, if the household values food safety, anticipated sources of loss (mold, insects, etc.), awareness of aflatoxin, if they use pesticides, and household demographic characteristics, such as size, number of children, education of household head, and number of wives.

[Insert Table 2 here]

Although is Equation (1) written as a probit model, once the data is collected, we will model the data as probit, logit, and log-log link functions, using the maximized log-likelihood and pseudo R^2 values to determine the best fit to the data. To test H_1, we will use Equation (1) with the binary variable of drying off the bare ground {0,1} as the improved drying method. We will use a log-likelihood ratio test to determine if $\beta_1 = \beta_2 = \beta_3 = \beta_4$. We will conduct the same test with the binary variable of hermetic storage {0,1} as the improved storage method to test H_2. When testing H_1, we expect $\beta_1, \beta_2, \beta_3 > 0$ and significant, but do not know if receiving the PICS bag will cause households to emphasize storage to the detriment of drying. Conversely, when testing H_2, we expect $\beta_1, \beta_4 > 0$ and significant, but do not know if receiving the drying technologies will cause households to emphasize drying to the detriment of storage.

The regression model to test hypothesis 3, which has a censored dependent variable, is

$$Aflatoxin_i = \alpha_0 + \alpha_1 \widehat{Imp_D} + \alpha_2 \widehat{Imp_S} + \delta X_i + \varepsilon_i \tag{2}$$

where the dependent variable is the aflatoxin level [0,100] of maize from household *i* that has been stored for 3-4 months. The VICAM Afla-V AQUA kits that we used to test maize aflatoxin levels right censors readings at 100 parts per billion (ppb), thus we used a censored regression to estimate Equation (2). $\widehat{Imp_D}$ and $\widehat{Imp_S}$ are the predicted probabilities of the household implementing the improved drying and storage practices from Equations (1), respectively

We will test for heteroscedasticity of the error term, and calculate robust standard errors as needed. We will conduct F-tests to determine if $\alpha_1 + \alpha_2 = 0$ to test H_3. When testing H_3, we expect $\gamma_1, \gamma_2 > 0$ and significant, as drying and storage practices are critical in reducing aflatoxin contamination and spread.

Preliminary results

Preliminary results from the May 2016 baseline study find that households are autarkic in maize production, with 99 percent consuming their own maize, 70 percent retaining their own seed, and only 7 percent selling their maize. Additionally, 24 percent dry their maize directly on the ground or on a road-side pavement, thus post-harvest aflatoxin contamination from soil is a real concern.

We have also found that simple training was important in increasing household knowledge of aflatoxin's toxicity. The percentage of farmers who think aflatoxins are harmful increased by 35 to 45 percentage points between the baseline (May 2016) and the January/ February 2017 surveys in the groups that received the training, versus a 7-percentage point decrease in the same statistic for those in the control group. An interesting finding, the cause for which we hope to establish with further analysis, is that the percentage of farmers who dry their maize on the ground decreased by 23 percentage points in Group 5 which received the plastic sheet and the PICS bag. However, there was a 14-pecentage point decrease in ground-drying in the control group, which was not expected. Finally, Group 4 which also received a plastic sheet did not perform any better than the groups which received training but not a supplemental material on which to dry their maize (Table 3).

[Insert Table 3 here]

When measuring maize MC at the point of storage (January/ February 2017), we found that MC of maize going into storage was not a concern, with 89% of households storing their maize at ≤ 12% MC. Thus, we do not think that hygrometer provision affected outcomes of aflatoxin levels.

Preliminary aflatoxin results found 27% of samples were above the 10 ppb safe threshold used by Europe, indicating that aflatoxin-infected maize is a real concern in the study area. Participants in Group 5 had better outcomes, with the largest percentage of samples with no aflatoxin (26%) and the lowest mean for samples below the 100 ppb limit (7.70 ppb). Despite the provision of an improved drying surface, Group 4 again did not perform better than Groups 2-3 which only received training improved drying surfaces.

[Insert Table 4 here]

Data is still being transmitted from Senegal and analyzed, but subsequent analyses will focus on examining Equations (1) and (2) to better understand the differences we see in the treatment groups.

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Table 1. Respondents by wave and treatment group

	1) Control		2) Training Only		3) 2 + Hygrometer		4) 3 + Plastic sheet		5) 4 + PICS bag		TOTALS	
	N	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% HH**
Nº. of Villages	41	20%	41	20%	42	20%	42	20%	43	21%	209	
Nº. of HH (May 2016)	382	19%	394	20%	398	20%	410	21%	409	21%	1993	
Nº. of HH (Jan/Feb 2017)	382	19%	389	20%	397	20%	408	21%	405	20%	1981	99%
Nº. of HH aflatoxin sample (May 2017)	145	16%	174	19%	173	19%	201	22%	201	22%	894	45%

Table 2. Summary Statistics for Baseline Data

	1) Control		2) Training Only		3) 2 + Hygrometer		4) 3 + Plastic sheet		5) 4 + PICS bag		TOTALS	
	N	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% HH**
Average age of HH Head^n	46		46		47		47		48			
Total HH members^n	12.9		13.4		13.4		11.9		12.6			
Nº Youth Under 10^n	5.6		5.7		5.7		5.0		5.4			
Nº Polygamous Households^n	139	20%	137	20%	142	21%	136	20%	134	19%	688	34%
Yrs Maize Farming Experience of HH Head^n	18.8		19.7		19.7		20.4		21.4			
Education of HH Head^n												
None	180	21%	179	21%	150	18%	169	20%	172	20%	850	43%
Elementary	60	23%	49	19%	54	21%	51	20%	43	17%	257	13%
Secondary	11	17%	16	25%	16	25%	11	17%	11	17%	65	3%
Koranic School	74	15%	80	16%	123	24%	114	23%	112	22%	503	25%
Kg Maize Harvested in 2015^n	638.1		743.8		743.8		722.4		659.6			
Kg Maize Purchased in 2015^n	122.4		118.0		118.0		109.1		106.9			
Stored Grain Type												
On Cob	146	19%	172	22%	141	18%	154	20%	152	20%	765	38%
Shelled	212	20%	193	18%	222	21%	223	21%	223	21%	1073	54%
Maize Drying Method												
Directly on the ground**	96	19%	114	23%	115	23%	79	16%	99	20%	503	25%
On road side pavement	10	21%	2	4%	9	19%	12	25%	15	31%	48	2%
Terrace roof	76	19%	70	17%	74	18%	89	22%	94	23%	403	20%
Concrete floor	63	19%	70	21%	62	19%	72	22%	63	19%	330	17%
Wooden platform	41	19%	44	20%	41	19%	46	21%	46	21%	218	11%
Field dry only**	49	25%	26	13%	47	24%	39	20%	34	17%	195	10%
Ground on sheet or mat	20	29%	15	22%	10	14%	10	14%	14	20%	69	3%
In the storage technology	10	12%	21	25%	16	19%	25	30%	12	14%	84	4%
Other	21	16%	26	20%	20	15%	34	26%	29	22%	130	7%

Table 2. Summary Statistics for Baseline Data

	1) Control		2) Training Only		3) 2 + Hygrometer		4) 3 + Plastic sheet		5) 4 + PICS bag		TOTALS	
	N	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% HH**
Storage Technology												
Single layer plastic bag	173	20%	154	18%	181	21%	165	19%	187	22%	860	43%
Woven bag	57	20%	47	16%	58	20%	71	25%	54	19%	287	14%
Traditional granaries	39	19%	52	26%	36	18%	39	19%	35	17%	201	10%
Heaped in House	22	22%	28	28%	23	23%	12	12%	16	16%	101	5%
Open-air hanging**	14	15%	25	26%	13	14%	29	30%	15	16%	96	5%
Improved granaries	9	23%	10	25%	4	10%	8	20%	9	23%	40	2%
Terrace roof	7	33%	2	10%	5	24%	5	24%	2	10%	21	1%
Other	7	16%	10	23%	8	18%	6	14%	13	30%	44	2%

[n] Not yet tested for independence across treatment groups.
** Variable is not independent across treatment groups. $p < 0.05$

Table 3. Behavior change from May 2016 to Jan/Feb 2017 by treatment group

	1) Control		2) Training Only		3) 2 + Hygrometer		4) 3 + Plastic sheet		5) 4 + PICS bag		TOTALS	
	Δ N	**% group**	**Δ N**	**% group**	**Δ N**	**% group**	**Δ N**	**% group**	**Δ N**	**% group**	**Δ N**	**% HH**
Believe aflatoxin is toxic	-28	-7%	138	35%	178	45%	156	38%	161	39%	605	30%
Dried maize on ground	-52	-14%	-72	-18%	-76	-19%	-68	-17%	-96	-23%	-364	-18%

Table 4. Aflatoxin results by treatment group

	1) Control		2) Training Only		3) 2 + Hygrometer		4) 3 + Plastic sheet		5) 4 + PICS bag		TOTALS	
	N	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% row**	**N**	**% samples**
Samples analyzed (N)	242	15%	301	19%	295	19%	371	23%	375	24%	1584*	
0 ppb (N)	74	13%	116	20%	118	20%	126	22%	151	26%	585	37%
0 < ppb ≤ 100 (N)	131	15%	162	19%	155	18%	208	24%	209	24%	865	55%
≤ 10 ppb (N)	81	19%	77	18%	78	18%	112	26%	76	18%	424	27%
< 100 ppb (N)	37	28%	23	17%	22	16%	37	28%	15	11%	134	8%
Mean if 0 < ppb ≤ 100	11.13 ppb		9.45 ppb		10.11 ppb		10.71 ppb		7.70 ppb		9.67 ppb	

*We intended to take two samples per household from the 894 households that still had maize in May 2017 from the late 2016 harvest. For reasons that are not yet fully understood, enumerators took only one sample from 204 households.